Dose Calculation Accuracy in the Presence of High-Z Material using Megavoltage CT for Treatment Planning

R. Hecox[1], J. Gibbons[2], D. Followill[1], G. Ibbott[1]

(1)University of Texas M.D. Anderson Cancer Center, Houston, TX, (2)Mary Bird Perkins Cancer Center, Baton Rouge, LA

Introduction

As a male ages, the probability of developing prostate cancer greatly increases from 1 in 9879 below age 39 to 1 in 7 after age 60.[1] With increased age also comes an increased incidence of total hip replacement using metallic, high-Z implants. Data from 2002 shows a hip replacement rate in the 65 to 74 age group of more than 1 in 400.[2]

The need to accommodate patients with both prostate cancer and a prosthetic hip is supported by a survey conducted by the AAPM which reported that between 1% and 4% of patients have prosthetic devices that can affect external beam radiation treatment.[3] It has been shown that the beam attenuation and reduced target coverage caused by a hip prosthesis is significant and must be included in treatment planning.[4-7]

When kilovoltage CT (kVCT) is used, the increased attenuation in high-Z materials compared to normal body tissues, causes artifacts due to incomplete projection data. These artifacts obscure anatomy detail and incorrectly report material density which can impact dose calculation accuracy.[8] High-Z artifacts are greatly reduced in megavoltage CT (MVCT) and may allow improved dose calculation accuracy for patients with metallic implants.[9]

For this study, the Radiological Physics Center's (RPC) anthropomorphic pelvic phantom fitted with a commercial Co-Cr-Mo hip prosthesis was used. The TomoTherapy, Hi-Art II system was used for MVCT imaging, treatment planning and treatment delivery.

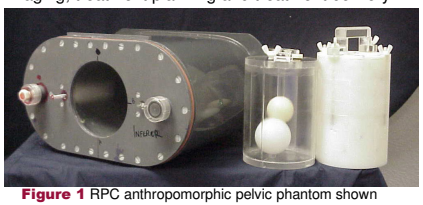


Figure 1 RPC anthropomorphic pelvic phantom shown with imaging and dosimetry insert

Materials & Methods

Phantom

- Anthropomorphic pelvic phantom with imaging and dosimetry inserts
- Removable 52mm Co-Cr-Mo hip prosthesis
- TLD-100 capsules located in the center of the prostate and right femoral head
- EBT radiochromic film located in the coronal and sagittal planes and intersecting at the center of the prostate

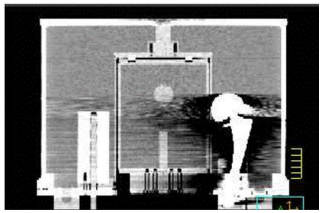
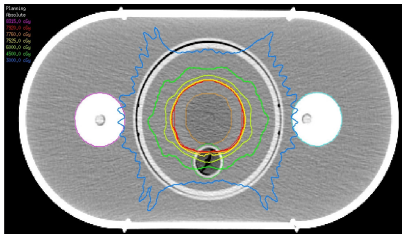
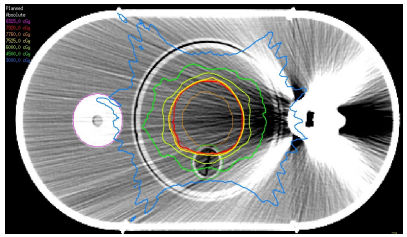


Figure 2 Coronal kVCT slice showing the prosthetic hip location inside the pelvic phantom

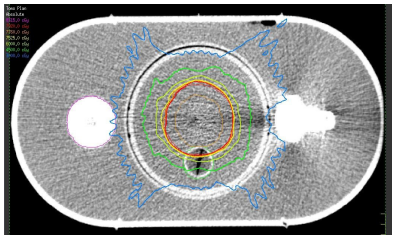
kV Normal Dose Distribution



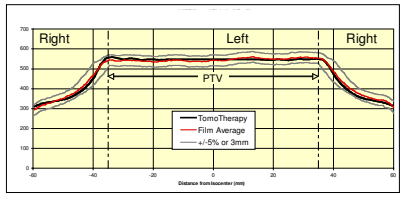
kV Prosthesis Dose Distribution



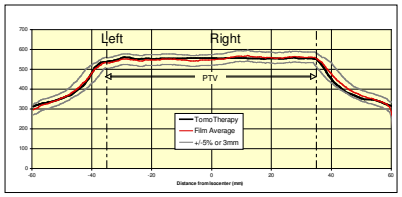
MV Prosthesis Dose Distribution



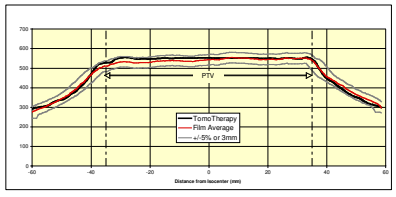
kV Normal Transverse Profile



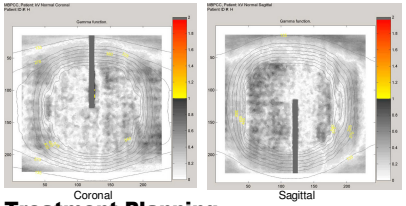
kV Prosthesis Transverse Profile



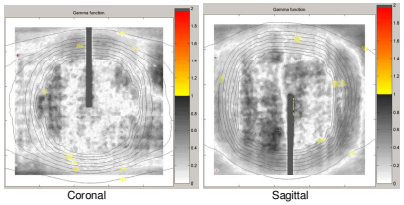
MV Prosthesis Transverse Profile



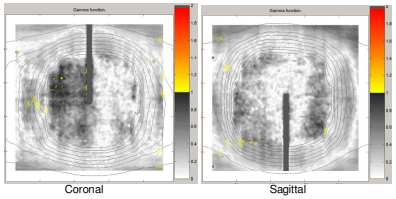
kV Normal ±5%/3mm Gamma



kV Prosthesis ±5%/3mm Gamma



MV Prosthesis ±5%/3mm Gamma



Treatment Planning

- RTOG protocol P-0126 used to define prescription and critical structure dose
- PTV prescription: 79.2 Gy in 44 fractions
- Plans created using beamlet optimization on helical tomotherapy system
- Image value to density table extended to high densities using stainless steel and lead samples
- Master contour set created on kVCT images without prosthesis and transferred to other plans
- Heterogeneity correction was used and beams were allowed to pass through the prosthesis
- Three plans were developed

1) kVCT simulation, no prosthesis
- Treated as a typical patient

2) kVCT simulation with prosthesis
- Worst-case scenario
- Image artifacts uncorrected
- CT-to-density table truncated at high density

3) MVCT simulation with prosthesis
- Plan created using MVCT images for optimization and dose calculation

Measurement

- Plan irradiations repeated at least three times
- TLD dose corrected for linearity, energy, fading and machine output
- Film optical density converted to dose and normalized to adjacent TLD
- Acceptance criteria of ±5% of prostate TLD dose or 3mm distance to agreement used in analysis

Results

Central PTV transverse profiles were measured on the coronal film. Corresponding profiles from multiple plan irradiations were averaged and compared to the calculated profile along with ±5%/3mm bands of acceptance. Gamma index distributions were created for both the coronal and sagittal films using ±5%/3mm.

Prostate TLD

	TLD (cGy)	Calculated (cGy)	Calculated/ Measured
kV Normal	546.3	547.6	**1.002**
kV Prosthesis	551.6	556.1	**1.008**
MV Prosthesis	547.2	552.0	**1.009**

Table 1 TLD results agreed with calculations to within 1% at the center of the prostate

Percent of Pixels Passing Gamma

	Percent Passing ± 5%/3mm
kV Normal	**99.9%**
kV Prosthesis	**99.9%**
MV Prosthesis	**98.5%**

Table 2 More than 98.5% of pixels passed ±5%/3mm gamma index criteria for all plans studied

Conclusions

- These results confirm that dose calculations based on MVCT images allow the accurate calculation of dose distributions in the pelvic region when treating through a high-Z prosthetic implant.
- Heterogeneity corrections accurately performed in the plan based on normal kVCT and the plan based on MVCT with prosthesis
- The plan based on the kVCT with prosthesis showed surprisingly good agreement with calculation. This was attributed to the small proportion of beams entering through the prosthesis due to helical tomotherapy geometry.

References

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