Dosimetric Study of Radiation Therapy in the Region of Stabilized Spine

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Introduction

Implants complicate radiotherapy planning and delivery, especially in cases involving hip replacements or spinal stabilization hardware.

Depending on their material, implants can create CT artifacts that degrade image quality, impair OAR and PTV delineation, and reduce dose calculation accuracy.

While artifacts can be partially corrected, the implants themselves remain problematic—especially in spine cases where they form part of the PTV and beam avoidance is not feasible.

This work compares the impact of two types of spinal fixation hardware.

Materials / Methods

Two spinal fixation types were used: Ti6Al4V alloy and carbon with a 0.05 mm titanium surface layer, as shown in Figure 1.

Figure 1 - Fixation hardware used in this study: titanium alloy (left), carbon-based fixation (right).

To evaluate artifacts, CT scans of both fixation types were performed in a water-filled phantom and analyzed in Eclipse v15.6 using the Acuros XB (AXB) material table. For dose comparison, a custom phantom with a porcine spine was used (Figure 2) in three setups: no fixation, titanium, and carbon. Gafchromic film was placed in the sagittal plane through the spine. VMAT plans (two full arcs) with 6 MV, 10 FFF, and 15 MV photons simulated vertebral irradiation with spinal cord sparing. Calculated and measured dose distributions were compared using gamma analysis. The workflow is shown in Figure 3.

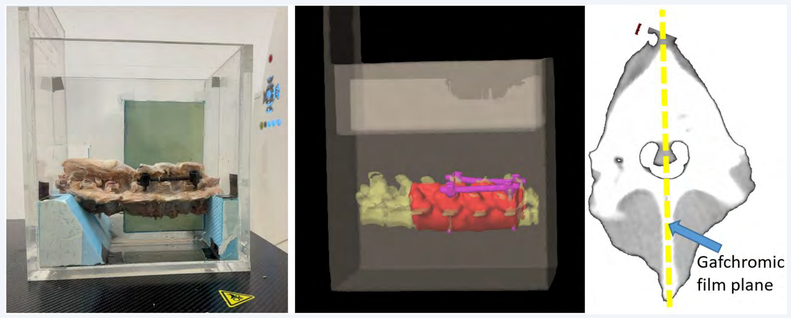

Figure 2 - Phantom used in the study with carbon fixation (left), its representation in the treatment planning system after contouring (center), and schematic depiction of the film plane (right).

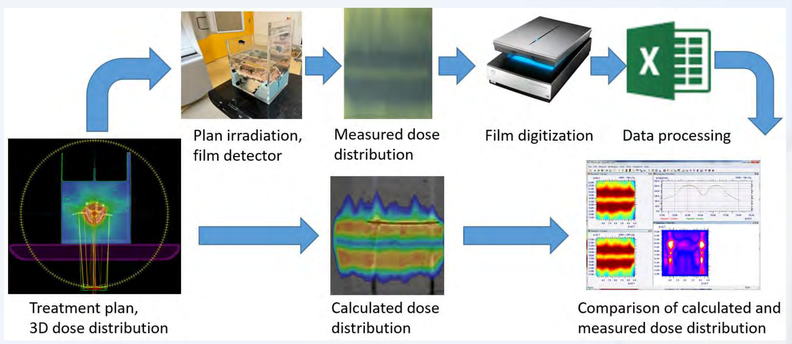

Figure 3 - The experimental workflow.

Results

Figure 4 compares CT scans of both fixation types in water, using identical imaging parameters. Titanium implants caused prominent artifacts, leading to misinterpretation of density and composition in TPS. In contrast, carbon fiber, with physical properties closer to human tissue, produced minimal artifacts.

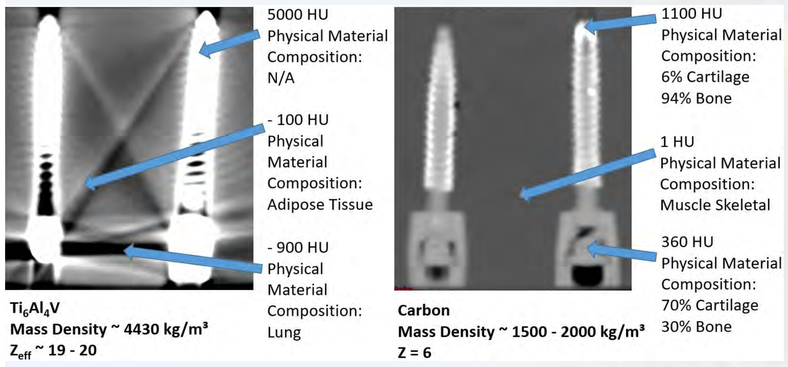

Figure 4 – CT scan comparison of titanium (left) and carbon fixations (right).

An example of measured vs. calculated dose comparison for a 6 MV beam, AAA algorithm, and the phantom without fixation is shown in Figure 5. The gamma analysis (3%/3mm) indicates very good agreement.

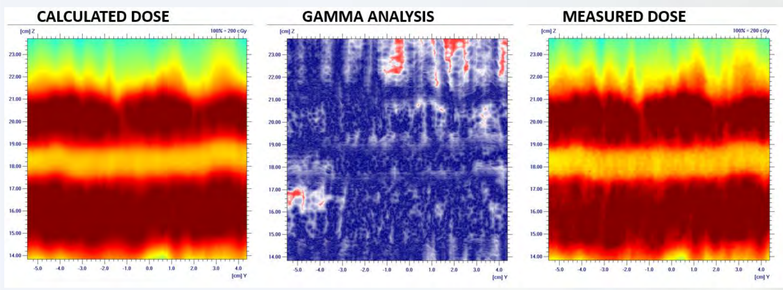

Figure 5 – Example of film evaluation: 6 MV beam, AAA, no fixation.

Titanium fixation led to reduced agreement between measured and calculated doses, most notably with the 6 MV beam. Measured D_{min} in spinal cord was up to 7% higher than calculated.

Carbon fixation caused no significant disturbance, with results comparable to the no-fixation scenario. Gamma analysis and profile comparisons for all three scenarios are shown in the following figure.

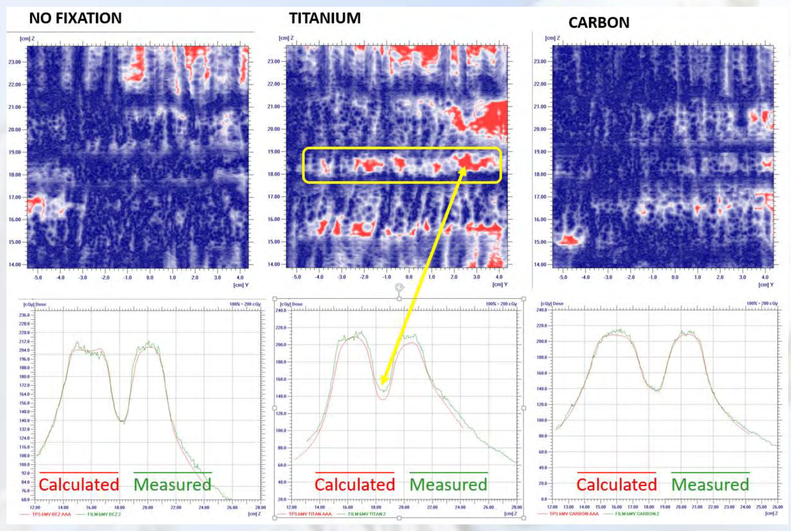

Figure 6 – Gamma analysis and profiles for 6 MV, AAA.

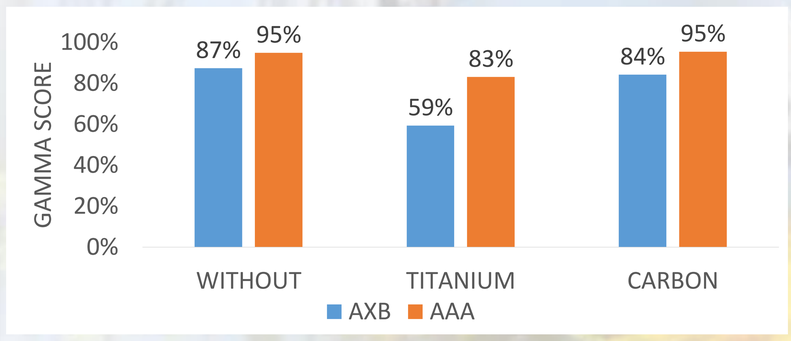

Figure 7 – Gamma score for 6 MV.

Summary of gamma analysis results for additional beam energies is provided in the table below.

FIXATION	6 MV		15 MV		10 FFF	
	AXB	AAA	AXB	AAA	AXB	AAA
WITHOUT	87,30	94,83	93,78	98,81	94,56	95,15
TITANIUM	59,31	83,02	65,84	77,81	78,36	92,48
CARBON	84,17	95,40	97,03	99,95	98,74	98,81

Figure 8 – Gamma score [%] 2%/2mm for three phantoms and three energies.

Conclusion

Carbon-based fixation produced minimal CT artifacts and showed no noticeable impact on dose calculation accuracy.

In contrast, titanium fixation generated significant artifacts and negatively affected the accuracy of calculated dose distributions.

The results indicate an underestimation of the spinal cord dose by several percent.

Better agreement with measured data was achieved using the AAA algorithm, even in the no-fixation scenario.

This may be attributed to the energy cut-off inherent to the AXB[1], which, in specific cases—such as vertebral irradiation with a steep dose gradient toward the spinal cord—can lead to dose underestimation.

[1]Hughes et al. Calculation algorithms and penumbra: Underestimation of dose in organs at risk in dosimetry audits. Med Phys. 2021; 48(10):6184–6197. doi:10.1002/mp.15123