Implications of metallic spine hardware on dosimetry and image verification in Spine SBRT

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JULY 12–16 2020 VIRTUAL JOINT AAPM | COMP MEETING EASTERN TIME [GMT-4]

INTRODUCTION

Spine SBRT is a prevalent treatment of choice for spinal metastases. SBRT is often recommended following surgical decompression for patients with cord compression (1,2). Many of these patients will also require spinal stabilization or fixation with surgical hardware which can present challenges for radiation therapy.

AIM

To quantify the impact of metallic fixations used in surgical spine stabilization on radiation dosimetry and CBCT image quality in spine SBRT

METHOD

Phantom:

- Spine phantom was printed of VeroBlue polymer
- Medtronic rods (cobalt chromium), multi-axial (Solera) screws, set screws, and a Stryker VLIFT cage (titanium alloy) were set in place by the neurosurgeon
- Phantom and hardware were submerged in an organic gelatin composed of water, propylene glycol and gelatin, Fig 1. (3)

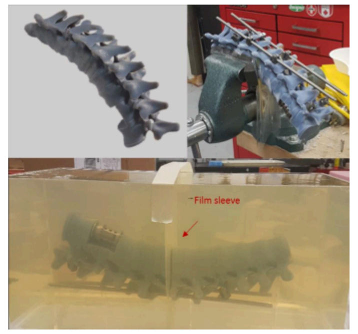

Fig. 1. 3D-printed phantom with spinal hardware submerged in gelatin. Also shown the location of film sleeve used for film dose measurements

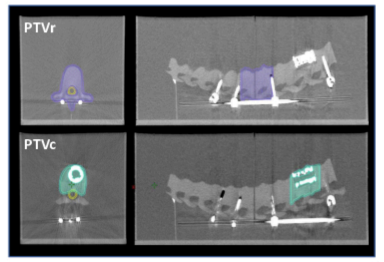

Fig. 2. CT scan of Spine phantom with 2 PTV contours: Top – vertebral body next to metallic screws and rods (PTVr); Bottom – Encompassing VLIFT cage (PTVc)

CT & Contouring:

- Spine SBRT CT protocol with 1mm slice thickness and OMAR (orthopedic metal artifact reduction) reconstruction was used to scan the phantom
- Contouring of CTV/PTV was done by Radiation Oncologist based on spine SBRT guidelines, Fig 2 (4).

Dosimetry:

- Treatment plan was created using Eclipse v13.6 and optimized using the AAA model
- The plan was re-calculated using the Acuros algorithm for comparison
    - With rods assigned as stainless steel (8.0 g/cm^3) and screws/cage assigned as titanium alloy (4.42 g/cm^3)
- AAA and Acuros calculated doses were compared to EBT3 GafChromic film measurements

CBCT image quality - phantom:

- Pelvis and Thorax imaging protocols were investigated with 1 standard and 5 advanced iterative CBCT reconstruction algorithms (advanced v2.7 imaging on Varian TrueBeam systems)
    - Since Clinical Thorax protocol doesn't support iCBCT it was recreated using Pelvis protocol and matching kV and mA to the Clinical Thorax protocol
- Cumulative HU histograms were created for PTV contours for each imaging protcol and each reconstruction algorithm using MIM Maestro (MIM Software Inc., Cleveland, OH)
- Image quality was assessed based on the amount of high-density (>200 HU and >500 HU) and low-density (<-100 HU and <-300 HU) artifact present within PTVs

CBCT image quality – Patient data:

- Imaging data was collected on 3 patients with Upper/Middle T-Spine treatments that had metal hardware
- Standard CBCT was compared to 5 iCBCT reconstruction techniques quantitively using PTV HU histograms as well as using qualitative assessment

RESULTS

Dosimetry:

Gamma analysis:

- Gamma pass rates for comparison of Film, AAA and Acuros are summarized in Table 1
- For PTVr AAA and Acuros agreed within ~2%, while the average local dose differences between film and AAA/Acuros were 1.6%/0.5% , Fig 3
- Film measurements were not collected for PTVc due to cage geometry, on average AAA and Acuros agreed within 3.5%

	Film	Acuros
AAA	99.7%/N/A	100%/ 97.3%
Acuros	99.8%/N/A	

Table 1. Gamma pass rates comparison PTVr/PTVc

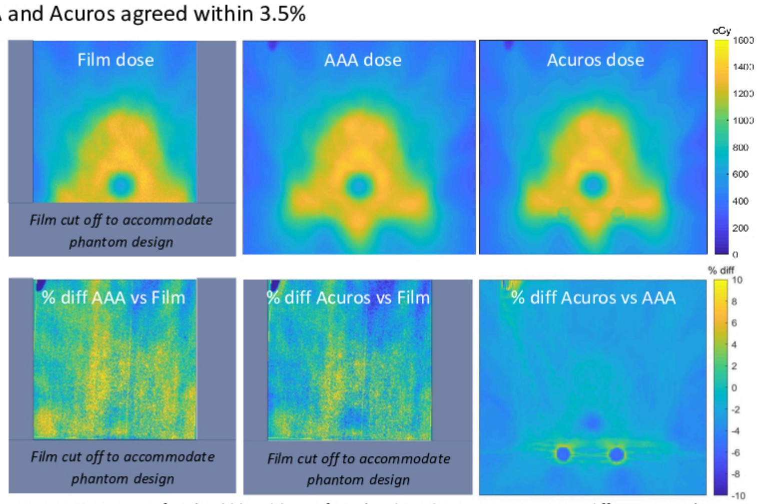

Fig 3. Top: Dose maps for Film, AAA and Acuros for a slice through PTVr. Bottom: Percent difference maps between film and AAA/Acuros and comparison of AAA and Acuros for PTVr

DVH Comparison:

- PTV and Spinal cord DVH are shown in Fig. 4 and summarized in Table 2
- V100 decrease by up to 5% for Acuros, however, V90 &V80 were within 1% of AAA
- Hot spots adjacent to metal were predicted by Acuros but not AAA and were more pronounced around the VLIFT cage (up to 8%), Fig 4

	Rods and Screws		Cage	
	PTVr V100%Rx	*Spinal Cord Dmax (0.03cc)*	*PTVc V100%Rx*	*Spinal Cord Dmax (0.03cc)*
AAA	91.8%	1807.4cGy	76.3%	1534.4cGy
Acuros	85.2%	1764.3cGy	71.1%	1497.6cGy

Table 2. DVH summary for PTV coverage and Spinal cord Dmax for PTVr and PTVc

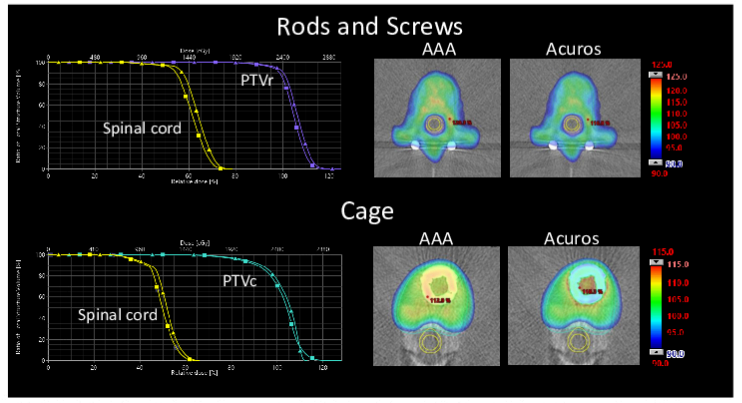

Fig 4. Left- DVH for PTV and Spinal cord for AAA (Δ) and Acuros (☐), Right- dosimetric maps for PTVr (Top) and PTVc (Bottom)

CBCT image quality - phantom:

- Standard CBCT reconstruction had the highest contribution of high and low density artifacts for Pelvis and Thorax protocols
- Pelvis protocol showed a marginal improvement for high density artifact, while the Thorax protocol had reduced low density artifact
- Comparison of 5 iCBCT reconstruction techniques showed modest benefit
- Best artifact reduction was found when using Smoothing Filter with Very High noise suppressions and Adaptive detruncation volume
- Results were similar for PTVr and PTVc

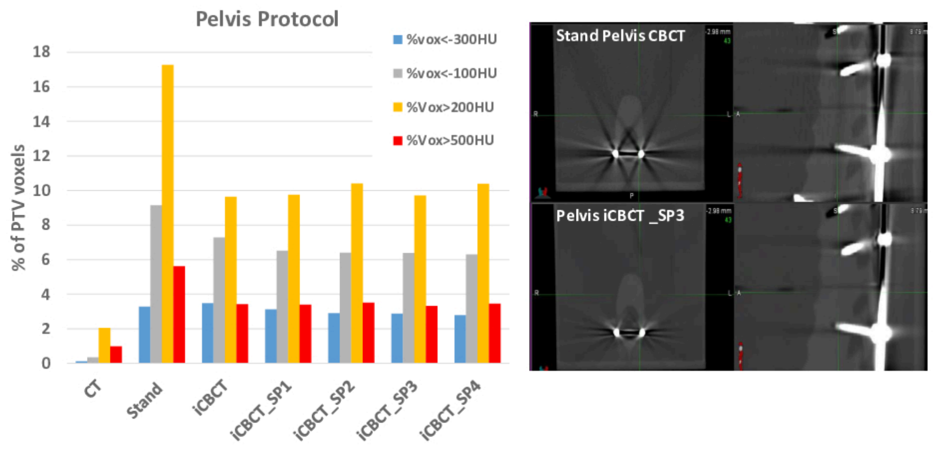

Fig 5. Left- Histogram analysis showing the percentage of voxels within the PTVr structure for different reconstruction algorithms for Pelvis protocol; Right- CBCT images for Standard CBCT and optimized iCBCT pelvis protocols

	Standard	iCBCT	iCBCTSP1	iCBCT_SP2	iCBCT_SP3	iCBCT_SP4
Filter	Auto	Standard	Smooth	Smooth	Smooth	Smooth
Noise suppression	N/A	Medium	High	High	Very High	Very High
Detruncation volume	N/A	Adaptive	Adaptive	Full	Adaptive	Full

Table1: Reconstruction algorithm parameters

CBCT image quality – Patient data:

- In upper/mid thoracic region iCBCT reconstruction appears to accentuate high density artifact. Possibly due to the breathing motion (Fig 6)
- iCBCT impact on low density artifact was variable from patient to patient with only 1 showing improvement

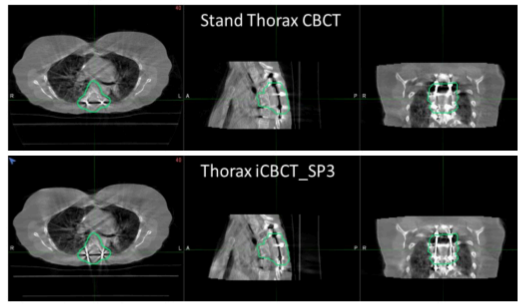

Fig 6: comparison of Standard thorax CBCT to custom Thorax iCBCT protocol

CONCLUSIONS

Results of this study can serve as guidance for centers performing spine SBRT treatments when spinal hardware is present

Recommendations:

- AAA does not underestimate the dose in the Spinal cord but may overestimate PTV coverage at V100%. Dose agreement between AAA and Acuros improves below the prescription dose
- Hot spots adjacent to metal implants can occur, particular with use of cage implants
- These hot spots are not well estimated with AAA, therefore, caution should be taken if an implant is abutting critical organs (i.e. spinal canal)
- iCBCT can reduce metal artifacts in CBCT, however it may not perform well in upper/mid thorax region due to respiratory motion artifact

**** Investigation of application of iCBCT for patients with lower T-spine and L-spine regions is on-going***

ACKNOWLEDGEMENTS

Authors would like to acknowledge Alberta Cancer Foundation Clinical Rsearch Fellowship for funding (HM), J Hindmarsh for use of gamma analysis Matlab code, Dr. B Jacobs for fixation of surgical spinal hardware, Dr. M Doak for contouring, and the TBCC design lab for assistance with phantom creation.

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