The case of the disappearing skull

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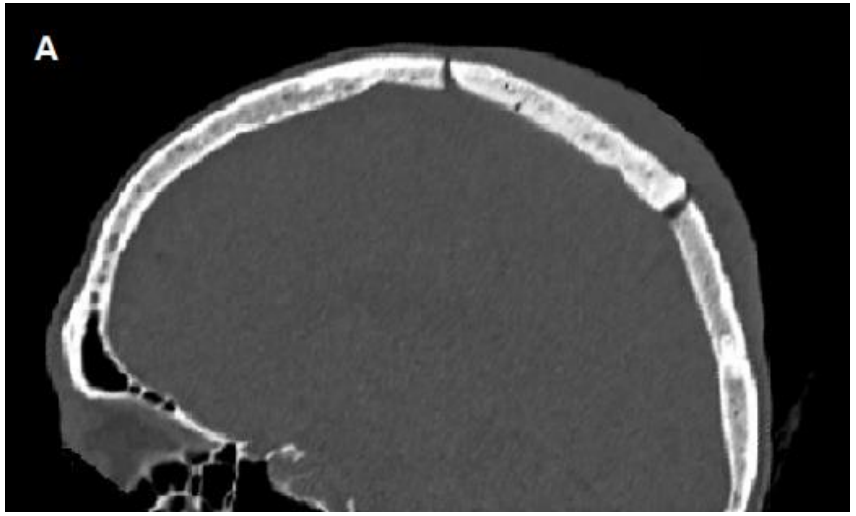
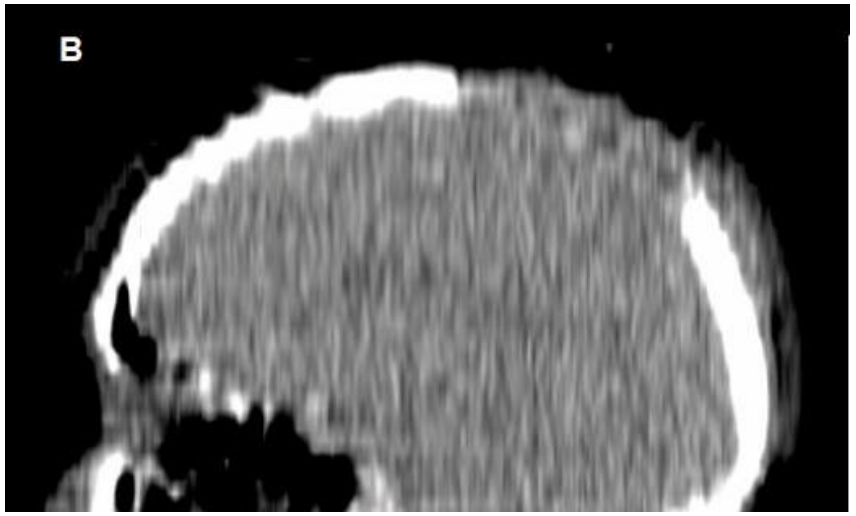


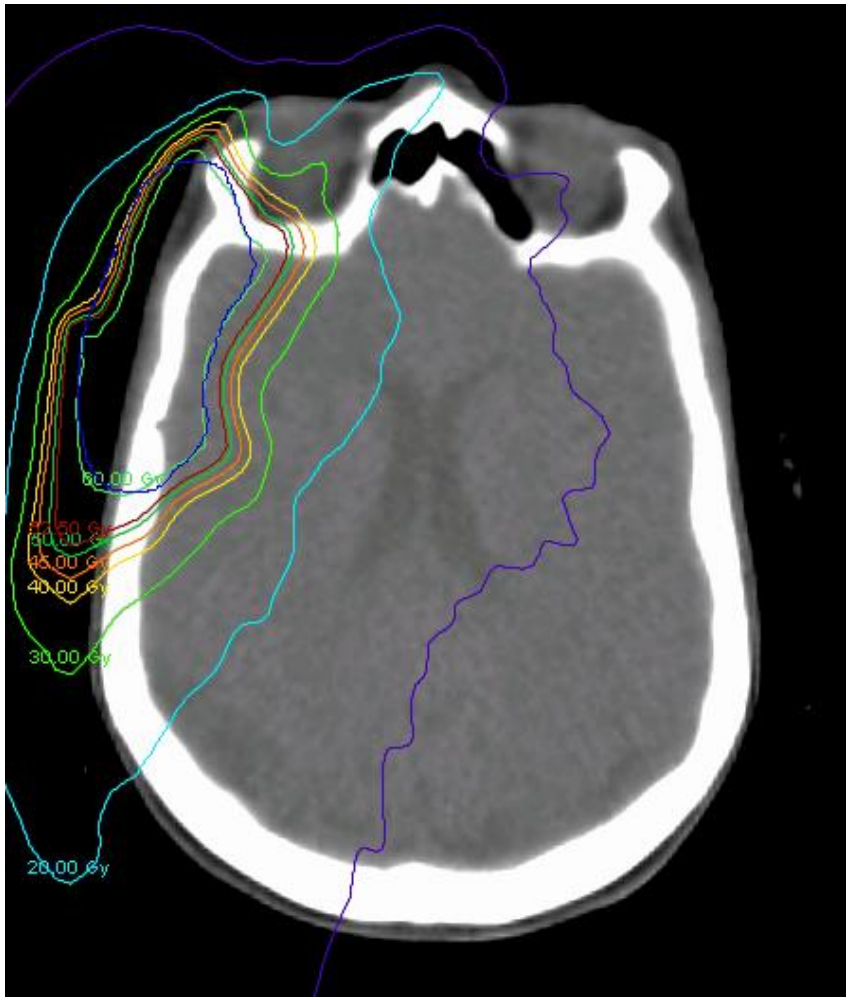


Setting the scene

- Treatment of a scalp planned for TomoTherapy system
- "Bone flap" visible on kV CT (120 kVp)
- MVCT of patient taken on TomoTherapy system (3.5 MV), for position verification.
- **NO BONE FLAP !!!!**
- TomoTherapy planned adaptive module suggesting significant dose differences (up to 10%).

Bone cements

- Bone cements are used to replace bone flaps when there is involvement.
- PMMA-based cements are common, and contain radiopacifying additives, for contrast
- This is so orthopaedic surgeons can monitor the cement, e.g. to look for fractures.
- Most commonly used radiopacifiers are barium sulphate, zirconium dioxide and iodine.



Radiological properties

- Physical cross sections for bone and bone-cement vary with energy - looking similar at 120 kVp doesn't mean they will behave similarly at treatment beam energies
- There is subsequently a risk of error in dose delivery in patients presenting with PMMA-based cements; where these additives are not appropriately handled within the treatment planning system, e.g. through the use of density overrides.

Investigating potential errors

- We wanted to characterize the potential dose disagreement resulting from treating a PMMA-based bone cement flap as what it appears as: bone.
- To do this, we needed to characterise the radiological properties of the material.
- We did this by:
  - Measuring effective ρ and RED (ρ_e / $\rho_{e,w}$) from CT images
  - Measuring effective RED from transmission measurements / radiological thickness
  - Monte Carlo simulation of material

CT imaging of sample

- A physical sample was secured and imaged in a small water bucket.
- ImageJ was used to obtain mean ± standard deviation in a region of interest, not including any substantial air bubbles.
- Gammex CTED data used for ρ and RED.

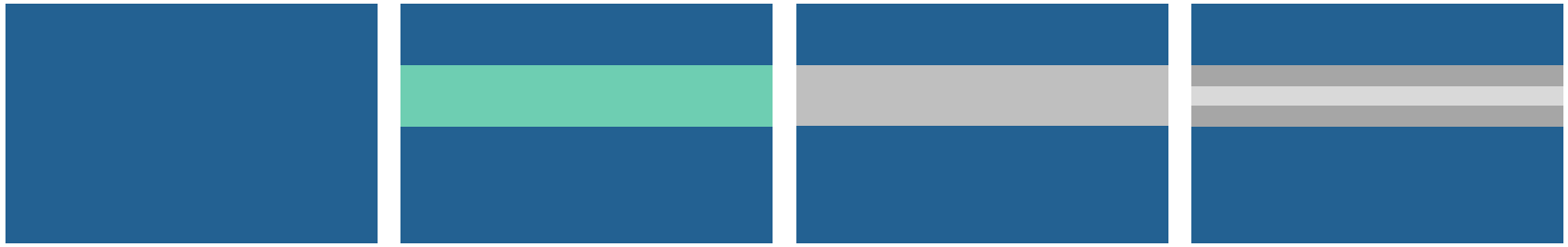
Modality	Energy	CT number (HU)	ρ (g/cm^3)	$\rho_e/\rho_{e,w}$
Siemens kV CT	120 kVp	1100 ± 60	1.78 ± 0.04	1.66 ± 0.03
TomoTherapy MV CT	3.5 MV	50 ± 30	1.06 ± 0.04	1.04 ± 0.03

Radiological thickness

- Transmission measurements were performed using a TPR-type experiment geometry, i.e.
  - Fixed detector position, with 10 cm backscatter provided as possible.
  - TPR data obtained for varying thickness of virtual water.
  - TPR data obtained with bone cement added to the geometry.
  - Water-equivalent radiological thickness of the bone cement determined by interpolation.
  - Divided by the physical thickness of the bone cement sample, to obtain effective RED.

Modality	Energy	Detector	t_w (mm)	$(\rho_e/\rho_{e,w})_{eff}$
WOmed T-300	100 kVp / 6.3 mm Al HVL	Roos	25.3 ± 1.3	2.5 ± 0.1
Varian Clinac	6 MV	Roos	10.2 ± 0.1	1.02 ± 0.08
Varian Clinac	6 MV	EPID	10.9 ± 0.8	1.08 ± 0.10

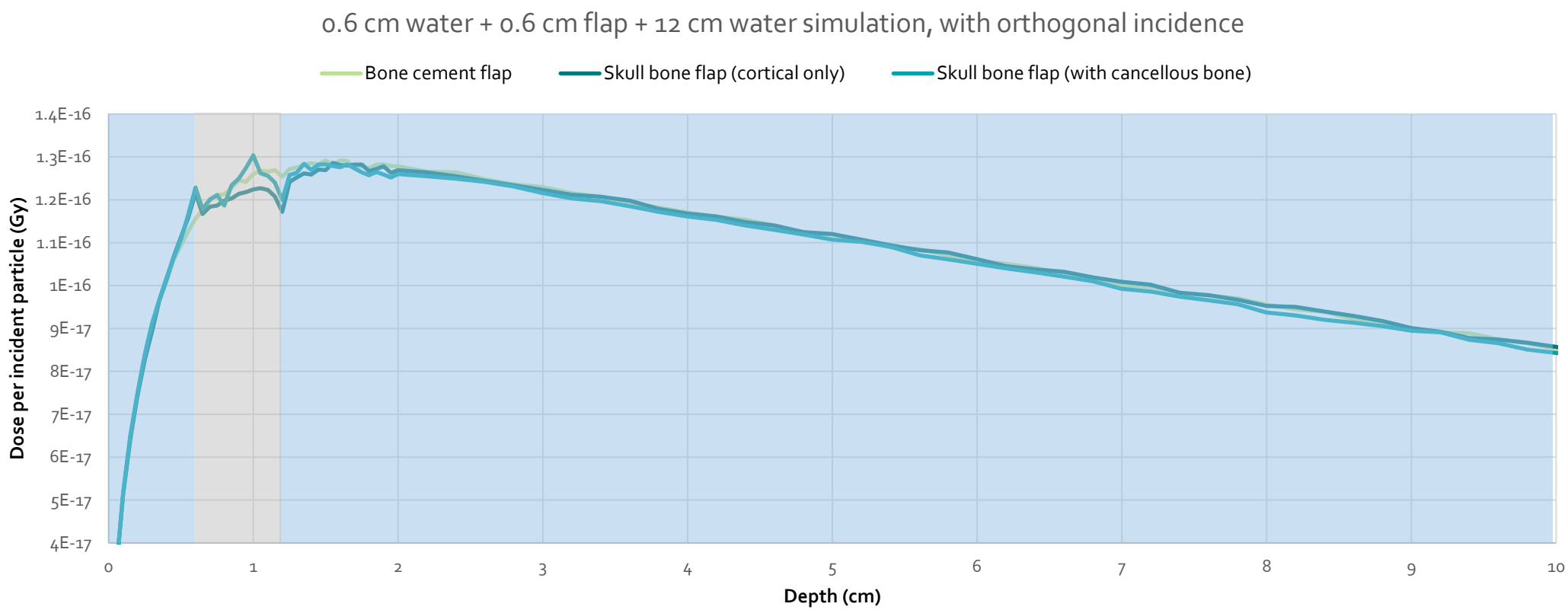
Monte Carlo simulations



- Monte Carlo simulations were performed using known composition, for a 10 x 10 cm^2, 6 MV field, 100 cm SSD.
- PDDs were produced for 4 geometries:
  - 13.2 cm water
  - 6 mm water, 6 mm bone cement, 12 cm water
  - 6 mm water, 6 mm cortical bone, 12 cm water
  - 6 mm water, 2 mm cortical bone, 2 mm spongy bone, 2 mm cortical bone, 12 cm water

Ingredient	Molecular Formula	% composition by mass
Solid component (40 g)		
Gentamicin sulphate	$C_{19}H_{40}N_5O_{11}S$	4.22
Polymethyl Methacrylate	$C_5O_2H_8$	84.73
Benzoyl Peroxide	$C_{14}H_{10}O_4$	1.95
Barium Sulphate	$BaSO_4$	9.10
Liquid component (20 ml, approx. 18.8 g)		
Methyl Methacrylate	$C_5H_8O_2$	98.50
N,N-Dimethyl-p-toluidine	$C_9H_{13}N$	≤1.50
Hydroquinone	$C_6H_6O_2$	*75 ppm

Monte Carlo results



Conclusion

- For beams orthogonally incident on 6 mm flaps, dose differences of 7% between bone and bone cement were observed at the interface. Given cements are usually inserted when there has been involvement (i.e. bone cement would be in / near treatment volume), this is clinically significant.
- Differences will depend on size of flap along beam axis (which may be tangential), cements with less air infiltration (which will have a reported higher HU), smaller fields.
- CT numbers produced for conventional energies (i.e. 80-140 kVp) not suitable for dose calculations, so overrides are necessary.
- Depending on air infiltration, you may not know that it is bone cement!