Development and Validation of a 3D Printed Phantom for Off-Axis Dosimetry for External Beam Radiotherapy

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2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

ABSTRACT

Purpose: To develop and validate a cost-effective 3D printed phantom for off-axis dosimetry using ion chambers

Methods: The phantom was designed using Autodesk Fusion and printed on a Prusa XL fused deposition modelling 3D printer using polylactic acid (PLA) filament. The phantom was designed to allow for water-filling and be large enough to accommodate a variety of clinically relevant off-axis positions. The phantom comprises 25 cavities that allow for ion chamber placement up to 8cm off-axis in the lateral and anterior-posterior directions and 25cm in the superior-inferior direction. An external wall thickness of 5mm provides support for water filling and an internal cavity wall thickness of 3mm minimizes the amount of PLA in the interior of the phantom. Solid plugs were printed to fill the hollow cavities, and a single plug printed to accommodate a CC13 ion chamber (which can be printed to accommodate any superior-inferior chamber position). The phantom was printed in two pieces (a cap, and a base) which were epoxied together. The interior of the phantom was coated with a thin layer of 2-part silicon for watertightness. The phantom was CT scanned and imported into the TPS. Point dose measurements at various depths on axis were acquired within the phantom to determine the optimal HU density override of PLA in the TPS needed to best match measurement.

Results: The phantom was successfully printed, and the use of epoxy and silicone was sufficient to provide watertightness. By minimizing the RMSE, the optimal density override was determined to be 225 HU, providing agreement between calculated and measured point doses within 1%

Conclusions: The phantom provides a cost-effective option for performing off-axis dosimetry with ion chambers and will be used for applications such as single-isocenter multi-metastases brain treatments or characterization of novel MLC models.

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INTRODUCTION

- **Volumetric Modulated Arc Therapy (VMAT)** is a common technique for radiotherapy
- Highly conformal and complex plans can be created using dynamic modulation by varying gantry speed, dose rate and multi-leaf collimator (MLC) apertures.

- Varian recently introduced an **Enhanced Leaf Model (ELM)** in Eclipse v18.
- Prior to v18, MLCs were modelled MLCs as homogenous layers with binary transmission through the leaf ends
- V18 ELM considers the full shape of the MLC leaves
- This is expected to be especially relevant for off-axis dosimetry accuracy

- Many commercial phantoms are expensive and diode-based.
- Supplementary measurements using ion chambers are limited to isocenter.
- There is a need to develop an inexpensive phantom to allow for accurate off-axis measurements using gold-standard ion chambers.

- The purpose of the project is to design and validate HU of a phantom that accommodates off-axis measurements using ion chambers

METHODS AND MATERIALS

PHANTOM DESIGN

- **O**ff-axis **PH**antom for **E**nhanced **L**eaf modelling using an **I**nterchangeable **A**rray (**OPHELIA**)
- Designed using Autodesk Fusion
- Hollow, water-filled phantom
  - 5mm external wall thickness
  - 3mm internal cavity wall thickness
- 3D printed using polylactic acid (PLA) filament
- 25 chamber cavities allow for relevant off-axis positions:
  - +/- 10cm Sup-Inf
  - +/- 8cm Lat, A/P
- Solid plugs to fill in empty cavities
- Custom plugs to accommodate a CC13 ion chamber, but easily extendable to other small volume detectors
- Printed in 2 pieces: a cap and a base
  - Pieces glued together using epoxy
  - Interior coated with a 2-part silicon mixture for water-tightness

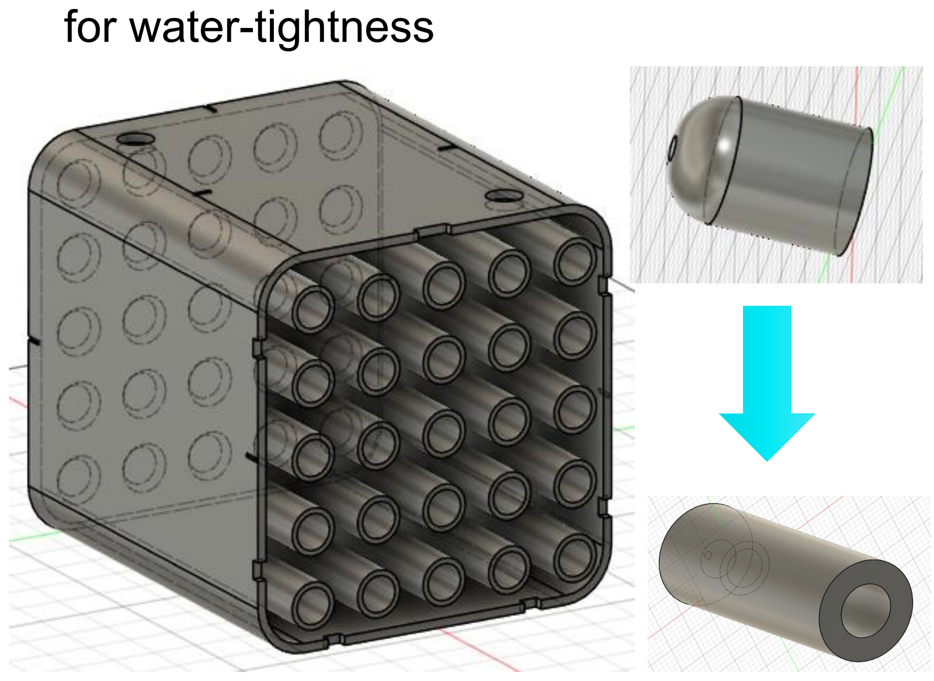

Figure 1. 3D modelling of phantom and CC13 plug insert.

METHODS AND MATERIALS

Figure 2 OPHELIA undergoing leak testing

PHANTOM VALIDATION

- OPHELIA was CT scanned and imported into the TPS
- Phantom attenuation was validated
  - PLA was contoured
  - Charge to dose calibration factor for CC13 chamber obtained using solid water reference conditions

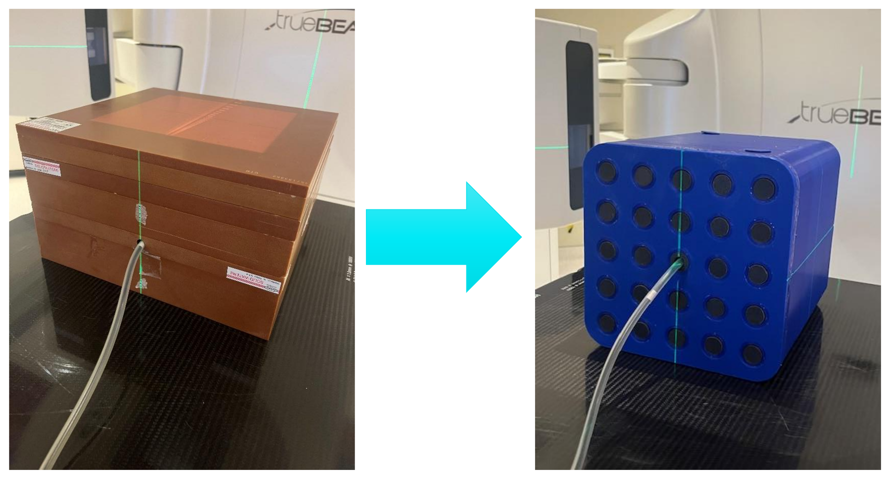

Figure 3 Reference conditions set up for HU validation

- Point dose measurements were taken and compared to TPS predicted doses at 5 different positions along CAX
- Depth dose ratios were also measured and compared to predicted ratios in the TPS

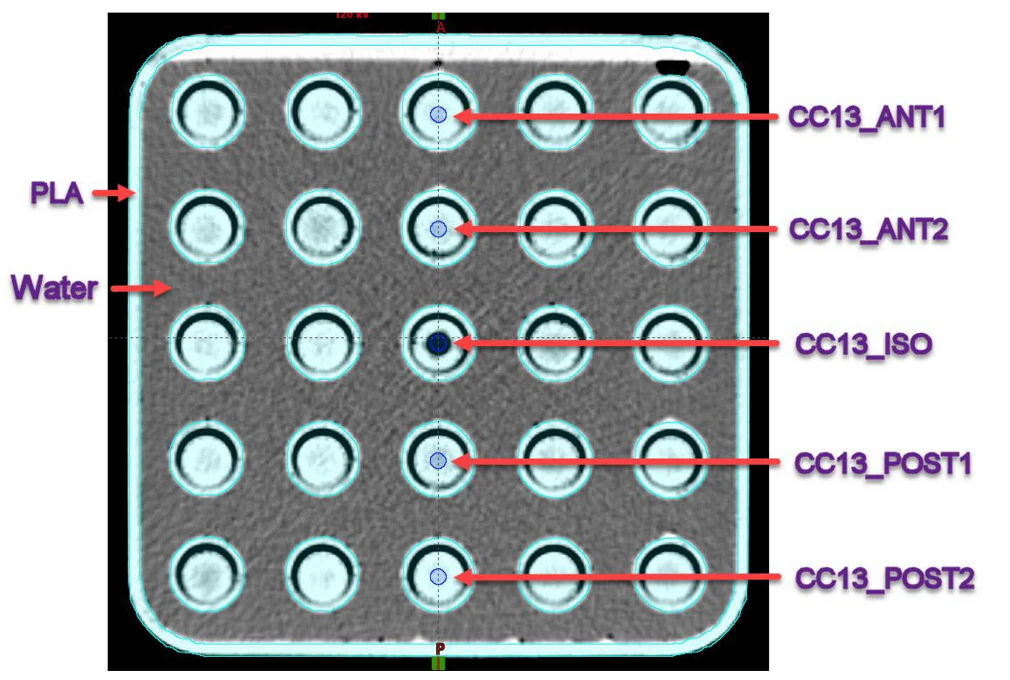

Figure 4. Locations of CC13 chambers for TPS and measurement comparisons

- Phantom was compared to ArcCheck with point dose measurements at isocentre (clinical standard)
  - Delivered 25 VMAT plans across Head & Neck, Lung, Esophagus, Rectum, Prostate and Brain
  - Compared measured point doses at isocentre to TPS for each phantom
  - Compared measured doses for 3 different dose calculation algorithms:
    - **V15clin**: spot size 1.5mm optimized for jaw-defined fields
    - **V15ss0**: 0mm spot size optimized for MLC-defined fields, but **old MLC model**
    - **V18**: 0mm spot size optimized for MLC-defined fields & ELM

RESULTS AND DISCUSSION

- Leak tests resulted in a cap-base interface re-design to improve sealing and structural integrity
- Optimal HU Density override was determined to be 225 HU
  - RMSE reduced from 1.90% with no density override to 0.27% with HU = 225

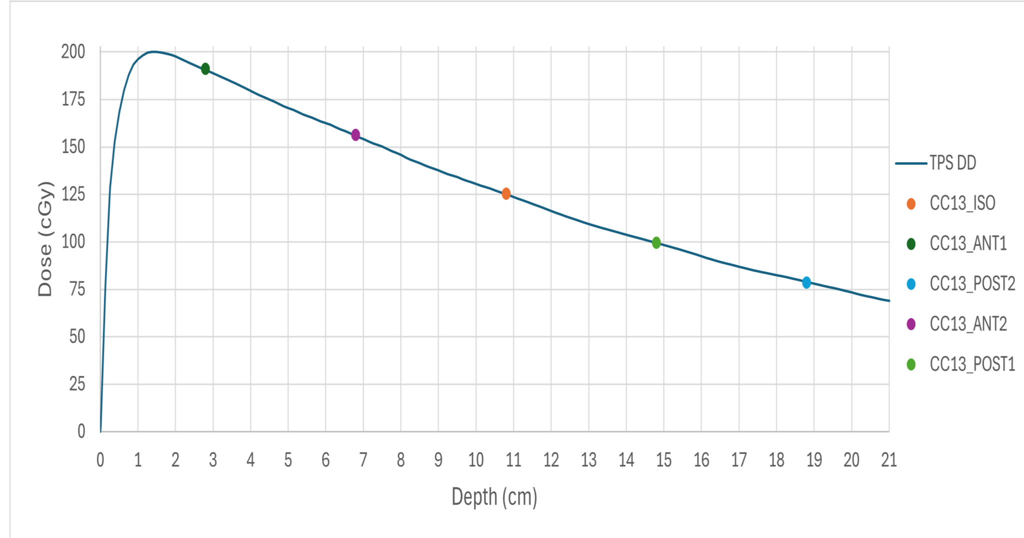

Figure 5. TPS depth dose and point dose measurements for HU = 225

- Significant improvement of ion chamber agreement using OPHELIA compared to the ArcCheck

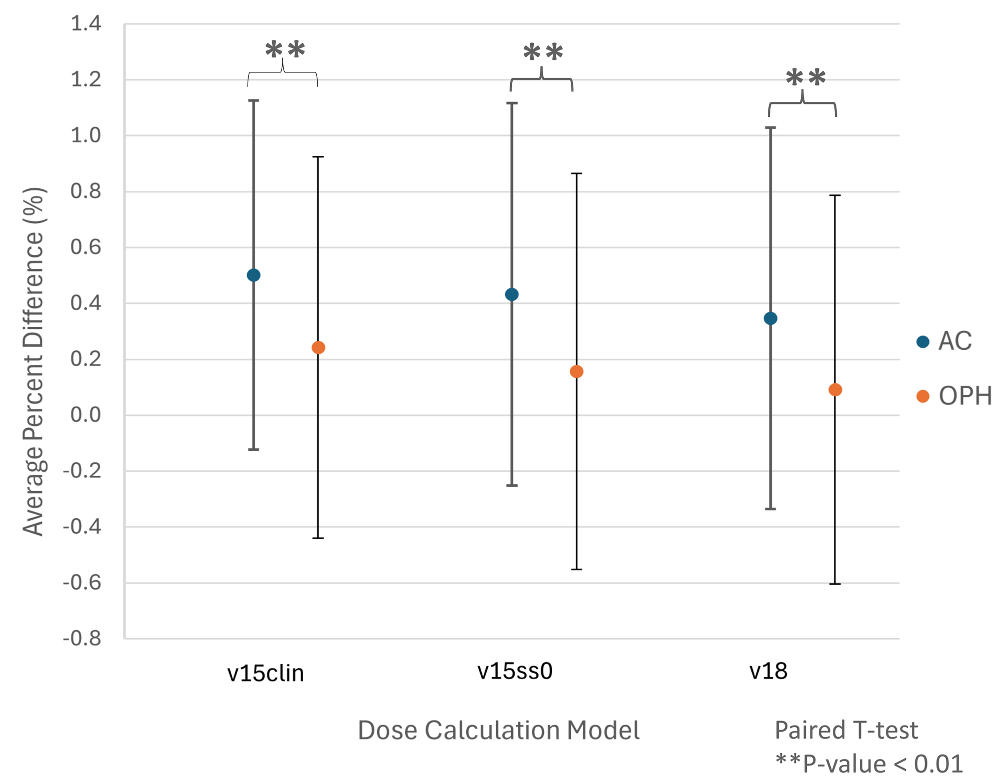

Figure 6. Average percent differences of measured vs. predicted TPS doses for CC13 ion chamber at isocentre using the ArcCheck (AC) and OPEHLIA (OPH) for each dose calculation algorithm

- Results at isocentre also show tentative improvement for v18 algorithm compared to the clinical v15 model. Further investigation is needed.

CONCLUSIONS

- OPHELIA provides a cost-effective option and is well modelled for performing off-axis dosimetry with ion chambers
- Future applications include characterizations of novel MLC models or applications in single-isocenter multi-metastases brain treatments

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