Master's Thesis Engineering Technology

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Design and manufacturing of a thoracic phantom using 3D-printing and bone equivalent material

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Introduction:

Phantoms for dosimetry verification play a critical role in the successful use of EBRT for therapeutic use and aid in the maximization of the therapeutic ratio. This is especially true for heterogenous volumes. The thorax is an example of such a volume containing soft tissue, lung tissue and bone tissue [1], [2], [3].

Three-dimensional models of various anatomical structures produced through rapid prototype development can be produced cost-effectively using polymers including polyurethane, polylactic acid (PLA) and epoxy resins [4], [5].

Commercially available phantoms that contain **bone equivalent material** often show low accuracy for either imaging or dosimetry purposes and are very expensive [4], [6].

Aim: Investigation of design parameters and materials to manufacture a **3D-printed thoracic phantom** containing the relevant tissue equivalent materials while finding an alternative for bone equivalent material by using different types of RTV-silicone.

Method and materials:

1) **Designing a model** of the thoracic phantom for 3D-printing using representable materials and infill-parameters (Fig. 1).
2) **A substitute for bone equivalent material** is investigated using two types of RTV silicone mixed with various amounts of $CaCO_3$.
3) **Imaging verification** and **radiotherapy dosimetry verification** using a combination of EBT3 gafchromic films and L-α-alanine pellets placed in the phantom was performed (Fig. 2). This happened in 2 separate clinics using different setups and calibration methods. At clinic 1 a larger field size was utilized combined with a standard calibration for the film dosimetry. At clinic 2 a smaller field size was used combined with the single scan recalibration method. Alanine dosimetry was performed using electron paramagnetic resonance (EPR). TPS calculated dose was compared to the measured doses after which could be concluded if the 3D-printed phantom conforms to demands

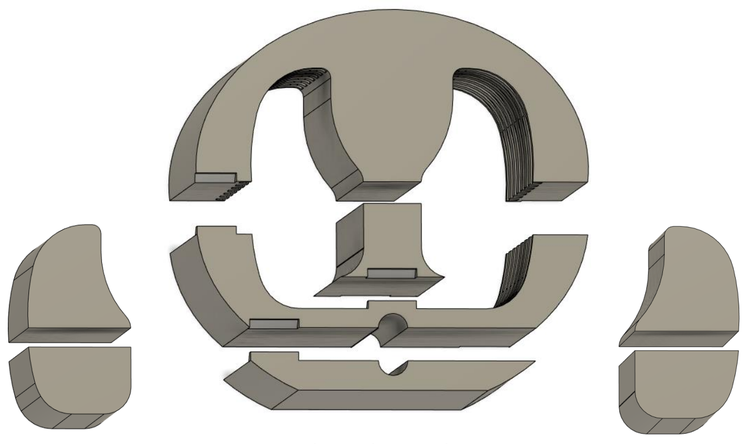

Fig. 1: 3D-design thoracic phantom

Bone equivalent tissue

- CT- values corresponding to real patient bone tissue
- Measured Mass density < calculated by TPS
  ⇔Relative electron density < calculated by TPS

Soft tissue

- Inter-segment variations of 80 HU
- Still good accordance to TPS calculations

Lung tissue

- Correspondence to TPS for CT-values and Densities

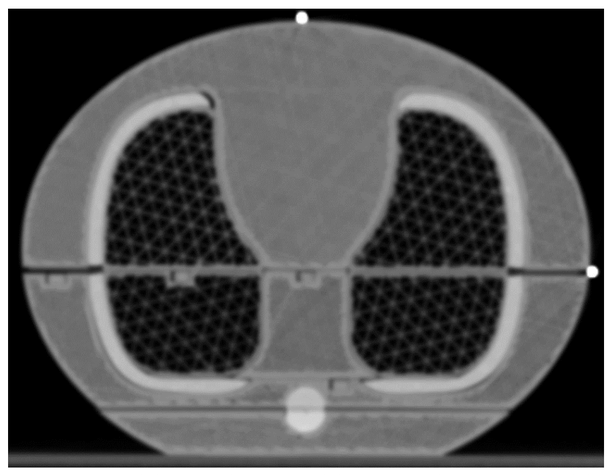

Fig. 2: CT-scan 3D-printed thoracic phantom with bone equivalent material and dosimeters

Dose comparison clinic 1

- Non-conformity between film (352 hours) and TPS (Fig. 3)
- Dose comparison between TPS, alanine and film (Fig. 4)
- Alanine depicts most significant differences of 3.2 % in right lung and -1.8 %, the only significant negative difference, in transition area
- Films show an unacceptable difference to TPS calculations on all positions in the phantom at every read-out moment (5.5 % to 15.5 %)
- Measurable relation between loss of irradiation data to amount of time passed for the films with 1 exception at the spine area

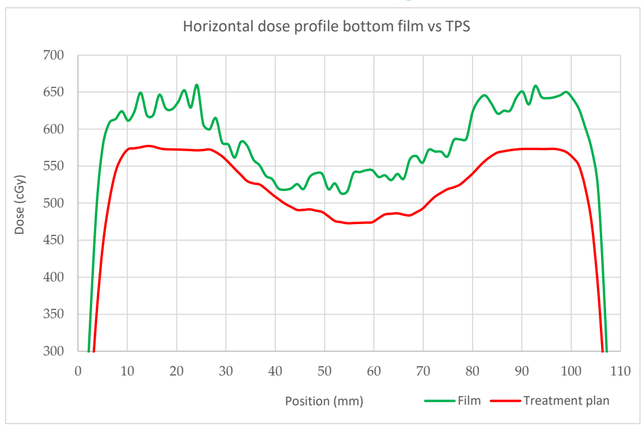

Fig. 3: Horizontal dose profile comparison between TPS and EBT3 film after 352 hours for the bottom film location in the phantom

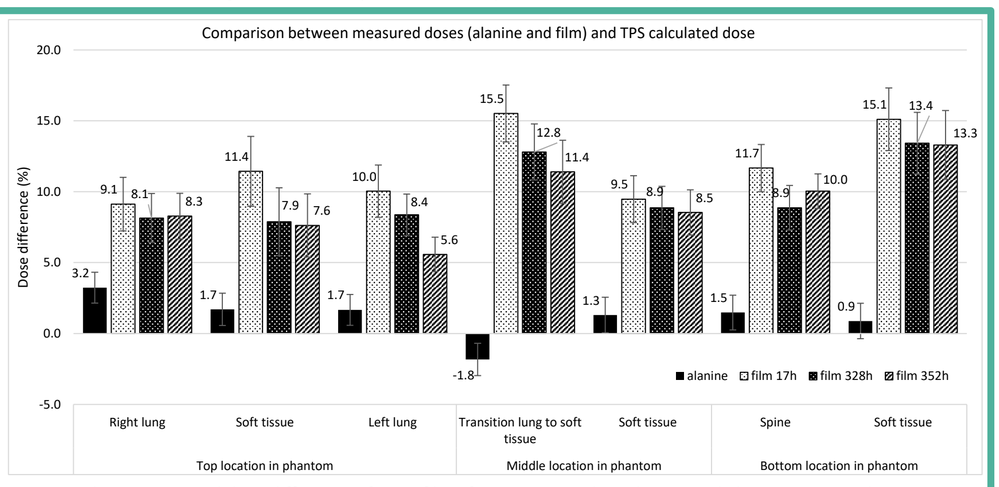

Fig. 4: Relative measured dose difference of EBT3 film after 17, 328 and 352 hours, and alanine compared to TPS

Dose comparison clinic 2

- Higher accuracy achievable using one-scan method
- Overall, films show good accordance to calculated dose. At transition areas containing bone equivalent material a mean and max difference of respectively 4.1 % and 7.0 % is present (Fig. 5)
- Dose comparison between TPS, alanine and film (Fig. 6)
- Alanine depicts most significant difference of 3.1 %, negative differences are found in soft tissue close to spine.
- Acceptable underestimations by the TPS for alanine location in bone area (spine) of 1.7 – 2.0 %
- Films depict the highest differences to TPS calculations in the spine with values of 4.39 % and 4.77 %
- At top location in phantom Alanine presents overestimations while the film depicts underestimations at all alanine locations

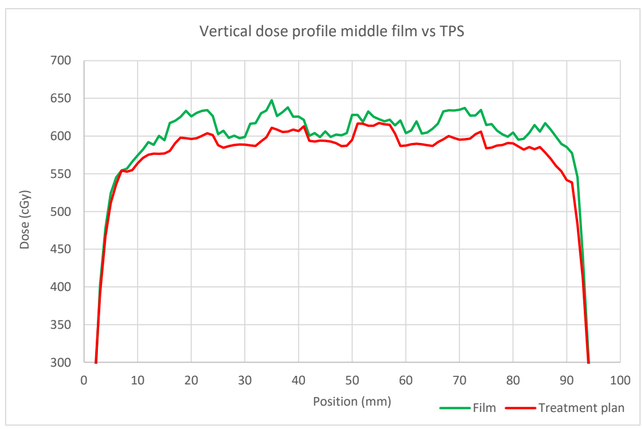

Fig. 5: Vertical dose profile comparison between TPS and EBT3 film for the middle film location in the phantom

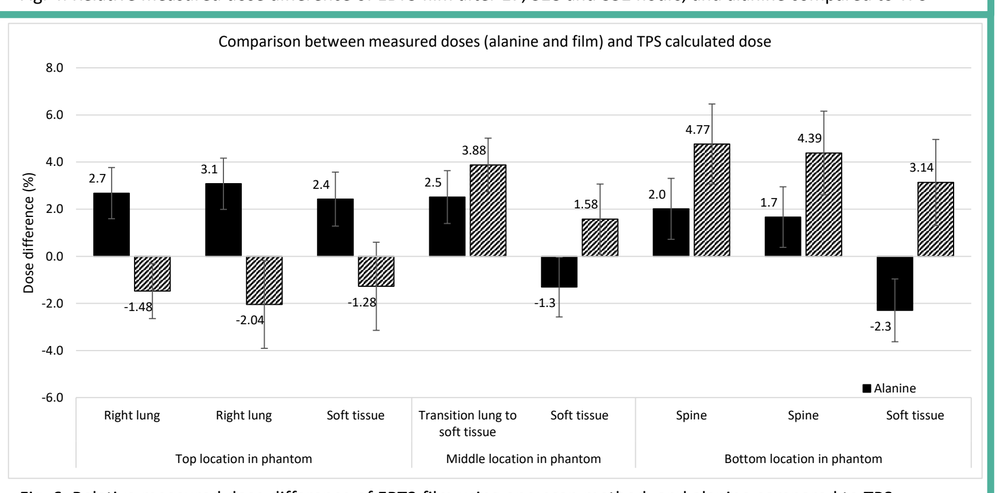

Fig. 6: Relative measured dose difference of EBT3 film using one-scan method, and alanine compared to TPS

Conclusion

Adaptations to the dimensions of the various segments of the thoracic phantoms should have been considered in order to ensure a perfect fit with little to no sanding after 3D-printing. All segments of the 3D-printed soft tissue (90 % infill) and lungs (30 % infill) presented good equivalency for both imaging and dosimetry purposes. ZA 00 Translucid RTV silicone mixed with CaCO3 proves capable of mimicking bone for imaging properties, for dosimetry purposes a more dens alternative to $CaCO_3$ would be advised. Concerning EBT3 film dosimetry, using the single scan method provides the most accurate measurement method. Transition areas containing the bone equivalent material presented the most significant dose differences calculated by the TPS. Overall, Alanine measurements were in accordance to the calculated dose.

Future adaptations should be considered for 3D-printed phantoms containing bone equivalent material. Edges of low infill 3D-printed segments should be fabricated as thin as possible to establish more homogenous structures. Furthermore a high-quality 3D-printer would be advised for the fabrication of accurate and detailed results.

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References

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