

Radiobiological and Physical Evaluation of the Effect of Metal Artifacts with VMAT and IMPT Plans

T Lee¹, W Hsi², Y Mekuria³

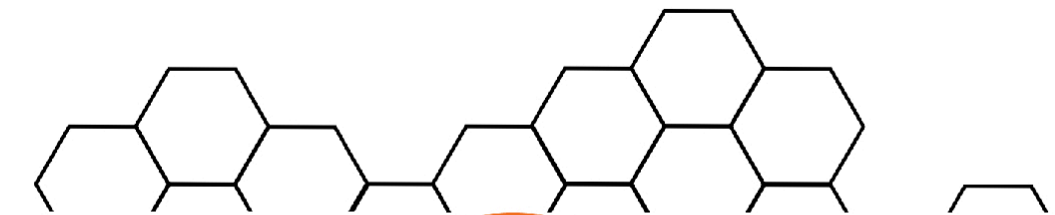
1 Indiana University Health Arnett, Lafayette, IN, USA

2 University Florida Health Proton Radiotherapy Institute, Jacksonville, FL, USA

3 St. Joseph University Hospital, Patterson, NJ, USA



Indiana University Health



INTRODUCTION

The accurate segmentation of tumor and its surrounding normal tissues in CT images is essential in radiation treatment planning processes. However, the presence of metallic objects, i.e. high-Z materials, in CT images can create significant artifacts which are accompanied by bright and dark shadows and streaks due to beam hardening and scattering that affect the image reconstruction processes, and such artifacts introduce incorrect CT numbers in surrounding areas. The impact of the incorrect CT numbers caused by these artifacts can lead to inaccurate dose computation in treatment plans so that incorrect radiation dose could potentially be delivered to the patients. This study presents the radiobiological and physical evaluation of the VMAT and IMPT prostate plans in regards to the effect of metal artifacts and metal artifacts reduction.

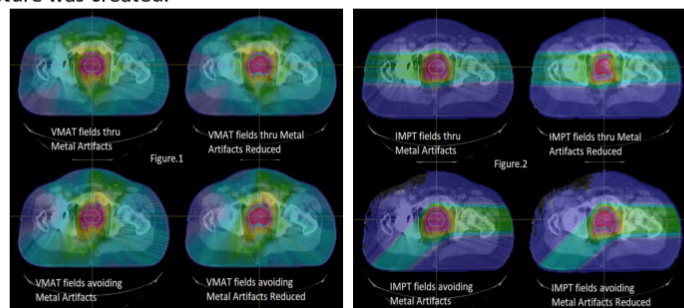
AIM

This study was performed with three aims.

1. To employ the algorithm that reduces metallic artifacts.
2. To recalculate optimized beam setting with CT images with metallic artifacts reduced for prostate plans created with VMAT and IMPT
3. To compare radiobiological and physical plan evaluation metrics between the plans with metal artifacts and those with metal artifacts reduced and statistically analyze using student t-tests.

METHOD

10 prostate cases with metal prosthesis were studied. PTV margins were 5.0mm except posterior margin being 3.0mm, and while STV (Scanning Target Volume) is clinically used for IMPT, PTV was used for current study 2 full-arc VMAT plans with and without defining metal as an avoiding structure for planning and 2 field IMPT plans with and without avoiding metal rotating fields by 25-30 degrees posteriorly from 90 and/or 270 degrees for IMPT field on metal side. Optimized plans were created on CT images with metal artifacts reduced and the dose was recalculated. 4 plans from each case were created and previously developed RTPET (RadioTherapy Plan Evaluation Tool) was used to evaluate and compare the plans in terms of TCP, NTCP, Cumulative DVHs, Conformity Index (CI), Dose Homogeneity Index (DHI) as well as dose statistics, e.g. Dmean, Dmax and Dmin. TCP/NTCP and DVH plots as well as the statistical analyses of metrics of each evaluated structure was created.



Figures 1 & 2 present dose distribution focused on tumor target.

RESULTS

VMAT plans were barely affected by the presence of metal artifacts with all evaluation metrics within +/- 2.0% differences, while IMPT plans significantly affected.

Figure 1 shows VMAT plans not significantly affected by presence of metal artifacts. On the other hand, figure 2 presents IMPT dose distribution is deteriorated by presence of metal artifacts (comparing the plans with metal artifacts and metal artifacts reduced), while IMPT dose distribution is minimally affected when the field is avoiding metal artifacts. Figures 3 (lateral IMPT fields through metal artifacts) and 4 (IMPT fields avoiding metal artifacts) show corresponding TCP/NTCP plots and DVHs. Left hand-side plots of each figure represent those from original plan with metal artifacts, and those on right hand-side those plans recalculated on CT images with metal artifacts reduced. Especially, it is clear that TCP is decreased by the presence of metal artifact by which the portion of the tumor target is missed.

Table 1 presents p-values of radiobiological and physical plan evaluation metrics calculated with student's t-test. Considering that $p < 0.05$ indicates the differences are statistically significant, calculated p-values for VMAT plans present statistically insignificant differences, which is expected because photons are relatively insensitive to heterogeneities around metal and its artifacts. p-values calculated for IMPT plans present differently. For TCP calculated for CTV, p-values show statistical insignificance. However, for CI for PTV, p-values show statistically significant differences, which indicates that any set-up errors can introduce metal-artifact induced Tumor Control deficiency for CTV. Dmean and Dmin of normal tissues also present $p < 0.05$ because they are in close vicinity to high dose change due to metal artifacts.

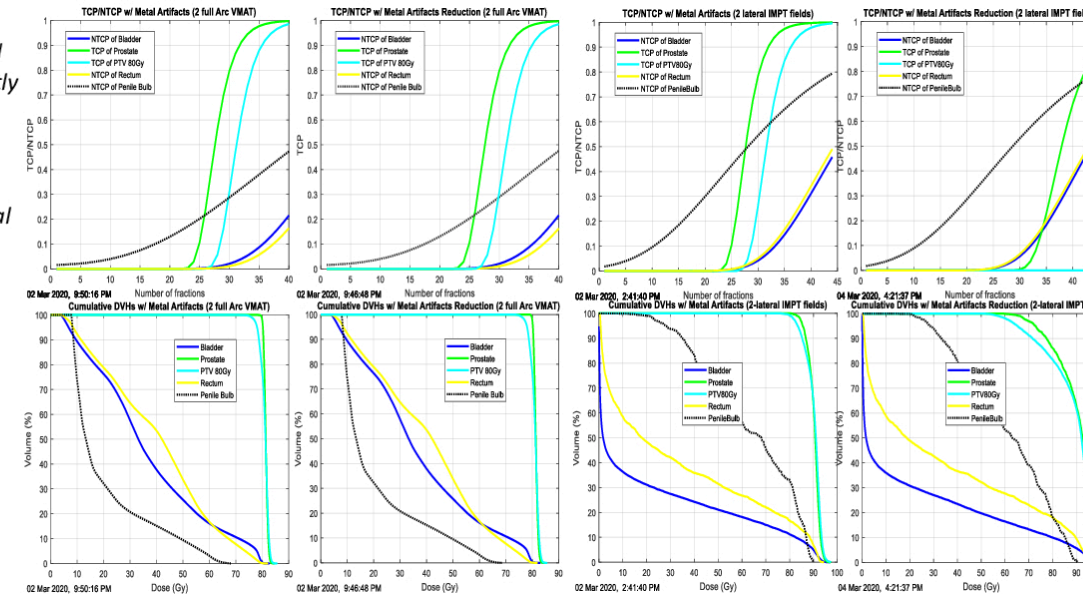


Figure 3. TCP/NTCP and Cumulative DVH plots with metal artifacts and with metal artifacts reduced from one of prostate VMAT plans

Figure 4. TCP/NTCP and Cumulative DVH plots with metal artifacts and with metal artifacts reduced from one of prostate IMPT plans

Table 1. P-Values

	CTV (TCP) / PTV (CI/DHI)			Bladder (NTCP, Dmean, Dmax,Dmin)		Rectum (Dmean, Dmax,Dmin)		Small Bowel (Dmean, Dmax,Dmin)		Penile Bulb (Dmean, Dmax,Dmin)	
	VMAT										
	Full Arc	Avoiding Metal		Full Arc	Avoiding Metal	Full Arc	Avoiding Metal	Full Arc	Avoiding Metal	Full Arc	Avoiding Metal
TCP	0.221	0.133	NTCP	0.169	0.094	0.173	0.087	1.000	1.000	0.167	0.085
CI	0.167	0.169	Dmean	0.164	0.176	0.170	0.087	0.096	0.172	0.157	0.162
DHI	0.150	0.172	Dmax	0.191	0.167	0.178	0.169	0.125	0.239	0.170	0.168
Dmin	1.000	1.000	Dmin	0.128	0.096	0.127	0.108	0.111	0.172	0.136	0.153
	IMPT										
	Lateral (90-270)	Avoiding Metal		Lateral (90-270)	Avoiding Metal	Lateral (90-270)	Avoiding Metal	Lateral (90-270)	Avoiding Metal	Lateral (90-270)	Avoiding Metal
TCP	0.161	0.488	NTCP	0.116	0.132	0.083	0.089	0.196	No diff.	0.013	0.171
CI	8.62E-5	1.24E-4	Dmean	0.043	0.043	0.173	0.206	0.002	0.011	0.041	0.425
DHI	0.265	0.247	Dmax	0.418	0.250	0.411	0.160	0.386	0.247	0.187	0.063
Dmin	0.067	0.079	Dmin	No diff.	No diff.	0.029	0.029	No diff.	No diff.	0.137	0.173

CONCLUSIONS

VMAT and IMPT plan evaluation and comparisons show that the presence of metal artifact can affect dose statistics as well as radiobiological outcomes, e.g. TCP / NTCP. Especially for IMPT, CTV may show good tumor control with the presence of metal artifacts, but the setup to certain degree can introduce metal-artifact induced Tumor Control deficiency for CTV. Also for IMPT, normal tissue surrounding the tumor target are significantly affected by the presence of metal artifacts. Overall, the presence of metal artifacts could compromise radiobiological outcomes as well as sparing power of surrounding normal tissue in IMPT.

REFERENCES

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ACKNOWLEDGEMENTS

The authors are thankful to the author of metal artefact suppression code, Dr. Chun-I Lin. Her Matlab-based GUI code streamlined the process of presented study. There is no conflict of interest to disclose.

CONTACT INFORMATION

E-mail: physcein@Hotmail.com