Dosimetric Impact of CT Artifacts for Spine SBRT

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AAPM SPRING CLINICAL MEETING 2022

PURPOSE

Spine SBRT patients frequently have stabilization hardware implanted along the vertebral bodies. This hardware consists of rods running parallel to the spine, large screws securing the rods to the vertebral bodies, and occasionally support cages where vertebral bodies were surgically removed. While some of the hardware can be carbon-fiber, more often, titanium hardware is used for its increased strength and durability. Titanium creates streak artifacts on CT that increase and decrease the observed Hounsfield Units (HU) in the treatment area. Hardware and artifacts may be contoured, overriding their densities with the goal of improving dosimetric accuracy. However, contouring the hardware and resulting CT artifacts is time consuming and increases the planning workload. Variations in artifact contouring and tissue delineation can also result in incorrect density corrections. This study aimed to assess the impact of density corrections on targets and organs at risk (OAR) for spine SBRT. A second endpoint of this study was to compare the contouring time against the resulting dose differences to determine the feasibility of an abbreviated process.

MATERIALS / METHODS

16 spine SBRT cases originally planned with density corrections were recomputed, removing the applied density corrections. Hardware and artifacts were contoured in MIM Software. Spinal hardware, bright-artifacts (artifacts with increased Hounsfield Units), and dark-artifacts (artifact with decreased Hounsfield Units) were contoured through every slice of the target, extending ≥ 1cm superior and inferior to the edges of the PTV. Artifacts were then categorized as bone, muscle, and adipose.

All cases were planned in Raystation and exported to MIM for analysis. Dose differences between density corrected and non-corrected plans were recorded for targets (PTV, CTV, GTV) and nearby OAR with planning organ at risk volume (PRV), including cord, cauda, esophagus, bowels, stomach, kidneys, lungs, heart and scar tissue. Dose deficit and excess were defined compared to the corrected plan.

Selected cases were prescribed to 1,800 cGy in 1 fraction (12 cases), 2,400 cGy in 2 fractions (2 cases), 2,700 cGy in 3 fractions (1 case) and 3,000 cGy in 5 fractions (1 case). Plans involved 1-3 contiguous vertebral bodies spanning from C3 – L5. Clinical cases were planned with IMRT (13 cases) and VMAT (3 cases)*. Two cases were planned with both VMAT and IMRT to compare modalities. GE CT scanner metal artifact reduction software (MARS) was applied to the CT in two cases.

To assess contour accuracy and subjectivity between planners, 9 cases had artifacts recontoured by the same dosimetrist at least 6 months later, and 3 cases were contoured by another dosimetrist. An additional two cases also had the hardware intentionally overdrawn to determine the impact of improper delineation. Partial density corrections were performed on 5 cases to assess time savings versus plan accuracy. Partial density corrections were recomputed with the following conditions: only correcting hardware, only correcting tissues (bone, muscle, adipose) to a single density of 1.05 g/cm^3 and making a subset of dark/bright artifact density corrections.

* Our current standard is VMAT

RESULTS

While large volumes of dose differences were observed, the magnitude was found to be relatively small compared to prescription doses. All cases had < 10 cc @ < 1% RX and < 1 cc @ < 2% RX dose excess and < 10cc @ 2 % RX and < 1cc @ < 4% RX dose deficit.

The maximum observed differences were < 0.01 cc @ 150 – 210 cGy. Dose deficits and excesses were < 0.7 cc and < 0.3 cc @ 90 cGy, respectively. The average deficit was 10 cGy (σ = 27 cGy) and the average excess was 1 cGy (σ = 7 cGy). The largest differences were seen directly adjacent to, and downstream of the hardware (beam's eye view). This observation agrees with published data on the effect of hardware on dosimetry[1].

Hardware never extended into PRV, minimizing observed dose differences. When titanium support cages were present between the spine and esophagus, the proximity resulted in a dose excess near these OAR. Increases in the esophagus were < 0.3 cc @ 10 cGy. Increase in cord were < 0.02 cc @ 10 cGy (largest excess was 0.2 cc @ 10 cGy corresponding to screws abutting the spinal canal).

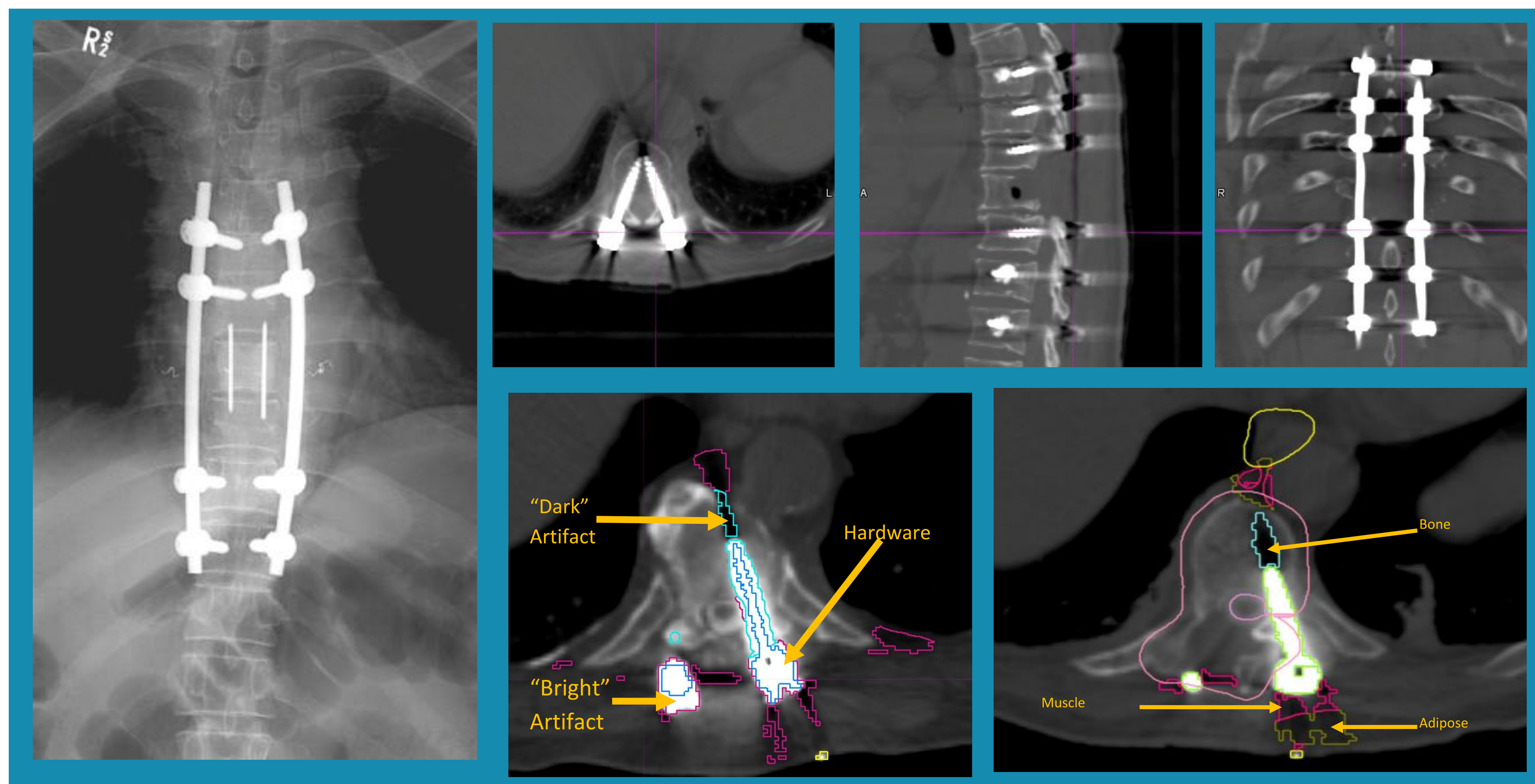
Dose excess was less significant for other OAR, while dose deficits were larger and more diffuse. The lungs had measurable dose differences in cases involving T7-10, which coincides with the proximity to the head of the screws. Lung dose excess was < 0.2 cc @ 10 cGy and dose deficits were < 100 cc @ 10 cGy and < 5cc @ 30 cGy.

Targets encompassed hardware, screws, and support cages, resulting in greater dose differences compared to OAR. Dose deficit and excess differences were < 90 cGy. Doses excesses were < 28 cc @ 10 cGy and < 1 cc @ 40 cGy. Dose deficits < 76 cc @ 10 cGy and < 1 cc @ 60 cGy.

Kidneys, bowels, and stomach are predominately distant to hardware, resulting in differences < 0.5 cc @ 10 cGy. Surgical scars were marked at CT with radio-opaque wire for planning avoidance. The wire causes small artifact resulting in dose deficits < 0.6 cc @ 10 cGy for the scar tissue. Heart dose deficits were < 3.3 cc @ 20 cGy, with the worst case corresponding to a T9 case where screw tips were anterior to the vertebral body, causing dark artifacts which streaked into the heart.

Comparing IMRT and VMAT, observed dose differences were less significant when using VMAT. Dose deficits for VMAT were < 195 cc @ 10 cGy and < 0.4 cc @ 90 cGy, while < 251 cc @ 10 cGy and < 251 cc @ 10 cGy for IMRT. Dose excess were similar for both modalities < 9.1-9.6 @ 10 cGy, but observable differences @ 90 cGy were notes (< 0.04 cc VMAT, 0.23 cc IMRT). Maximum excess was 140 cGy lower for VMAT compared to IMRT.

[1] Wang, Xin, Yang, James; et al. Effect of spine hardware on small spinal stereotactic radiosurgery dosimetry. Phys. in Med. and Bio. **58**:6733-6747 (2013)

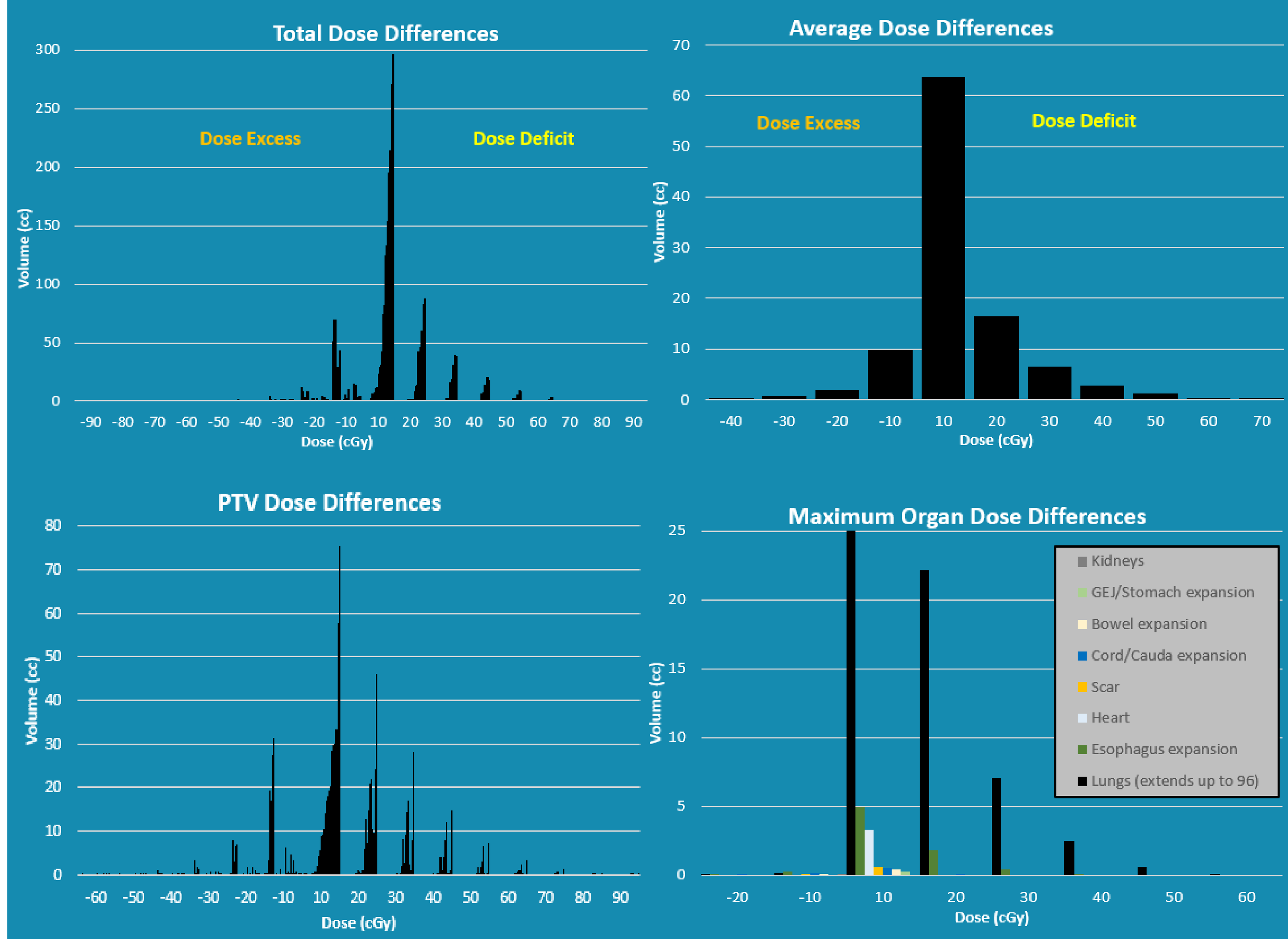


Titanium hardware and stabilization implants in spine SBRT patients. Metallic hardware result artifact streaking and distorts boundaries seen on CT images. Tissue contours used for density corrections are defined on axial slices.

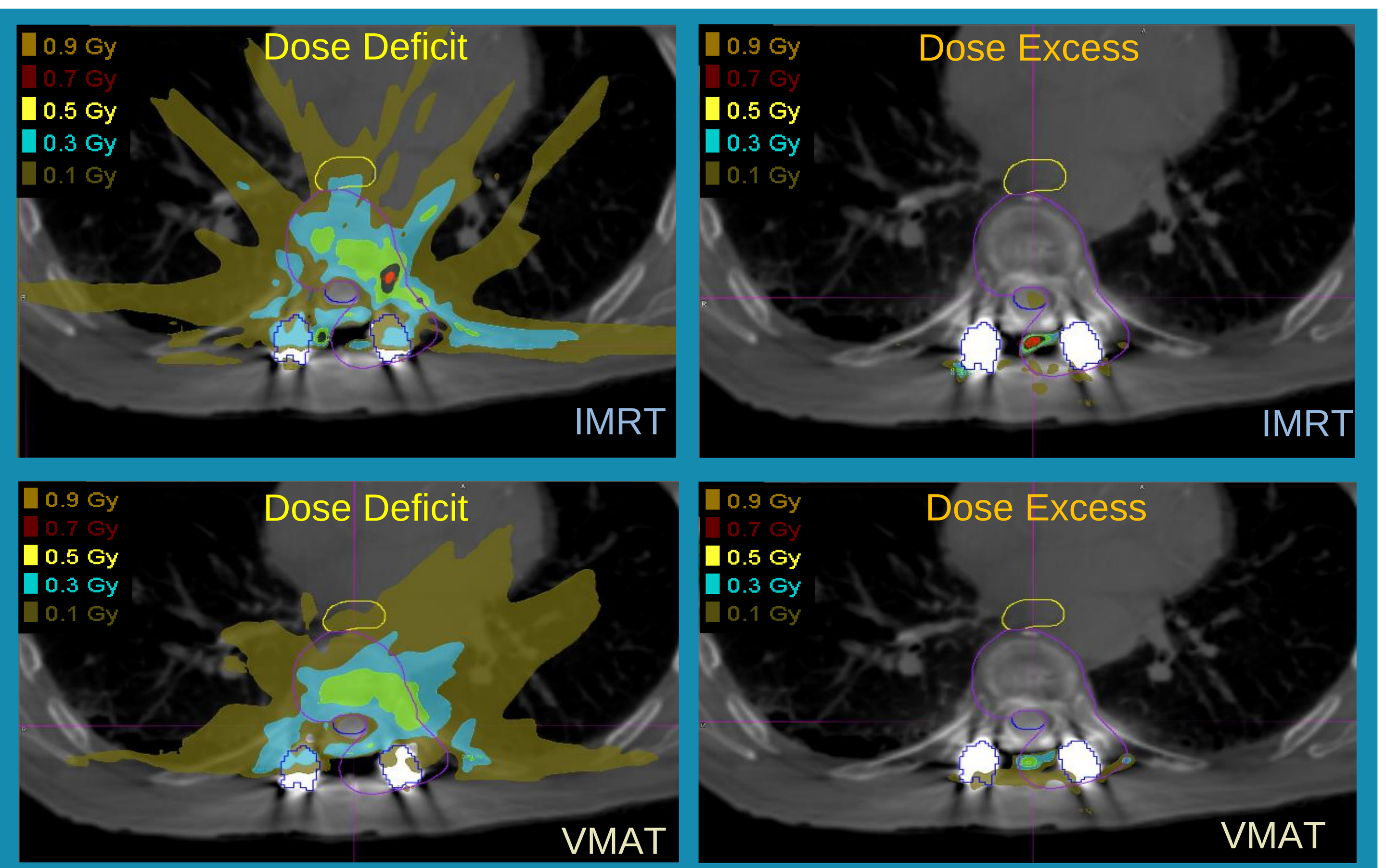
Mass Density Correction (g/cm^3)	
4.54	Titanium
1.7	Carbon Fiber
2.1 (1.85)	Bone
1.05	Muscle
0.95	Adipose

Contouring Time (minutes):	
5	Hardware
0-5	Wire
15	Dark Artifact
45	Bright Artifact
45-60	Bone
0-10	Lungs
10-40	Differentiate Tissues
120-180	Total

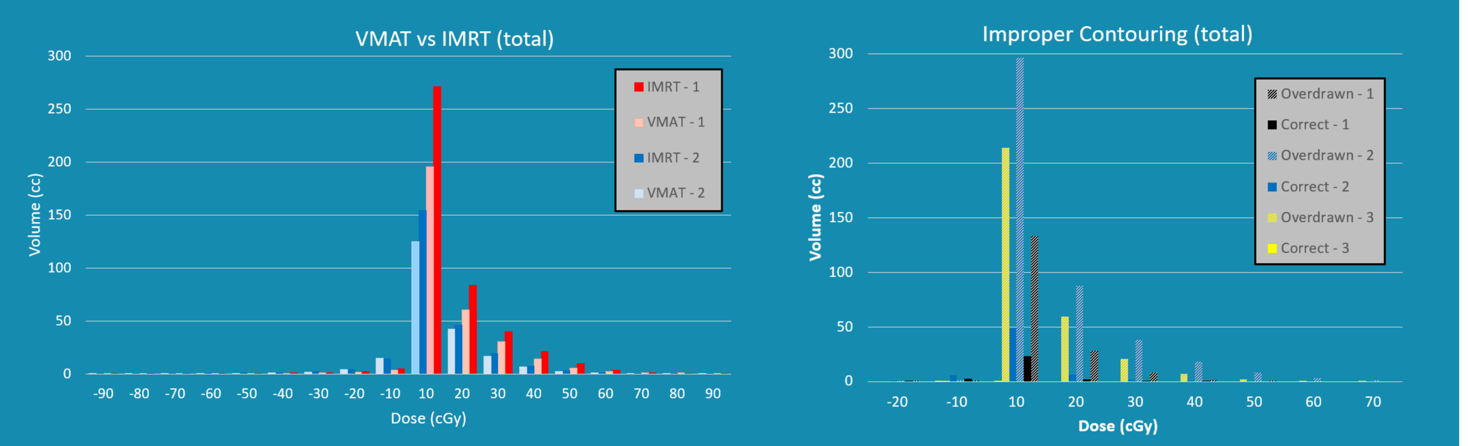
Applied mass density corrections and contouring time. Note the lengthiest contouring steps are delineating bone, contouring bright artifact, and differentiating tissues. These 3 steps make up approximately 80 % of the total time.



PTV and OAR dose differences for 16 cases prescribed to 1,800-3,000 cGy.



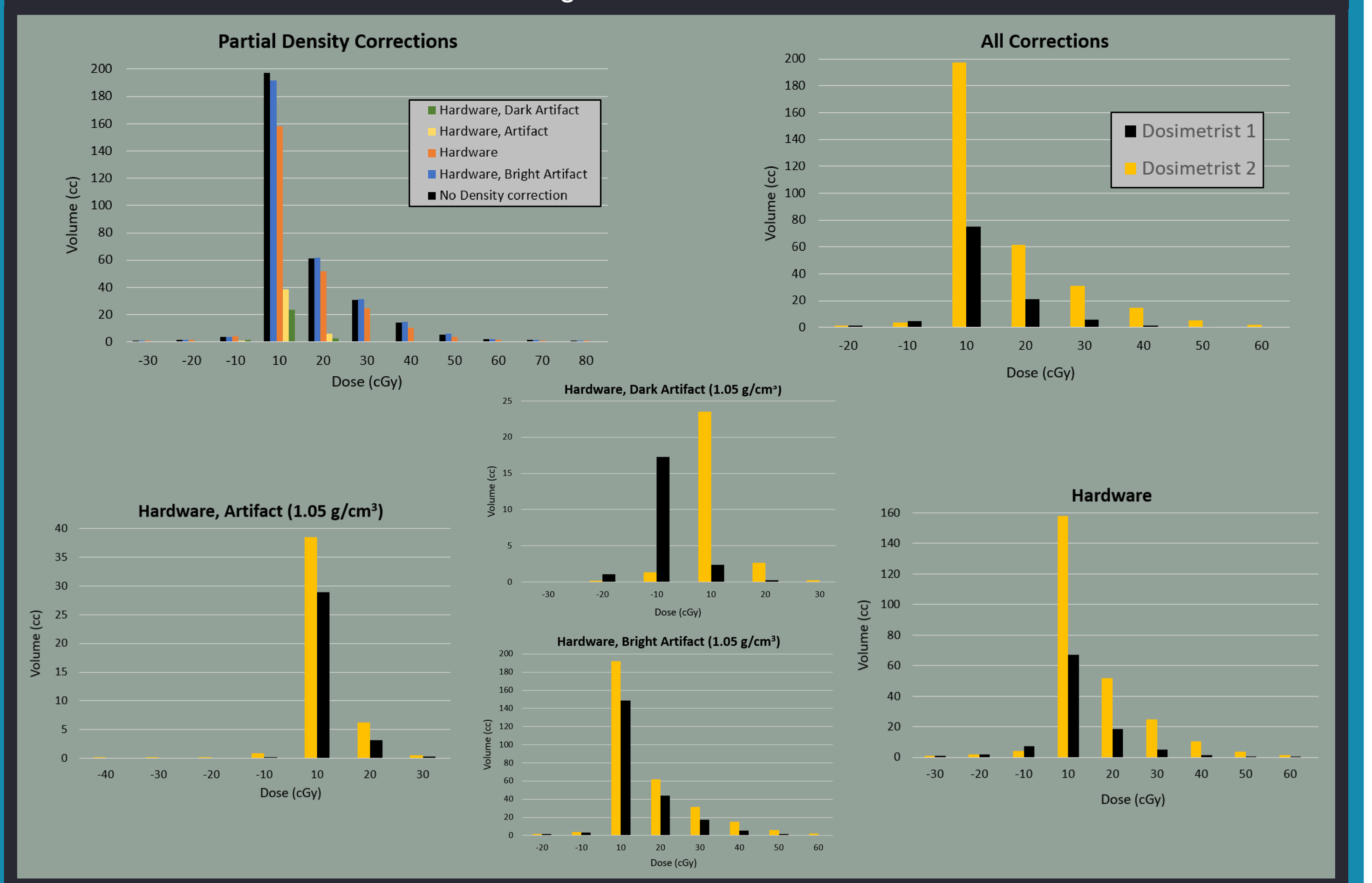
Dose differences displayed for the case with the most significant differences (top: IMRT, bottom: VMAT, left: dose deficit, right: dose excess). Corrected plan doses were subtracted from recomputed plans and compared. Dose excess is typically located between large screw heads, distant from the spinal cord and esophagus. Dose deficits are more dispersed throughout the treatment volume.



VMAT plans had less significant dose difference.

Recontoured cases resulted in observable dose differences, demonstrating the need for care and consistency to limit density correction errors.

Contouring Time vs Dose Difference



Cases were recomputed using a subset of density corrections to assess the trade-off between contouring time and dosimetric differences. Dark artifact corrections make the most difference, while hardware and bright artifact combined result in less significant contributions.

Discussion

This study demonstrates the impact of artifact density corrections for vertebral stabilization hardware when present for spine SBRT. On average, target dose deficits were < 1 cc @ 50 cGy and excesses < 1 cc @ < 30 cGy. OAR deficits were < 0.5 cc @ 10 cGy and excesses < 0.01 cc @ < 10 cGy. The most pronounced differences were directly adjacent to hardware and upstream of OAR. Stringent cord and esophagus constraints are achieved by MLC blocking of field segments, reducing artifact effects in these OAR. Most artifact corrections resulted in increased tissue density and subsequent dose deficits. Therefore, an uncorrected plan would typically deliver fewer MU and therefore less dose to targets and OAR. OAR distant to hardware and the resulting artifacts resulted in smaller differences. While dose differences observed in this study were not clinically concerning, individual cases should be assessed when stabilization hardware is close to the cord and esophagus. Artifact contouring may differ from user to user and impact estimated dose differences.

Conclusion

Artifact contouring is a labor-intensive process. Limiting contouring to hardware and dark-artifact resulted in a small dose difference adjustments and time savings of 100 -160 minutes. Completely omitting artifact contouring and density corrections resulted in an additional time saving of up to 20 minutes (120 -180). Based on this study, it may be appropriate and beneficial to simplify or omit artifact contouring altogether for spine SBRT using either IMRT or VMAT.