The Impact of HU Corrections in the Clinical Setting for Prostate Fiducial Marker Artifact

Jesse Speedy, B.S., R.T.(R)(T), Ahssan Balawi B.S., CMD, Jennifer Kimbler B.S., CMD, Seth Crumpton, B.S., R.T.(T), Ashley Hunzeker, M.S., CMD, Nishele Lenards, R.T.(R)(T), PhD, CMD, FAAMD

ABSTRACT

The purpose of this study was to examine the effects of fiducial marker-artifact and subsequent Hounsfield Unit (HU) correction on radiation treatment planning dose distribution to the prostate gland and critical structures. Implementation of the study was completed in two parts: an initial comparative analysis of fiducial-artifact in corrected and uncorrected data sets followed by a nation-wide electronic survey. For the comparative portion of the study, 25 early stage T1-2c prostate patients from two clinical sites were retrospectively selected for inclusion. In the first arm of the comparative study, 20 patients were planned using a manual HU correction and compared to uncorrected plans. For the second arm of the comparative study, 5 patients were planned with an applied metal artifact reduction (MAR) algorithm and compared to the same data sets with no correction. All 25 patients were planned to the same specifications: target volume delineation followed Radiation Therapy Oncology Group (RTOG) Protocol 0145 and critical structure contours were created in accordance with the RTOG Male Pelvis Normal Tissue Atlas. Prostate patient plans were calculated to deliver a total of 70 Gy in 2.5 Gy daily fractions using 6 MV energy. Analysis of the plans revealed that corrections for fiducial artifact resulted in less than 3% planning target volume (PTV) coverage differential when comparing corrected and uncorrected plans. Comparison of corrected and uncorrected plan critical structure doses ranged from 3% to 60% in the most extreme example. An electronic survey of 22 facilities found that no consistent implementation of prostate fiducial marker use existed in those interviewed. For respondents that did use fiducial markers, half used artifact reduction techniques. Further research is needed to provide sufficient data to prompt a change in the practices related to fiducial artifact reduction. This comparative analysis may provide the basis for a more large-scale study.

Key Words: Fiducials, HU corrections, Metal Artifact Reduction, Prostate

Introduction

Prostate cancer is one of the most common cancers to affect men in the United States. The Centers for Disease Control and Prevention (CDC) reported that 172,258 men were diagnosed in 2014 and 28,343 men died from prostate cancer in the same year.[1] Although there is considerable data related to prostate radiation treatment, there are still areas of study where little research has been done. Aspects of radiation treatment that have a large and more obvious impact on treatment planning have been studied at length. Less examined, but potentially important areas of prostate treatment, provide an opportunity to develop a more comprehensive knowledge base for prostate radiation therapy. One area where information seems to be lacking is the effect of metal fiducial markers on prostate treatment planning. Artifact and HU correction are topics that have been examined at length for larger medical implants and devices but further study is needed to examine the effects of artifact caused by prostate fiducial markers specifically.

Past studies have examined the effect of hip implant-caused artifact in CT simulation and the radiation treatment planning process. Li et al[2] examined the effect of orthopedic metal artifact on treatment planning. In this study, images of an uncorrected density phantom were compared to an orthopedic metal artifact reduction (OMAR) algorithm corrected image set. Findings of the study indicated that in the OMAR corrected scans, CT HU number accuracy was improved and critical structure and target visualization was notably better compared to non-corrected images. Gilde-Hurst et al[3] demonstrated how differing metal artifact reduction methods can have an impact on planning outcomes. In the Gilde-Hurst[3] study, a standard 12-bit MAR algorithm was compared to an enhanced 16-bit MAR algorithm to determine the accuracy of each method and its effect on plan dosimetry. Marked improvement was observed on the planning scans when 12 and 16-bit correction was enabled. In all cases, the 16-bit MAR corrected images provided a more accurate dosimetric calculation and improved image and structure visualization. Both studies examined artifact caused by femur and hip implants. In the context of prostate treatment planning, it is important to assess the impact of MAR methods and HU override techniques not only for prosthetic hip implants but also for fiducial markers to ensure facilities are delivering the most accurate plan possible.

Limited attention has been given to the role that metal artifacts from fiducial markers have on radiation treatment planning outcomes. One study examining this effect was performed by Kassim et al[4] in which metal artifacts from surgical clips, tumor markers, and prostate fiducial

markers were examined in one phantom and 15 patients (8 of which were prostate fiducial patients). A standard clinically applied filtered-background projection (FBP) was compared to MAR correction software to reveal reduced streaking artifacts in the MAR corrected CT scans. The Kassim et al[4] study cited that the main advantage of MAR correction was reduced streaking artifact which improved structure delineation and accuracy when matching to fiducial markers for PTV alignment. This suggested that the effect of MAR correction is small but still has the potential to be significant for daily treatment alignment. Further research is needed to confirm these findings and build a knowledge base comparable to that of larger metal implants.

This study was divided into two sections and data from each portion was analyzed to determine if the results found in the initial comparative analysis currently applies to the practices observed in the electronic survey portion. The first part of the study compared 2 prostate fiducial artifact reduction methods to an uncorrected control group. The goal of the comparative analysis was to determine if there was a difference in planning outcomes when comparing fiducial artifact corrected plans to uncorrected treatment plans. The second part of this study examined electronic survey results from 22 facilities to analyze trends in prostate radiation therapy (Figures 1-3). The goal of the final analysis was to determine if findings in fiducial marker artifact correction might have an impact on the current practices in prostate treatment.

Methods and Materials

*Patient*s

Twenty-five patient subjects were selected for this retrospective study with the goal of reducing variables related to fiducial artifact production. All selected patients met the specified diagnosis and pretreatment criteria including a positive diagnosis of prostate adenocarcinoma staged T1-2c and no prior pelvic surgery or alternate therapy. All selected patients had 3 fiducials and all fiducials were contained within the prostate. Any critical structure anomalies or irregularities barred patients from eligibility. All of the aforementioned factors were assessed and determined from retrospectively gathered data related to existing patient CT simulations.

Just as standardized individual patient anatomy and history were of importance in this study, a similar CT simulation process was observed at the facilities of data collection. To keep variables to a minimum, only two sites provided the data collected for this fiducial artifact analysis. Each site utilized a standard patient position to minimize variables. Treatment planning site A simulated all patients with an urethrogram, full bladder and empty rectum. Site A

patients were positioned supine, head first, with a square sponge under the head, and hands clasped on chest with a leg immobilizer. Treatment planning site B used nearly the same simulation position with the exception that no urethrogram was administered, a custom Vac-Lok was used to immobilize the legs, and a hand ring was used to stabilize hands on the chest. A full bladder and empty rectum were observed at planning site B as well. Both sites used a Siemens SOMATOM Definition AS 20 slice CT scanner. All patient scan volumes began above the iliac crest and scanned below the ischial tuberosity at a 3 mm slice thickness. The contouring procedure for this study was designed to compensate for differences between the two simulation methods and further standardize fiducial marker artifact assessment.

Contouring

The goal when contouring patients was to decrease variability and document all anatomic and treatment planning variables. This was done to ensure accurate assessment of the effect fiducial marker artifact has on treatment plan outcome. The treatment planning locations for this study utilized Eclipse treatment planning system (TPS) version 11 (Site A) and 13 (Site B) to contour and plan all patients. In each plan, the bladder, rectum, and penile bulb were defined as critical structures per the RTOG male pelvis contouring atlas guidelines.[5] Target volume delineation followed the parameters outlined in RTOG protocol 0415 which also utilized a low risk prostate patient selection.[6] Each plan included a physician-defined gross tumor volume (GTV) prostate volume. The clinical target volume (CTV) was defined as any area with microscopic disease. In this case, and due to low risk only patient selection, the CTV was the same volume as the GTV. A PTV expansion allowed a margin for daily setup variation and CTV motion. To standardize PTV volume among all plans, an expansion on the GTV/CTV of 0.5 cm was used posteriorly and 1 cm in all other planes.

Specific steps were taken to accurately contour fiducial markers and differentiate them from density corrected artifact. An Eclipse TPS high density artifact tool was used to segment the area of metal artifact (Figure 4). The tissue around the artifact area was surveyed and an average HU of 45 was found to accurately represent prostate tissue (Figure 4). A density override was performed on the contoured artifact and assigned an HU value of 45. The actual fiducial marker was left un-contoured to accurately represent any fiducial related beam attenuation in planning and dose calculation. Ultimately, standardized and accurate contouring provided the

necessary data to measure the fiducial-produced artifact effect on the treatment planning process.

Treatment Planning

Uniform treatment planning parameters were utilized to provide the most accurate representation of fiducial artifact and its impact on prostate treatment. The prescribed dose to the prostate PTV was 70 Gy delivered in 28 fractions at 2.5 Gy per daily fraction. Plans were generated using intensity modulated radiation therapy (IMRT). All radiation was delivered using 6 MV photon beams via seven field beam angles at 206°, 257°, 308°, 0°, 51°, 103°, and 157° respectively. Table angles were left at 0°, the collimator was turned to 180°, and inhomogeneity correction factors were enabled for each plan. Each beam isocenter was placed at the geometric center of each PTV. Varian Truebeam (Site A) and Varian iX (Site B) linear accelerator systems were the treatment machines selected to administer each treatment plan. All treatment plans were optimized per RTOG 0415 protocol.[6] The goal was to deliver 100% of the prescription dose to cover 98% of the PTV volume while limiting dose to critical structures within the dataset as much as possible.

Two control groups were established for this study to compare manual HU overrides and MAR overrides to uncorrected plans. For the first arm of this comparison, a total of 40 treatment plans (20 patients, two plans each) were generated to demonstrate the impact manual HU corrections have on the treatment planning process. In each case, one plan was done with a manual fiducial-artifact HU override and the second plan had no artifact correction applied. Ten patient plans were calculated at 2 treatment planning sites to produce a volume of 40 plans.

For the second arm of this study, 5 patient plans were selected with only an MAR algorithm correction applied to the treatment plan. Site B was the only treatment planning location with access to recently acquired MAR correction software. As such, the eligible patient selection pool was limited due to the specific patient selection criteria of this study. Five patient plans had the MAR algorithm correction applied and the same 5 plans were completed without the applied correction. Ultimately, the manual HU override plans from the first arm of the study, the MAR corrected plans from the second arm, and the corresponding uncorrected treatment plans were compared to determine the impact of fiducial-artifact on the treatment planning process.

Plan Comparisons

Plan analysis aimed to compare manual HU overrides and MAR corrections to uncorrected plans that were used as a control. The organs at risk (OAR) maximum dose, OAR mean dose and percentage of the PTV receiving the prescription dose were evaluated to determine the impact of each planning method on the treatment planning process. Dose volume histograms (DVHs) were used to determine OAR dose and PTV coverage in each of the 50 total plans.

Overall plan quality was assessed by averaging OAR and PTV coverage parameters to compare the impact of each correction method to an uncorrected plan. All PTV coverage percentages, mean OAR doses, and maximum OAR doses for corrected and uncorrected plans were averaged for each site respectively. This same process was done for manual HU override plans, MAR corrected plans, and uncorrected plans in each arm of study. The final averaged results compared the first manually HU corrected arm to the second arm of MAR corrections to determine their respective effects on treatment planning outcome.

Results

Analysis of PTV coverage in all artifact corrected and uncorrected plans demonstrated varying differentials between correction methods. Overall, PTV coverage analysis of the first arm of patients 1-20 averaged together for both site A and B shows that the manually HU corrected plans had 0.96% better coverage than the uncorrected plans (Table 1). Comparison of patients 1-5 of the second arm of study displayed 1.40% better PTV coverage in the MAR corrected plans compared to the corresponding uncorrected plans. In each arm of study, the corrected plans did show minimally better PTV coverage when compared to the uncorrected plans.

More notable differentials between the two arms of the study were observed when comparing OAR mean dose (Table 2). In the first arm of the study, a comparison of mean OAR dose to bladder, rectum, and penile bulb was performed between HU corrected and uncorrected plans. Patients with manually HU corrected plans at site A and B had an average mean dose of 23.0 Gy, 29.26 Gy, and 17.46 Gy, to the bladder, rectum, and penile bulb respectively. Patients with uncorrected plans had an average mean dose of 22.93 Gy, 29.66 Gy, and 19.10 Gy to the bladder, rectum, and penile bulb respectively. In the second arm of study 5 MAR corrected plans were compared to same 5 uncorrected plans. The averaged mean OAR doses for the 5 MAR corrected plans were 22.29 Gy, 27.40 Gy, and 8.17 Gy to the bladder, rectum, and penile bulb

respectively. The averaged mean OAR doses for the 5 uncorrected plans were 22.22 Gy, 31.95 Gy, and 9.37 Gy to the bladder, rectum, and penile bulb respectively.

Maximum OAR dose to the bladder, rectum and penile bulb, was assessed for each arm of the study in corrected and uncorrected plans (Table 3). In the first arm of comparison, maximum OAR doses for all manually HU corrected plans were averaged together and compared to the averaged values for uncorrected plans. Manually HU corrected maximum doses at site A and B were 73.66 Gy, 73.47 Gy, and 44.75 Gy, to the bladder, rectum and penile bulb respectively. Uncorrected plan maximum OAR doses at site A and B were 73.65 Gy, 73.04 Gy, and 46.53 Gy to the bladder, rectum, and penile bulb respectively. In the second arm of study, maximum OAR dose for the 5 MAR corrected plans were averaged and compared to the same 5 uncorrected plans. Maximum OAR doses for the MAR corrected plans were 72.62 Gy, 71.80 Gy, and 16.43 Gy, for the bladder, rectum and penile bulb respectively. The same 5 uncorrected plans showed averaged maximum OAR doses of 72.50 Gy, 72.36 Gy, and 31.0 Gy to the bladder, rectum, and penile bulb respectively.

Survey data from 22 treatment facilities provided some enlightening findings related to common practice related to fiducial artifact and associated reduction techniques (Figures 1-3). Survey results revealed a wide range in the volume of radiation treatments administered daily among respondents. On average, 59.1% of facilities interviewed treated 50+ patients per day, 18.2% treated 10-20 per day, 13.6% treated 20-30 per day, and 4.5% treated 30-40 while another 4.5% treated approximately 40-50 patients per day. Of those facilities, 63.6% interviewed reported that 1/3 or less of their total patient volume were prostate patients, 31% reported that 1/3 to 1/2 of their patients were prostate patients, and 4.5% reported that 3/4 or more of their patients were receiving prostate treatment. Of those interviewed, over half (54.5%) used fiducial markers while the remainder did not (Figure 1). The group that used fiducial markers was divided into 41% that used an artifact correction method while the remainder did not correct for fiducial artifact (Figure 2). When asked which fiducial correction method was used at their treatment facility, 50% of survey participants reported that they used manual HU override, 40% used MAR correction algorithm and 10% used multiple correction methods. Of the 10% that used multiple correction techniques, FBP and manual HU override were the correction methods used with manual HU override being used most frequently (Figure 3). Of all those interviewed, 47.6% felt some form of fiducial artifact correction should be used in treatment planning, 28.5%

felt no correction was needed, and the remainder selected "unknown" when asked about the topic. The information gathered among survey participants revealed significant divisions in prostate treatment approach with divisions nearly even in the areas of interest.

Discussion

Authors of this study examined the effects of manual HU override and MAR fiducial correction on the prostate treatment planning process in 2 facilities among 25 patients. The goal of the study was to determine if fiducial artifact correction provided a significant impact on treatment planning dose distribution. A dose differential between corrected and uncorrected plans was considered significant if it varied more than the clinically significant 3% dosimetric margin of accuracy specified by Svenson et al[7] in AAPM Report No.13. The greatest PTV coverage differential between all plans was well below 3%. The greatest PTV differential observed was in the MAR corrected plans at 1.40 % more prescription isodose coverage compared to uncorrected plans (Figure 5). Comparative analysis of OAR mean dose in the first arm of study revealed penile bulb differential to be the only value of significance at a difference of 8.97 % lower in the manually HU corrected plans when compared to the uncorrected plans (Figure 6). In the second arm of comparison, penile bulb and rectal mean doses were 13.38% and 15.3% lower in the MAR corrected plans when compared to uncorrected plans, respectively (Figures 6 and 7). Maximum OAR dose was only clinically significant in the penile bulb in the first arm of study. The penile bulb maximum dose was determined to be 3.9% lower for manually HU corrected plans when compared to the uncorrected plans (Figure 8). In the second arm of study, penile bulb dose provided the only significant difference at 61.44% lower in the MAR corrected plans when compared to the uncorrected plans (Figure 8). The penile bulb dose provided the most variable doses among all DVH statistics. This could be due to differences in interpretation of RTOG penile bulb contouring guidelines and patient anatomy. An overall comparative analysis between corrected and uncorrected plans did find OAR mean and maximum dose differentials larger than the 3% margin of clinical significance defined by AAPM Report No.13 when fiducial-artifact corrections were applied to prostate treatment plans. Observed differentials in corrected plans compared to uncorrected plans in all areas of assessment were markedly greater in the MAR corrected arm of study when compared to the manually HU corrected arm.

The data collected and analyzed in this study is supported by similar studies in this field. Gilde-Hurst et al[3] assessed patient plans with metal hip implants and found that MAR correction greatly benefitted the treatment planning process. Kassim et al[4] found that organ segmentation and daily treatment imaging alignment benefitted the most from fiducial artifact correction. Furthermore, artifact correction techniques provided a small but noticeable improvement related to treatment planning CT image quality improvement. The existing data suggested that fiducial-artifact correction should have a small but noticeable impact on treatment planning outcome. The data of the current study confirmed the suggestions of the other authors and builds on the body of fiducial specific treatment planning data.

Survey results indicated that prostate radiation therapy is a far from standardized field of practice when it comes to fiducial marker usage. Fiducial markers were used at prostate treatment facilities by 54.5% interviewed. Among those that used fiducial markers, 41% used a fiducial artifact correction technique. Groups that did use fiducial artifact correction were nearly evenly split between manual HU correction and MAR algorithm correction. Survey results made it clear that common practice differs widely from one location to another but findings from this fiducial artifact assessment present preliminary evidence that fiducial artifact correction may be advisable to all treatment sites utilizing fiducial markers.

Conclusion

The preceding fiducial-artifact reduction comparative analysis suggests that fiducial-artifact correction may provide a statistically significant reason to implement more widespread use among prostate treatment facilities. No current trend in fiducial use or implementation exists among those interviewed, but the results of this comparison of 50 prostate treatment plans may provide reason for a facility to modify current practices. Examination at two facilities compared manual HU overrides and MAR algorithm correction to uncorrected plans. Coverage of PTV and OAR mean and maximum doses were compared among all plans. Plan differentials greater than 3% were determined to be potentially clinically significant for treatment planning. In the observed plans, PTV coverages did not present significant differentials between corrected and uncorrected control groups. Mean and maximum OAR dose assessment did reveal differentials over the clinically significant measure of 3% in the rectum and penile bulb in both arms of study. No bladder doses in either arm of the study were above the 3% differential benchmark. Overall

final plan comparison found MAR correction to provide the biggest clinically significant impact when compared to uncorrected treatment plans.

This comparative analysis of HU overrides and MAR correction research adds to the relatively small body of knowledge on the topic of fiducial artifact reduction and its impact on treatment planning. Image quality was not assessed in this study and further research is needed to determine if fiducial artifact reduction can benefit the treatment process in other ways. Further study of a larger sample size and different plan assessment parameters may provide a more comprehensive look at the impact of fiducial-artifact reduction on the treatment planning process. This study provided evidence that manual HU overrides and MAR corrections have a clinically significant effect on dosimetric planning outcomes but further study is needed to definitively corroborate the findings. Supplementary evidence to support these findings may provide strong reason for those surveyed to implement more widespread use of prostate fiducial artifact correction.

References

1. Prostate Cancer Statistics. Center for disease control and prevention website. https://www.cdc.gov/cancer/prostate/statistics/index.htm. Updated on May 23, 2017. Accessed June 24, 2017.
2. Li H, Noel C, Chen H, Li HH. Clinical evaluation of a commercial orthopedic metal artifact reduction tool for CT simulations in radiation therapy. *Med Phys*. 2012;39(12):7501-7517. http://dx.doi.org/10.1118/1.4762814
3. Gilde-Hurst C, Chen D, Zhong H, Chetty IJ. Changes realized from extended bit-depth and metal artifact reduction in CT. *Med Phys*. 2013;40(6):061711:1-10. http://dx.doi.org/10.1118/1.4805102
4. Kassim I, Joosten H, Barnhoorn JC, Heijmen BJ, Dirkx ML. Implications of Artefacts Reduction in the Planning CT Originating from Implanted Fiducial Markers. *Med Dosim*. 2011;36(2):119-125. http://dx.doi.org/10.1016/j.meddos.2010.02.002
5. Gay HA, Barthold HJ, O'Meara E, et al. Male pelvis normal tissue RTOG consensus contouring guideline. Radiation Therapy Oncology Group (RTOG). https://www.rtog.org/CoreLab/ContouringAtlases/MaleRTOGNormalPelvisAtlas.aspx. Accessed on June 1, 2017.
6. Lee WR, Dignam JJ, Amin M, et al. NRG Oncology RTOG 0415: A randomized phase 3 noninferiority study comparing 2 fractionation schedules in patients with low-risk prostate cancer. Radiation Therapy Oncology Group (RTOG). *Int J Radiat Oncol Biol*. 2016;94(1):3-4. http://dx.doi.org/10.1016/j.ijrobp.2015.10.049
7. Svenson G, Baily N, Loevinger R, et al. *AAPM Report No 13: Physical aspects of quality assurance in radiation therapy.* American Association of Physicists in Medicine (AAPM). https://www.aapm.org/pubs/reports/RTP_13.pdf. Published 1984. Accessed June 24, 2017.

Figures

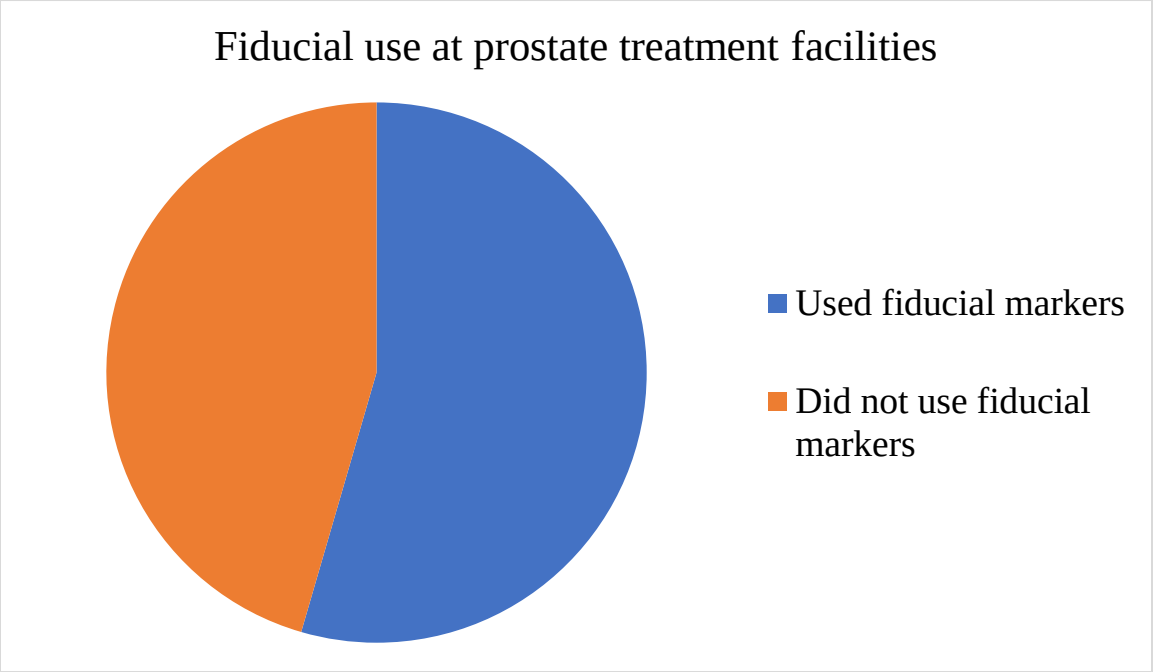

Figure 1. Fiducial marker use at prostate treatment facilities.

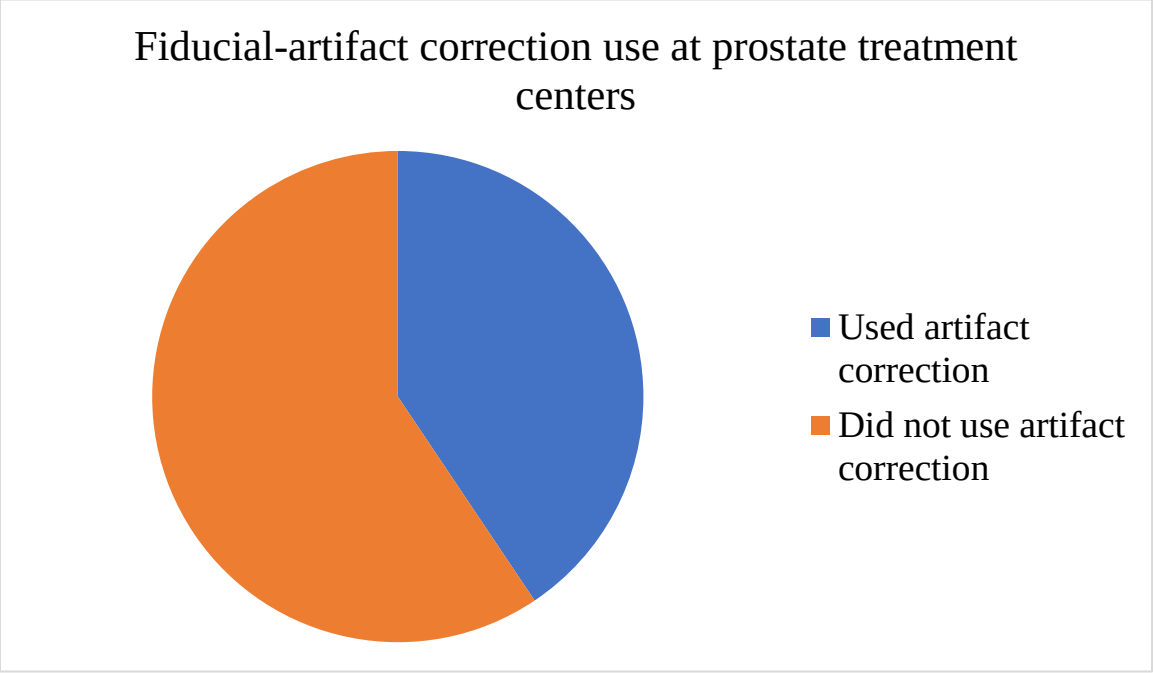

Figure 2. Prostate treatment facilities that utilize fiducial-artifact corrections.

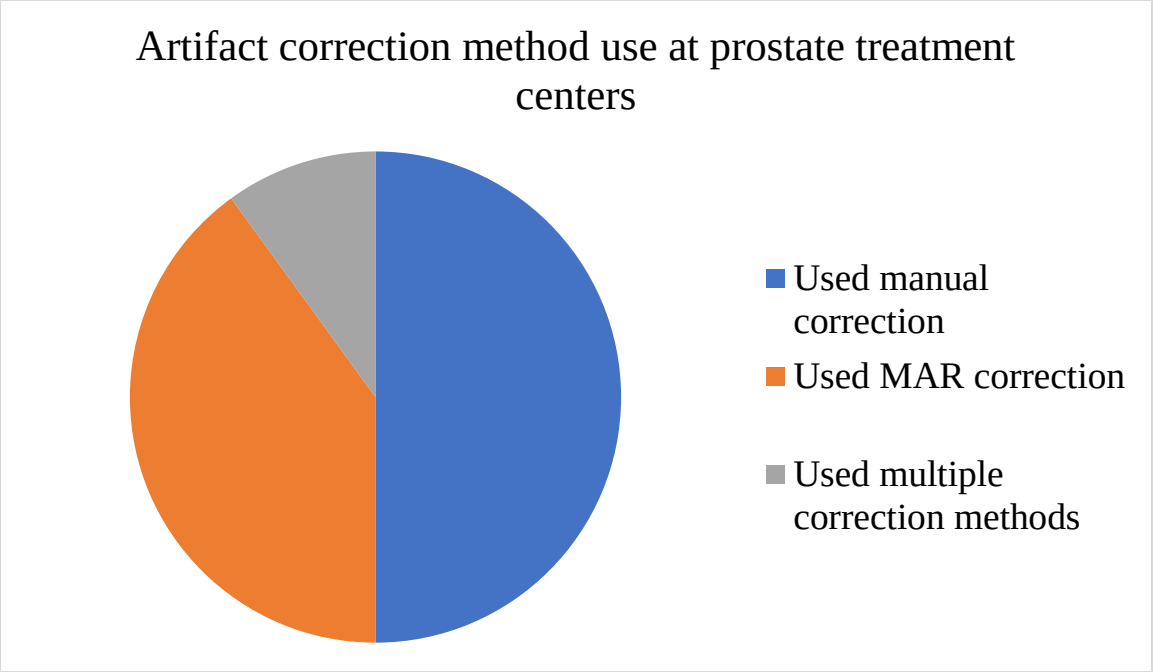

Figure 3. Artifact correction use at prostate treatment facilities.

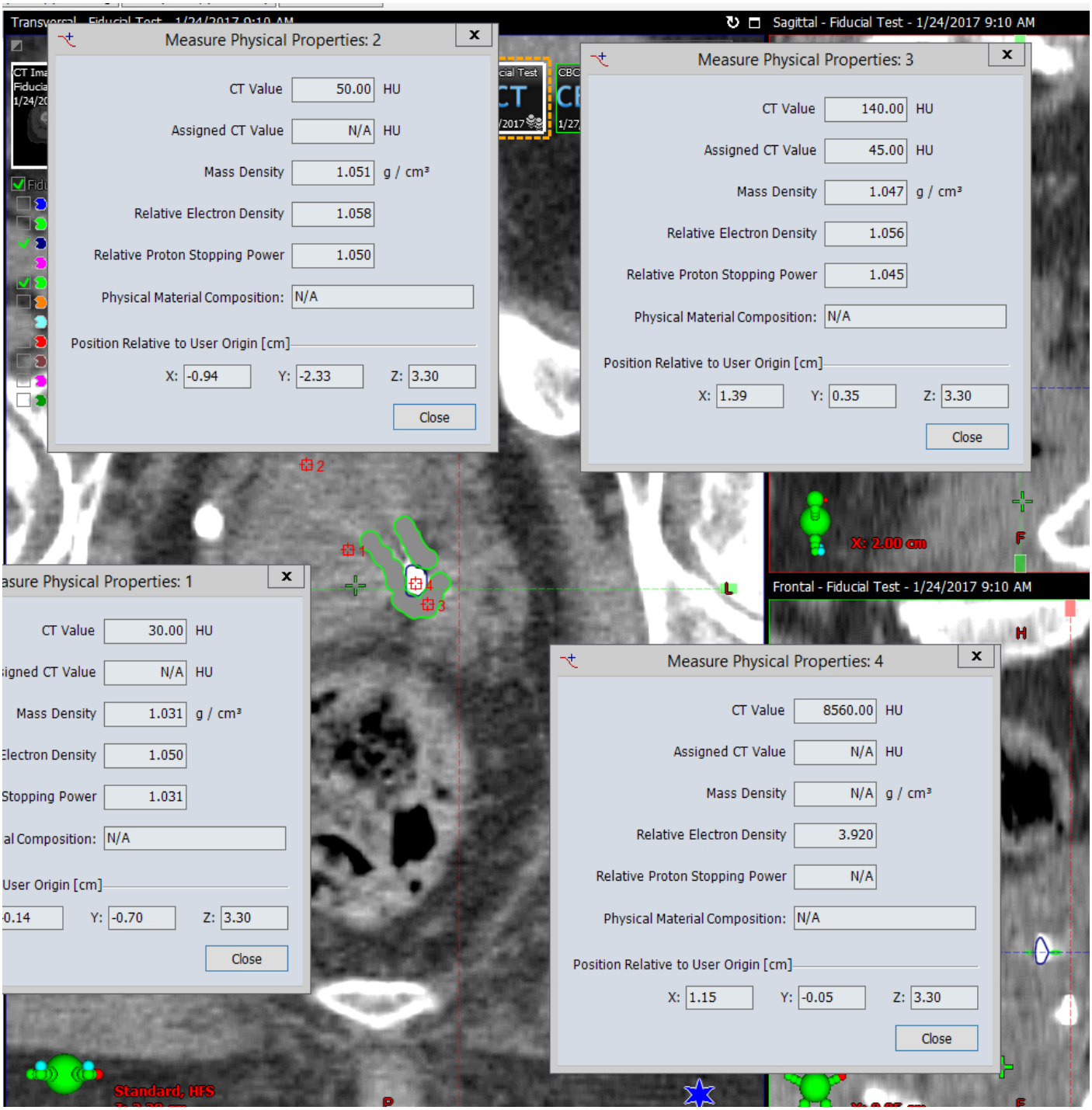

Figure 4. The manual HU override procedure used to contour all plans.

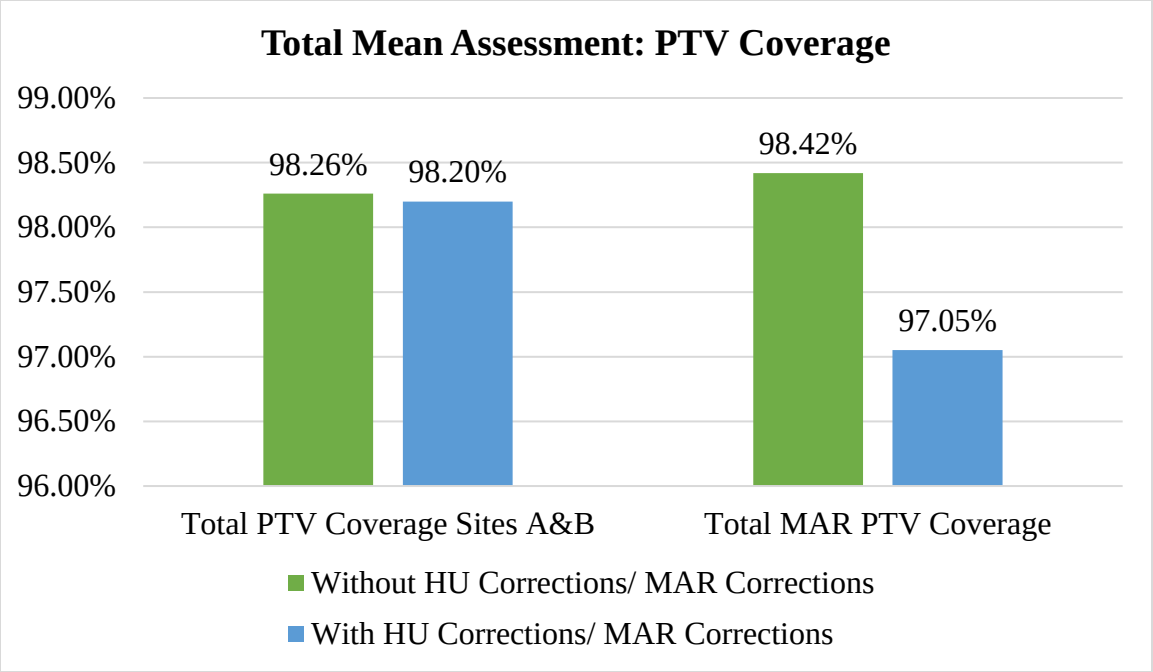

Figure 5. The PTV coverage difference between plans.

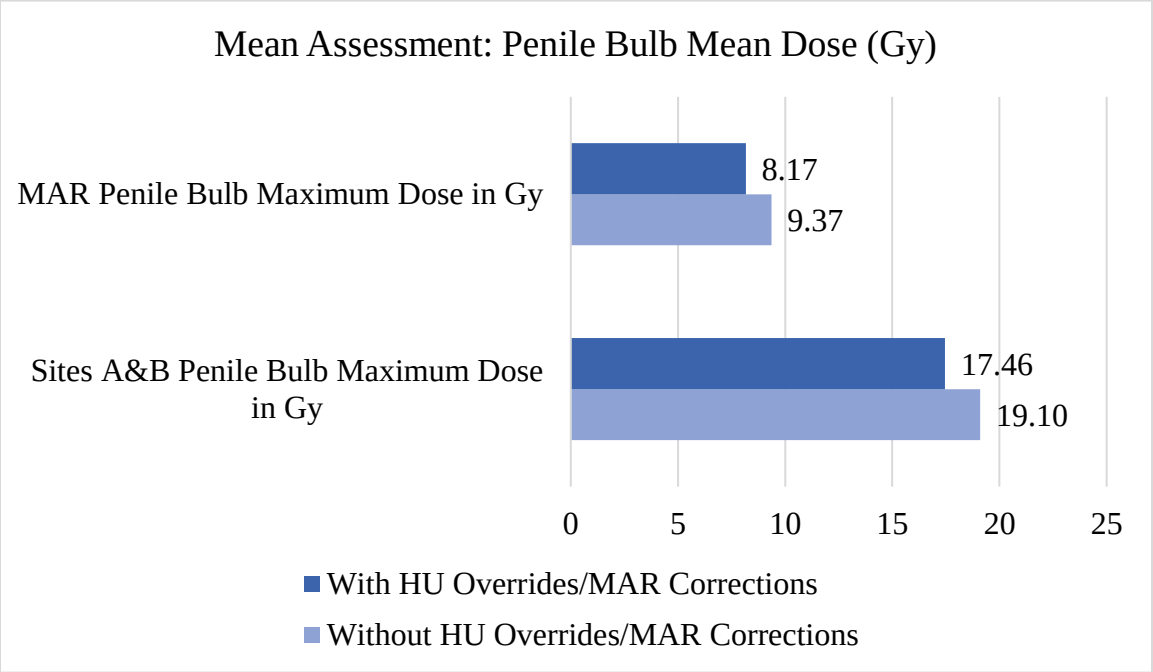

Figure 6. The variation in penile bulb mean dose between plans.

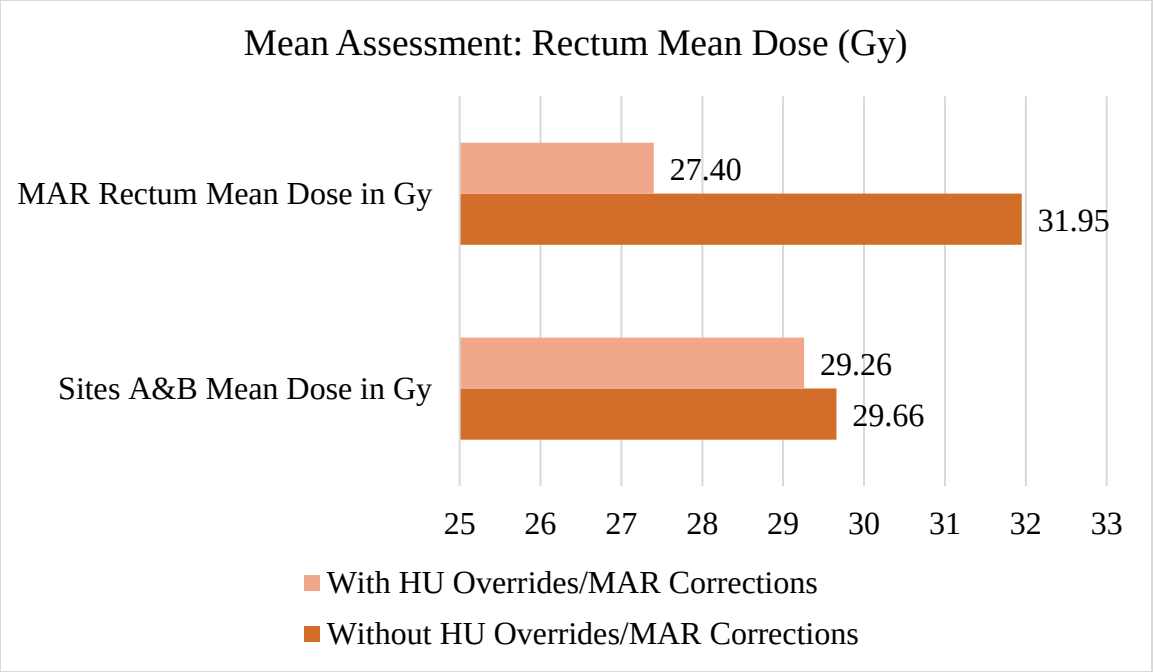

Figure 7. The variation in rectum mean dose between plans.

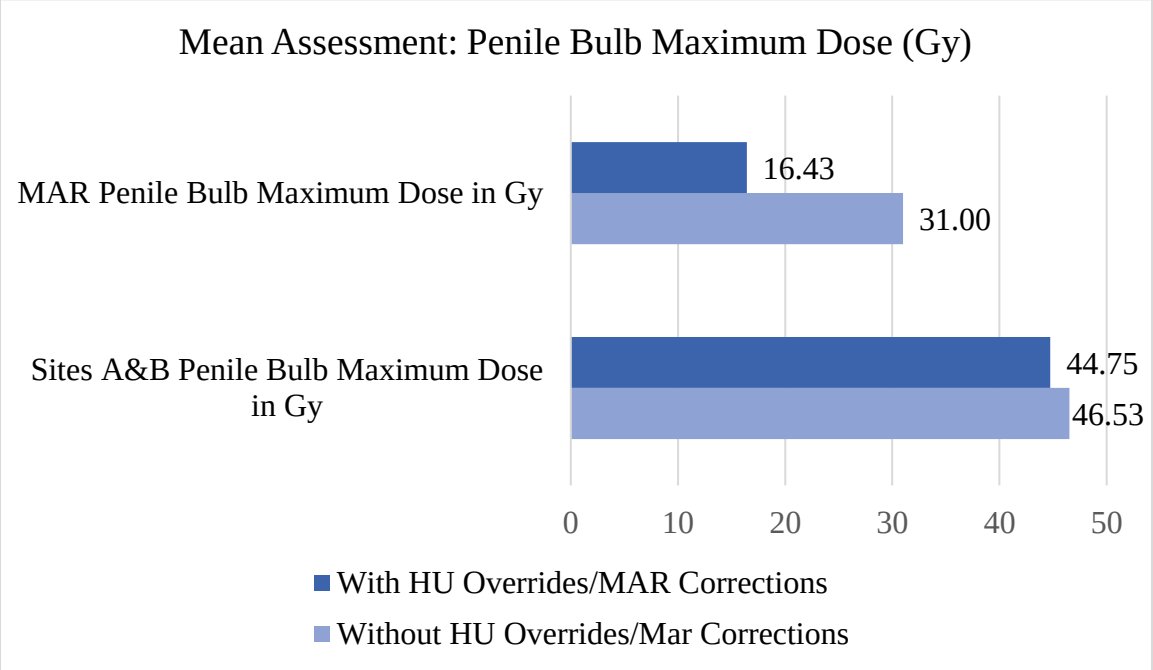

Figure 8. The variation in penile bulb maximum dose between plans.

Tables

Table 1. Planning target volume coverage percentages of corrected plans (plan A) and uncorrected plans (plan B).

PTV Coverage Assessment					
Patient	Plan A	Plan B	Patient	Plan A	Plan B
1	98.30%	98.70%	11	97.90%	98.00%
2	98.20%	98.60%	12	97.00%	97.00%
3	99.30%	98.90%	13	98.00%	96.40%
4	96.00%	99.30%	14	99.30%	99.90%
5	98.00%	98.30%	15	99.00%	99.00%
6	98.60%	99.00%	MAR 1	99.20%	100.00%
7	97.90%	98.00%	MAR 2	98.00%	97.11%
8	97.00%	97.00%	MAR 3	96.00%	100.00%
9	97.00%	97.00%	MAR 4	97.03%	97.00%
10	98.00%	98.10%	MAR 5	95.00%	98.00%

Table 2. Mean assessment of mean dose in the bladder, rectum and penile bulb.

Mean Assessment: Mean Dose			
	Bladder (Gy)	Rectum (Gy)	Penile Bulb (Gy)
Manual HU Corrected Plans	23.00	29.26	17.46
Uncorrected Plans	22.93	29.66	19.10
MAR Corrected Plans	22.29	27.40	8.17
MAR Uncorrected Plans	22.22	31.95	9.37

Table 3. Mean assessment of maximum dose in the bladder, rectum and penile bulb.

Mean Assessment: Maximum Dose			
	Bladder (Gy)	Rectum (Gy)	Penile Bulb (Gy)
Manual HU Corrected Plans	73.66	73.47	44.75
Uncorrected Plans	73.65	73.04	46.53
MAR Corrected Plans	72.62	71.80	16.43
MAR Uncorrected Plans	72.50	72.36	31.00