Titanium and Carbon-Fiber-Reinforced Polyetheretherketone (CFR-PEEK) Hardware in Spine Radiosurgery (SRS)

Lauren Weinstein, MS, DABR and Matthew Skinner, MS, DABR

Department of Radiation Oncology, Kaiser Permanente, South San Francisco, CA

KAISER PERMANENTE. thrive

Objectives

High quality imaging and accurate dosimetric calculations are key requirements in spine SRS and can be compromised by high-Z materials, such as titanium (Ti), used for mechanical stabilization. CFR-PEEK is an alternative to Ti due to its radiolucency that allows reduced imaging artifacts and dose perturbations of the SRS plan. We compared the impact of titanium and CFR-PEEK constructs against non-implanted bone using an anthropomorphic spine phantom, evaluating CT reconstruction artifacts, impact of metal artifact reduction and dual energy CT, and compared dosimetric accuracy of multiple treatment planning algorithms.

Methods

A coronally sectioned, anthropomorphic, film phantom was CT-simulated and fifty-five spine SRS plans were created for inserts containing normal bone, bone with a Ti construct and bone with a CFR-PEEK construct. CT was performed on a Siemens Confidence RT using both single-energy (SECT) and dual-energy (DECT) techniques with metal artifact reduction (iMAR). SRS plans were created with Varian Eclipse 16.1 (AAA; AcurosXB) and Brainlab Elements 3.0 & 4.0 (Pencil Beam & Monte Carlo) using 6FFF and 10FFF. Target volumes were circumferential to the spinal canal to provide a steep dose gradient typical in SRS spine. The phantom was aligned using Brainlab Exactrac 6.5 and treated on a Varian Truebeam Edge. Gafchromic EBT-XD film was placed between the anterior phantom slab for irradiation. Measured and calculated dose distributions were analyzed using point dose, line profiles and gamma analysis for each insert.

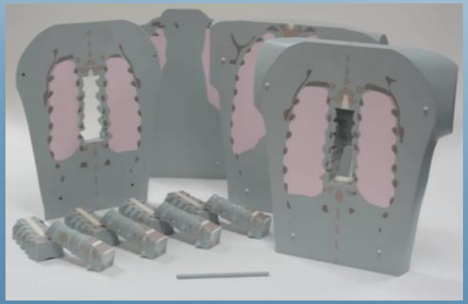

Fig 1. CIRS anthropomorphic thorax phantom with interchangeable spine inserts containing bone, titanium or CFR-PEEK constructs

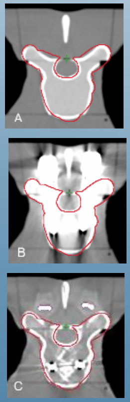

Fig 2 Raw CT of inserts illustrating artifacts caused by constructs compared to normal bone A) bone B) titanium C) CFR-PEEK *PTV used for SRS planning shown in red.*

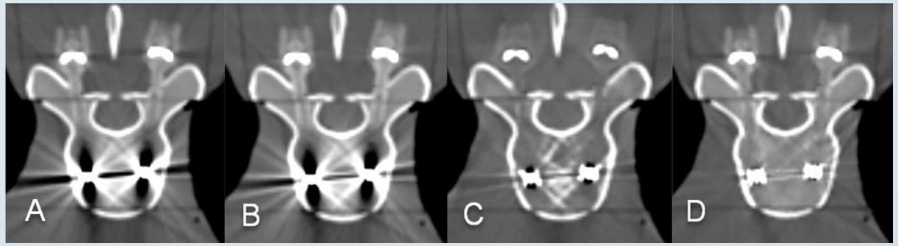

Fig 3 Raw and iMAR showing improved artifact A) Raw B) Spine C) Neuro coil D) Dental

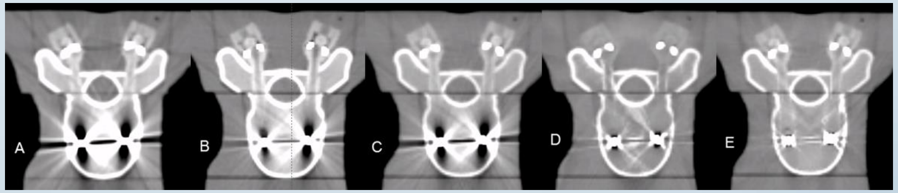

Fig 4 – CFR-PEEK inserts reconstructed with iMAR and/or DECT. A) Raw CT B) Dentai iMAR C) 160 keV DECT D) 160 keV DECT + neuro coil iMAR E) 160 keV DECT + dental iMAR

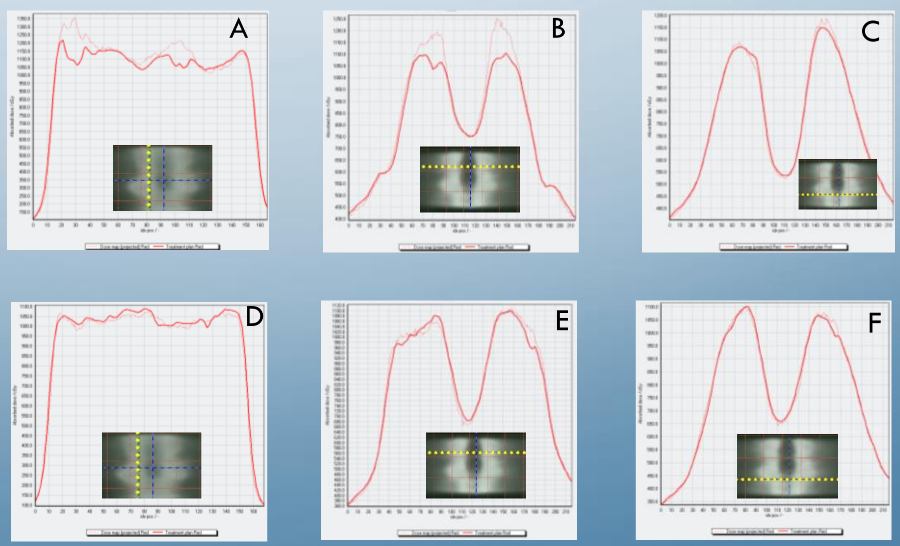

Fig 5. Intercomparison of x and y dose profiles through (A-C) titanium and (D-F) CFR-PEEK Large dose differences are evident in Ti profiles that bisect screws. CFR-PEEK shows close agreement in the same regions. *Calculated **thick** line; measured thin line.*

Results

Titanium constructs consistently induced significant image artifacts compared to both normal bone and CFR-PEEK in all image series. Ti artifacts were noticeably improved when iMAR was utilized. CFR-PEEK constructs demonstrated superior canal and vertebral body visualization in raw CT images with artifact limited to the radio-opaque tips and tulips. For CFR-PEEK the dental iMAR setting was found to be optimal for artifact suppression. Further reduction was achieved with 160 keV DECT combined with dental iMAR. The tantalum tip in CFR-PEEK screws caused minor streaking on CT but had negligible impact in film dose measurements With Ti inserts, Gafchromic film measurements showed differences of 15 - 20% between the TPS within 5 mm of the Ti hardware. By contrast the radiolucency of the CFR-PEEK constructs resulted in films that agreed closely, well within 5%, with the TPS and were comparable to measurements in native bone (Fig 5). Distant from all constructs, along the spinal cord itself, all TPS algorithms agreed within 5% or better to film.

Conclusion

Near the construct, CFR-PEEK had improved dosimetric accuracy, and in line with bone-only measurements when compared to conventional, Ti hardware. Moreover, CFR-PEEK offers superior image quality to Ti, even with only SECT and no MAR, offering significant advantages in visualization for iMAR. The facilities that do not yet have access to more advanced image reconstruction algorithms. iMAR improved metal artifacts significantly and further improvement was gained when combined with DECT. Artifact minimization near the vertebral body and spinal cord is advantageous for both MRI-CT fusion and the subsequent target and OAR delineation and can improve follow-up imaging and/or retreatment of disease. All TPS algorithms predicted spinal canal dose to sufficient accuracy, even in the presence of Ti, provided the distance to the spinal cord from hardware exceeded 5 mm. Our study demonstrates several advantages for the SRS planning process of utilizing CFR-PEEK constructs compared to conventional, Ti hardware.

Acknowledgements

Icotec ag for provision of anthropomorphic phantom used in this study