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Transit Dosimetry for VMAT Online Adaptive Radiotherapy with Monte Carlo-Generated Prediction Images

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INTRODUCTION

- Measurement-based, pre-treatment, plan-specific quality assurance testing is not feasible with **online adaptive radiotherapy (RT)**.
- **Transit dosimetry** has the potential to provide a during-treatment alternative.
- Transit dosimetry involves measuring the radiation exiting through the patient using the linac's **Electronic Portal Imaging Device (EPID).**

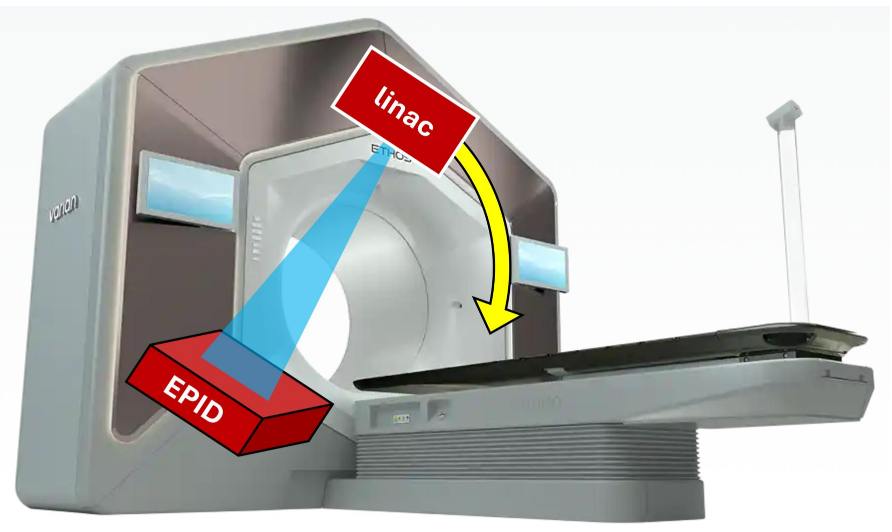

Figure 1: The Ethos adaptive radiotherapy system (Varian, Palo Alto, USA) has an EPID in the beamline, on the downstream side of the patient.

- This study considers transit dosimetry in the context of online adaptive RT with **Volumetric Modulated Arc Therapy (VMAT)**.
- Differences between predicted and measured transit dosimetry images can be indicative of treatment delivery errors such as machine malfunction, patient internal anatomical changes (e.g., bowel gas movement), or positioning changes.

RESULTS

- Transit dose was analyzed for 16 online adaptive prostate treatments (VMAT, 8 Gy per fraction).
- 30° gantry angle segments were considered, corresponding to integration of ~200 EPID frames per segment and 12 segments per arc.
- The computational model for one example patient is shown in figure 3, demonstrating the conversion from CT number to elemental composition and density (necessary for the Monte Carlo simulation).
- Results for all patients are summarized in figure 4. Results as a function of gantry angle are shown in figure 5 for one example patient. Example transit dose images are shown in figures 6 and 7.
  - Gamma criteria are 3% and 3 mm with a 10% dose threshold.
- CBCT reconstruction technique (with and without iterative reconstruction & scatter correction) had a negligible effect on MC-based transit dose prediction images in the case of a pelvis phantom.

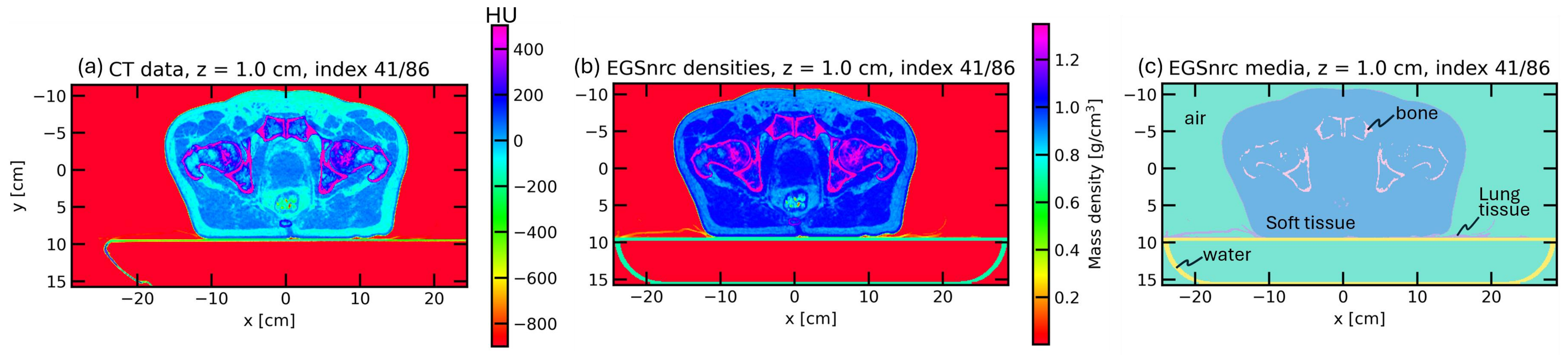

Figure 3: (a) CT data in Hounsfield Units (HU) is converted to mass density (b) according to the clinical calibration curve, for patient #10. (c) Media are assigned according to HU values. Small amounts of lung tissue are erroneously assigned to a blanket (the resulting dosimetric effect is expected to be minimal).

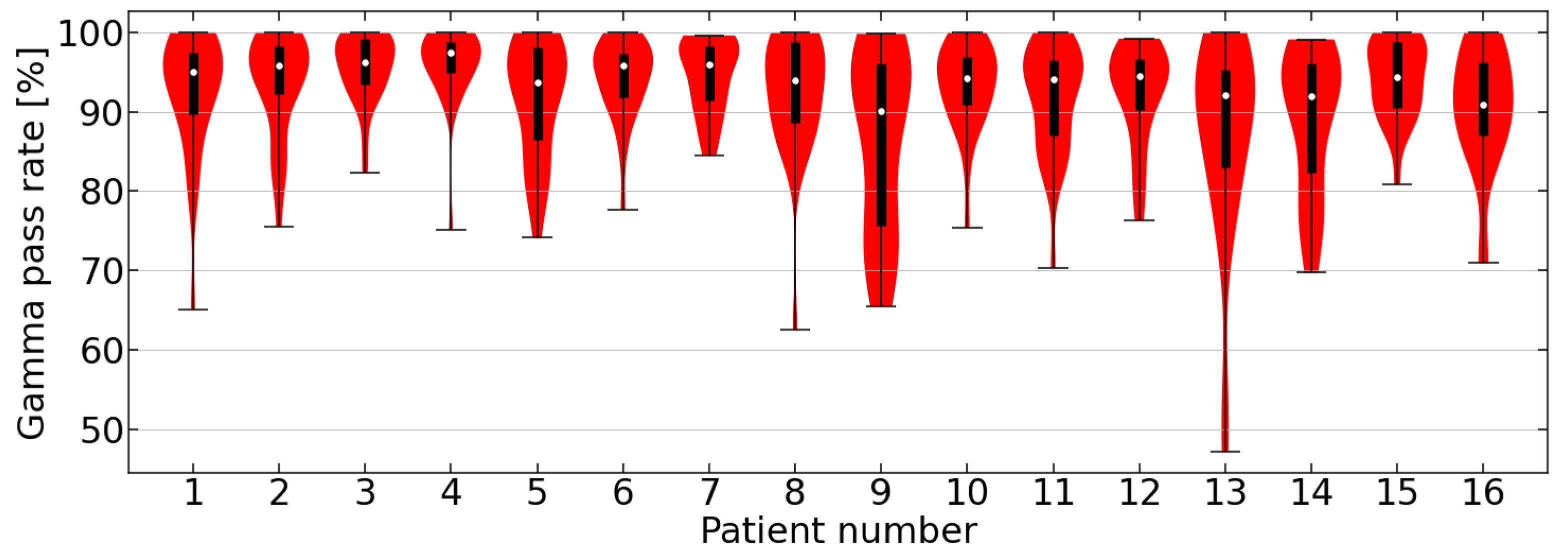

Figure 4: Violin plots summarizing the gamma pass rates for each gantry angle segment for each patient.

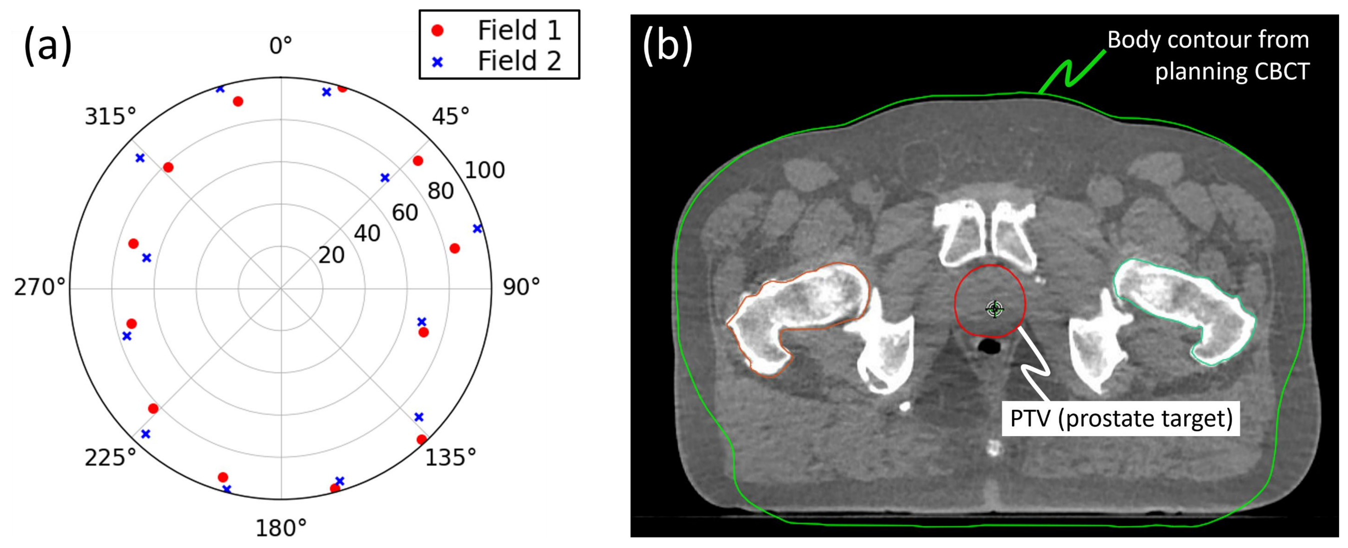

Figure 5: (a) Polar plot of gamma pass rates for 30° gantry angle segments for patient #9. (b) The intra-fraction CBCT for patient #9 demonstrates a change in body contour compared to the CBCT used for adaptive planning.

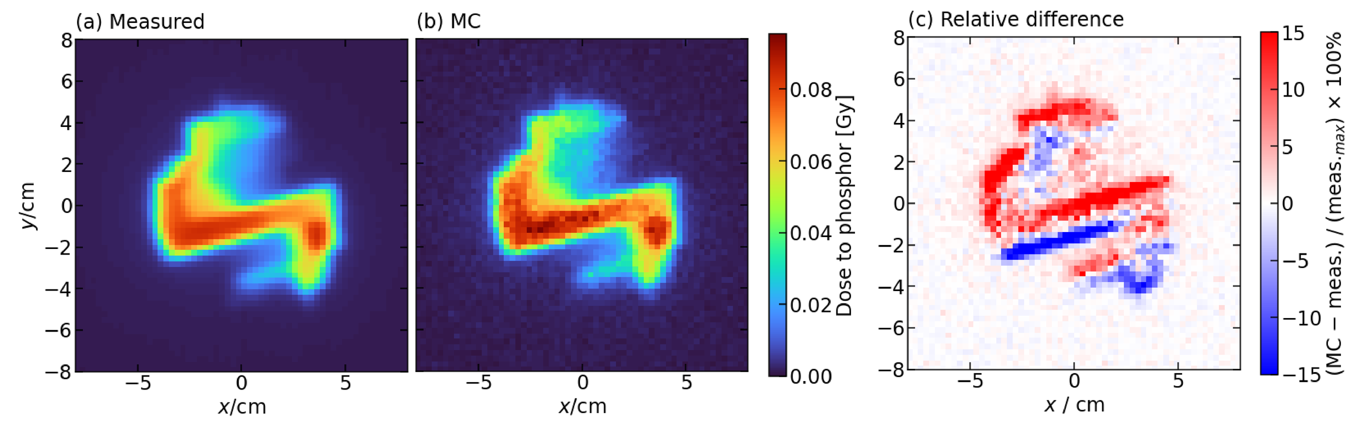

Figure 6: Comparison of (a) measurement and (b) Monte Carlo (MC) prediction of transit dose for patient #14 for the gantry angle segment centered at 137°. The relative transit dose difference distribution is shown in (c).

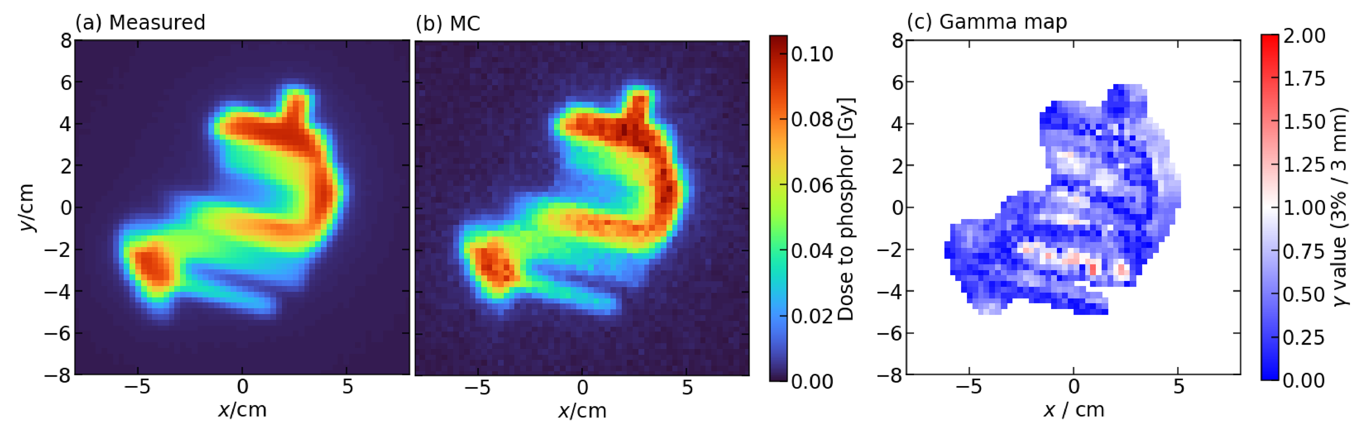

Figure 7: Comparison of (a) measurement and (b) Monte Carlo (MC) prediction of transit dose for patient #15 for the gantry angle segment centered at 283°. The corresponding gamma map is shown in (c).

METHODS

- Monte Carlo simulations are used to generate transit dosimetry prediction images based on
  1) the Cone Beam Computed Tomography (CBCT) image set that is used for adaptive planning (acquired using the HyperSight imaging system), and
  2) the adaptive plan-of-the-day.
- Simulations are carried out using BEAMnrc [1] and the egs_chamber application from EGSnrc [2], starting from a vendor-provided phase space [3] corresponding to a 6 MV FFF photon beam.
- Validation of the Monte Carlo model was carried out in a previous work [4].
- Transit dose data is acquired from the EPID using a frame grabber, thereby allowing for a gantry-angle-resolved analysis.

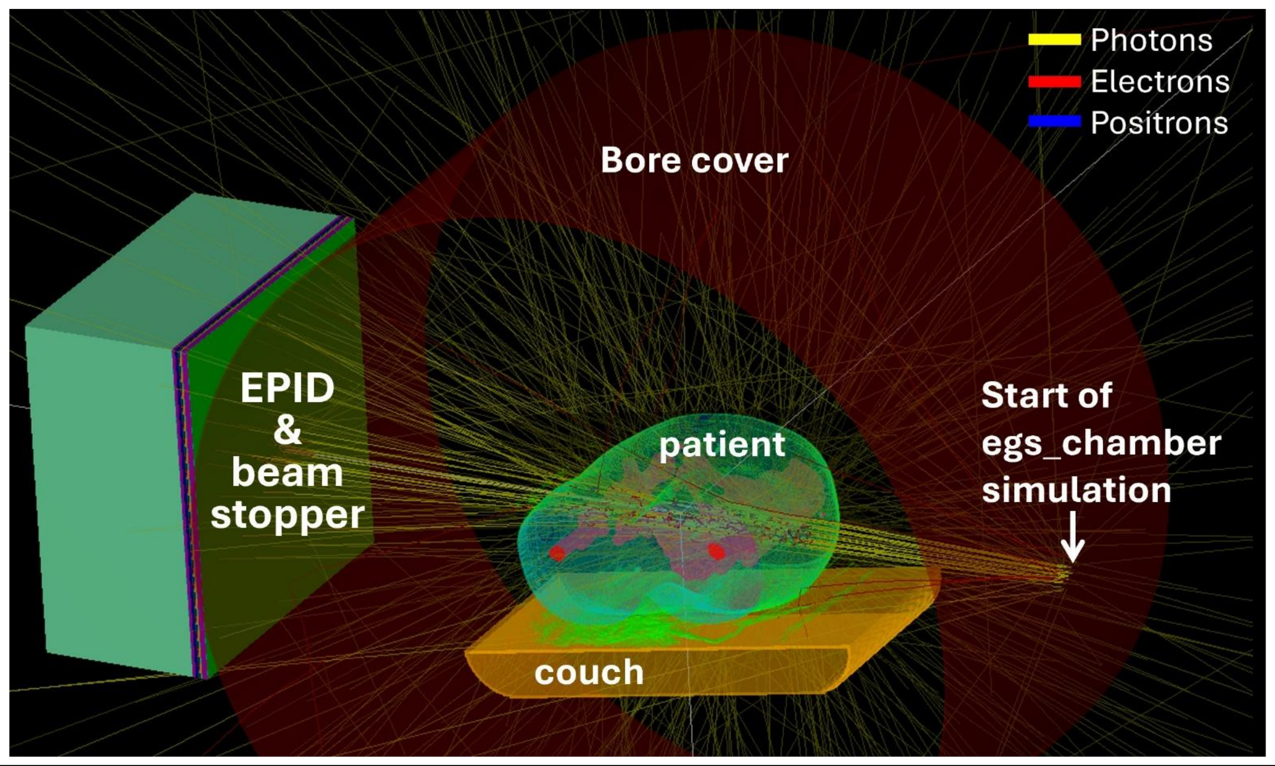

Figure 2: The egs_chamber portion of the simulation begins at the downstream end of the MLC. This portion of the simulation includes the bore cover, patient, couch, EPID, and beam stopper. Particle tracks are shown for one example field.

DISCUSSION & CONCLUSIONS

- This study is the first to consider transit dosimetry during online adaptive RT, using a frame grabber to allow for a gantry-angle-resolved analysis during VMAT treatment delivery. The utility of a Monte Carlo-based pipeline for generating transit dosimetry prediction images is demonstrated.
- Examination of the intra-fraction CBCTs in the lowest gamma pass rate cases (#9 and #13, corresponding to different fractions for the same patient) revealed body contour changes resulting from muscle relaxation compared with the CBCT used for planning (figure 5).
- **Other contributions to observed discrepancies in measured vs predicted transit dose**:
  - Discrepancies in the MLC penumbra (figure 6) that are observed to vary with gantry angle and are hypothesized to be due to gravitational effects.
  - Frames not dividing evenly into pre-defined gantry angle segments (frames correspond to a small gantry angle span that can straddle the boundary between adjacent segments)
  - EPID model limitations: optical effects are not accounted for (dose is scored in the scintillator as a surrogate for the actual signal generated by the amorphous silicon detector panel)
- **Future work**: additional treatment sites, determination of clinically relevant transit dosimetry action levels, further investigation of radiation transport and energy deposition within the EPID.

REFERENCES

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DISCLOSURES

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