

Barium-contrasted bone-cements: impact on dosimetry

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INTRODUCTION

Polymethyl methacrylate (PMMA) based bone cements are a commonly used cranioplasty material for the repair of cranial defects, e.g. where bone flaps are excised due to tumour involvement. PMMA-based cements include contrasting additives, such as barium sulphate, to provide x-ray opacity, so for patients undergoing computed tomography (CT) simulation for radiation therapy treatments, these cements appear as bone. However, the x-ray attenuation provided by contrast additives is dependent on photon energy: the photoelectric effect dominates at kV imaging energies, while Compton scattering dominates at MV treatment energies. As a result of these differences, these cements behave as PMMA, not bone, in MV treatment beams.

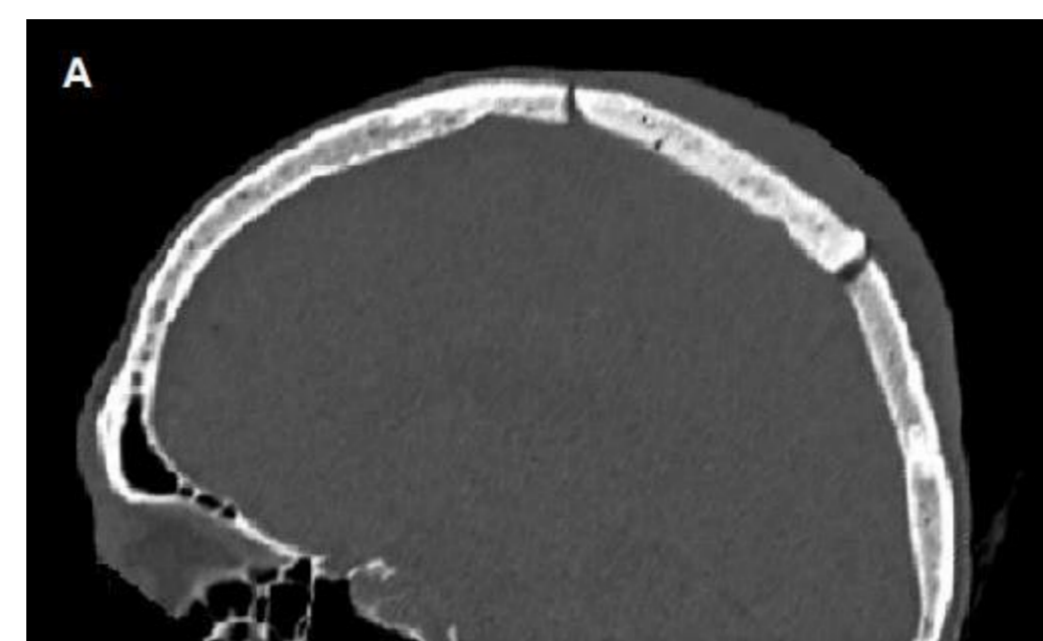
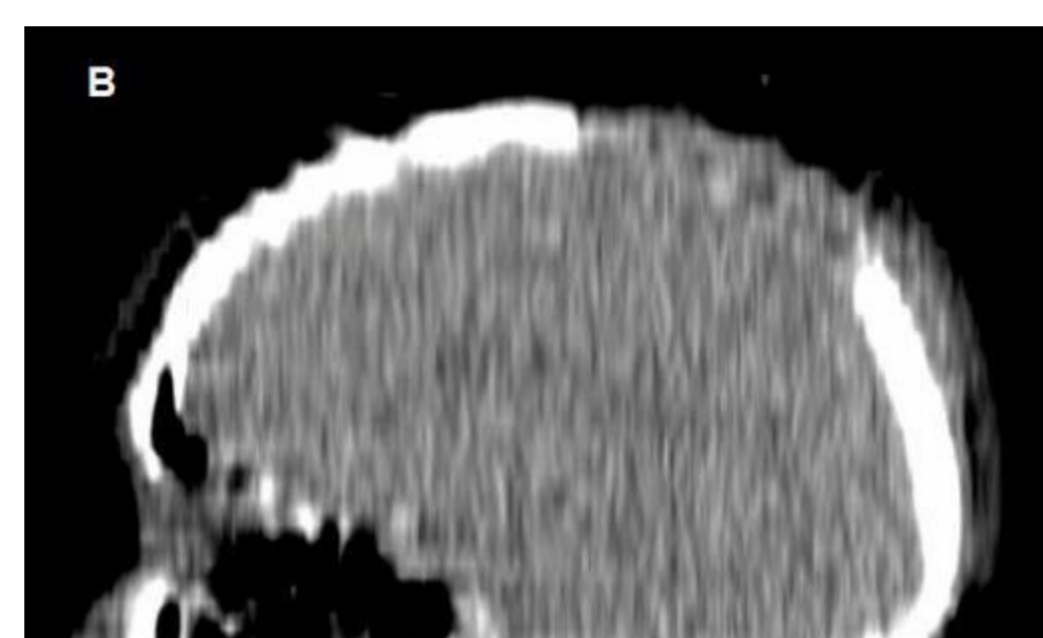


Figure (A) kV CT; (B) MV CT.



METHODS

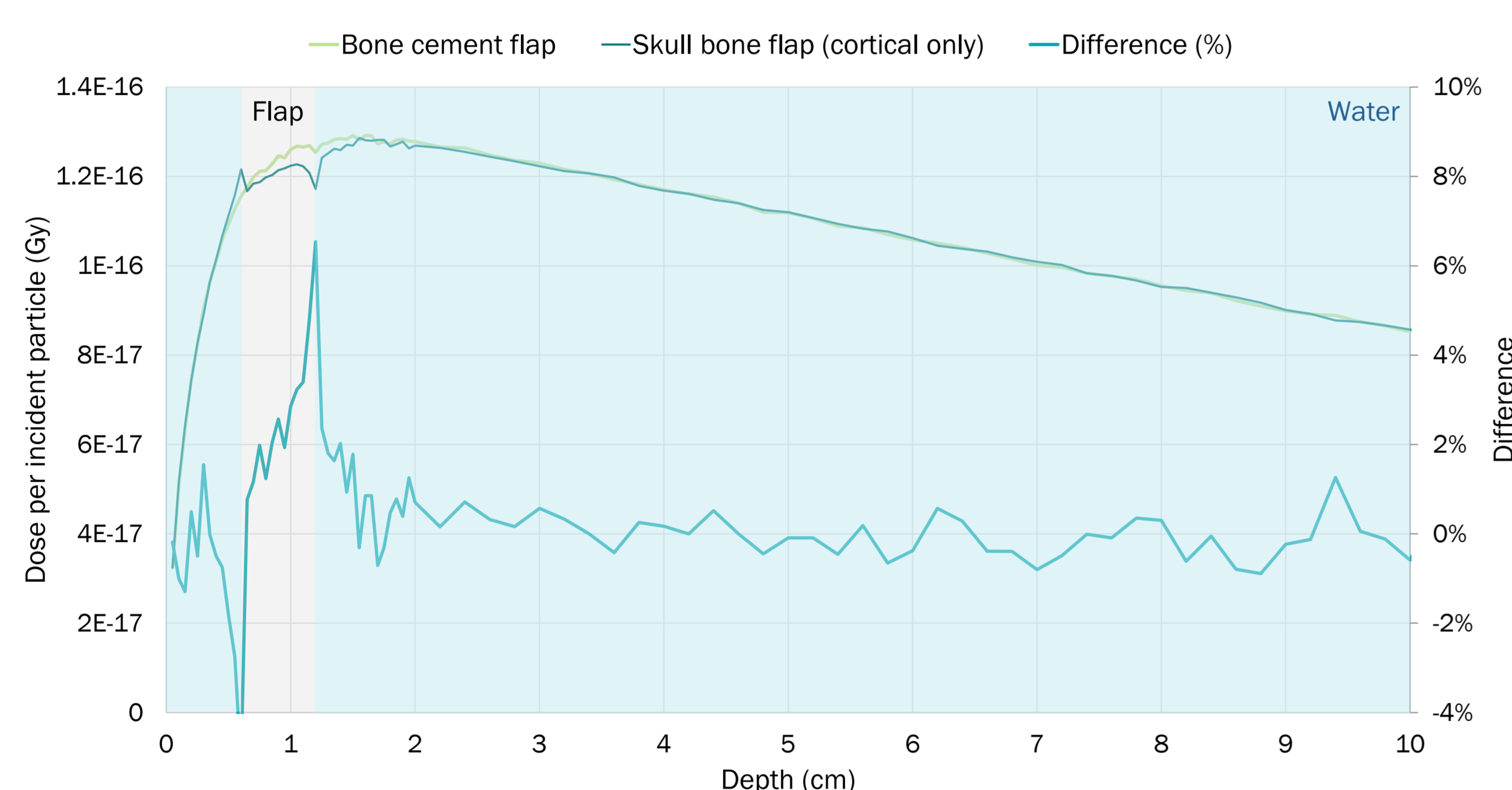
This study evaluated the behaviour of Barium-contrasted PMMA bone cement by:

1. Determining mass- and electron-densities of a physical DePuy CMW1 sample slab using kV (Siemens Somatom) and MV (TomoTherapy) imaging beams and reference HU-to-density data (Gammex); and performing radiological thickness transmission measurements with a 6 MV treatment beam and a Roos Chamber.
2. Determining dose perturbations using EGSnrc Monte Carlo simulations of Varian Clinac 6 MV linear accelerator treatment beams transported through virtual phantoms containing water, bone cement & bone materials.
3. Determining dose-volume metric differences resulting from incorrect handling of the material in the treatment planning system (i.e. treating the material as the bone it appears as, versus study-optimised user-defined density overrides in the bone cement volume) for a cohort of 10 cranial patients treated using volumetric modulated arc therapy plans. Dose volume metrics were calculated for the "PTV" and "PTV - Flap" volumes. These values were extracted using the Treatment and Dose Assessor (TADA) software [1].

RESULTS

MODALITY	ρ (g cm^{-3})	$\rho_e/\rho_{e,w}$
Siemens 120 kVp	1.78 ± 0.04	1.66 ± 0.03
TomoTherapy 3.5 MV	1.06 ± 0.04	1.04 ± 0.03
Varian 6 MV	-	1.02 ± 0.08

Left. Densities derived from CT and transmission data for physical bone cement sample. Below. Percentage depth dose profile for 6 MV beam in water and flap slab phantom (6 mm water + 6 mm flap + water).



TREATMENT SITE	PTV $\Delta D_{50\%}$	PTV ΔD_{MAX}	PTV ΔHI	PTV-flap $\Delta D_{50\%}$	PTV-flap ΔD_{MAX}	PTV-flap ΔHI
Frontal lobe 1	0.3%	0.8%	7.7%	0.3%	0.8%	1.2%
Frontal lobe 2	0.2%	-0.1%	-1.4%	0.2%	-0.1%	-0.9%
Frontal lobe 3	0.3%	0.4%	1.6%	0.3%	0.4%	1.3%
Frontal sweat gland	0.6%	0.1%	-2.2%	0.7%	0.4%	-1.9%
Lacrimal gland	0.1%	-0.5%	0.8%	0.2%	-0.2%	0.6%
Meninges	0.3%	0.9%	0.3%	0.4%	0.9%	-1.1%
Scalp 1	0.2%	0.7%	1.7%	0.2%	0.7%	-2.2%
Scalp 2	0.6%	0.3%	1.4%	0.7%	0.3%	1.0%
Scalp 3	1.1%	1.5%	1.9%	1.0%	1.5%	0.9%
Scalp 4	1.3%	1.6%	18.2%	1.2%	2.0%	18.2%
Mean	0.5%	0.6%	3.0%	0.5%	0.7%	1.7%

Above. Differences between dose volume metrics for dose distributions calculated with and without a $\rho=1.08 \text{ g cm}^{-3}$ (13 HU) override applied to the bone flap volume. A positive value indicates that the dose calculated with an override applied (i.e. calculated correctly, for a bone cement flap) is higher than the dose calculated without an override applied (i.e. calculated incorrectly). A flap existed in 6 of the previously treated patients, and a virtual flap was defined for the remaining 4 treatment plans. The overlap between PTV and flap volumes varied between 0.1 and 36.1 cm^3 (mean $9 \pm 10 \text{ cm}^3$). The average cumulative meter setting for the VMAT treatments was $660 \pm 470 \text{ MU}$.

DISCUSSION

Care should be taken when treating patients where PMMA-based bone cements may be present, as the radiological properties of these materials may appear similar to bone in kV treatment planning CT images, but vary significantly for MV treatment beam energies.

For single orthogonally incident beams, the delivered dose could be 7% higher than expected at the cement tissue interface. For treatments exploiting multiple angles of incidence, i.e. VMAT treatments, this deviation may be reduced, particularly for intracranial volumes. The largest dose deviations were observed for scalp treatments, where thin and slightly concave targets directly overlie the cranial bones and bone cement.

Minimal deviations were observed between dose-volume metrics calculated with and without density overrides for the "PTV - flap" volume compared to the unchanged PTV volume. On average the largest dose deviations occurred at hot spots. There was an increase in PTV dose homogeneity if an override was applied.

For treatments of volumes near a potential bone cement insert, we recommend attempting to identify if a bone cement insert has been used, e.g. by visual inspection of the appearance of the bone flap in the simulation CT image for any evidence of an artificial material (air cavities); by inspection of patient surgical records; communication with the surgical team; or obtaining an MV radiograph or MV cone-beam CT image of the anatomy.

For patient cases where bone cement may be present but cannot be verified, the dosimetric impact of incorrect handling of the material can be reduced by:

- Minimising weighting of beams/beamlets depositing dose downstream of bone flap, e.g. increase number of beams using arc treatments;
- Taking care when considering dosimetric trade-offs based on maximum dose or PTV homogeneity; i.e. the values most affected by presence of bone cement.

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