3D printed bolus for chestwall radiation therapy

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Objectives

3D printing technology introduces the potential for improved accuracy of in conforming bolus to patient anatomy and may also provide efficiency gains through automation of production based on planning CT data.[1,2] The objectives of this study are i) to compare build-up depth dose characteristics of solid and flexible 3D printed bolus material to both Solid Water and standard sheet bolus material, ii) to assess the fit of 3D printed bolus to chestwall anatomy based on CT imaging compared to sheet bolus, and iii) to examine variability of surface dose for 3D printed bolus to sheet bolus.

Methods

Dose build-up characteristics were measured for polylactic acid (PLA) and polyurethane (Ninjaflex) printable media using a Markus parallel plate chamber (PTW). In addition, for a fixed 5 mm thickness of PLA, surface dose was measured as a function of the infill factor used in the printing process.

Three ballistic gel phantoms were fabricated based on molds derived from CT chestwall patient CT data sets. The gel phantoms are realistic with regard to firmness and malleability. 3D printed boluses were produced based on the external surfaces of the phantoms. The phantoms were CT imaged with either standard sheet bolus (Superflab) or 3D printed bolus. Air cavities between bolus and skin were assessed with regard to total volume and maximum dimension normal to the surface.

6 MV field-in-field tangential treatment plans were established for the gel phantom geometries. Forward dose calculation was performed with the Eclipse AAA algorithm, (v10, Varian Medical Systems). Dose was measured at nine locations below the 3D printed bolus using Optically stimulated Luminescent Dosimeters (OSLDs) and compared to the treatment planned values at corresponding locations.

The uniformity of calculated surface dose was compared between plans established on CT sets with either sheet bolus or 3D printed bolus, for the three gel phantoms.

Results

In a 6 MV beam, both PLA and Ninjaflex printable media exhibit buildup characteristics within 5% of that of Solid Water (figure 1). An approximately linear relationship of surface dose with printed infill factor was observed, allowing control of surface dose with this parameter (figure 2).
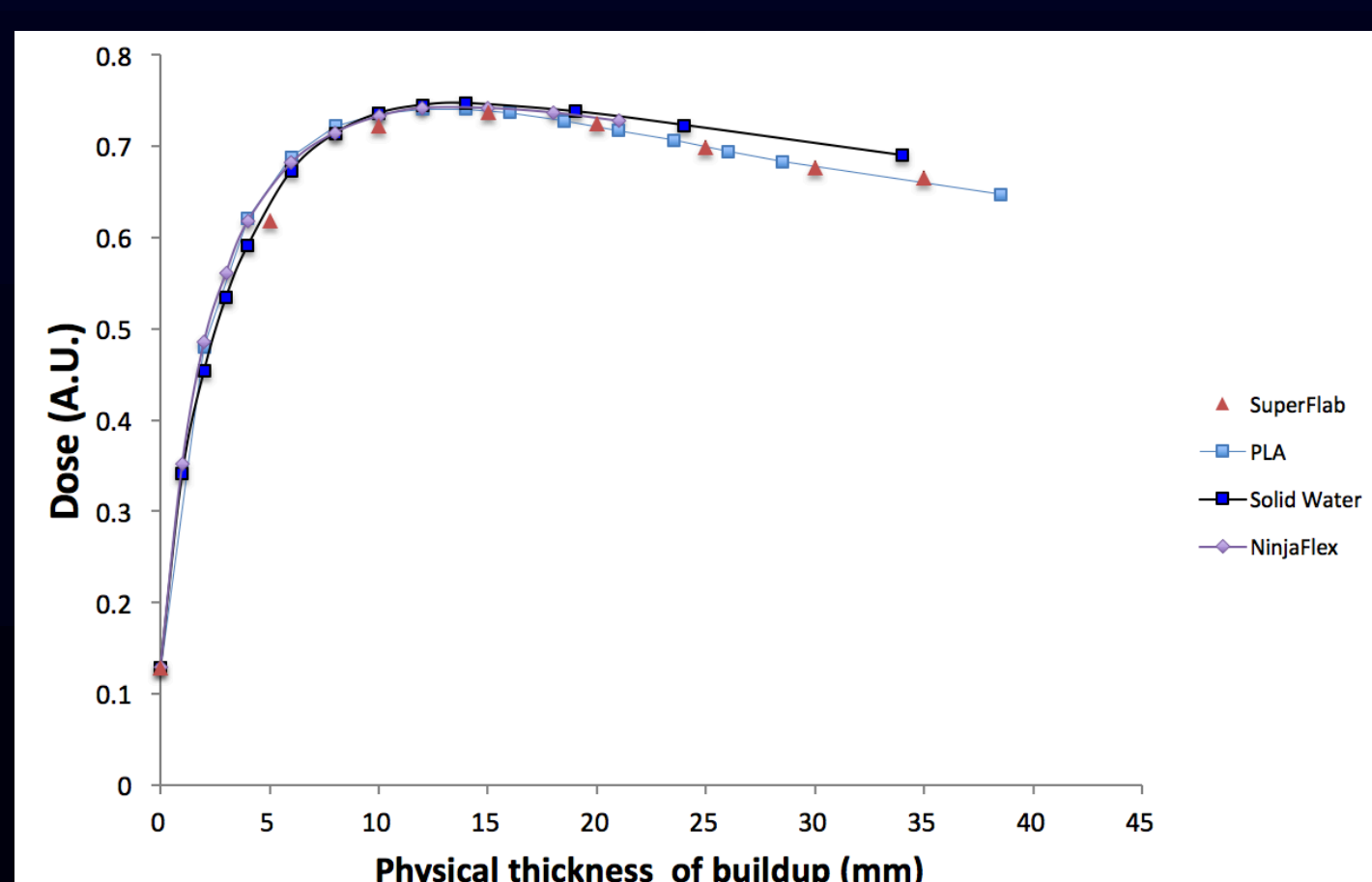

Figure 1. Buildup characteristics for PLA and Ninjaflex printable media, compared to Superflab and Solid Water.
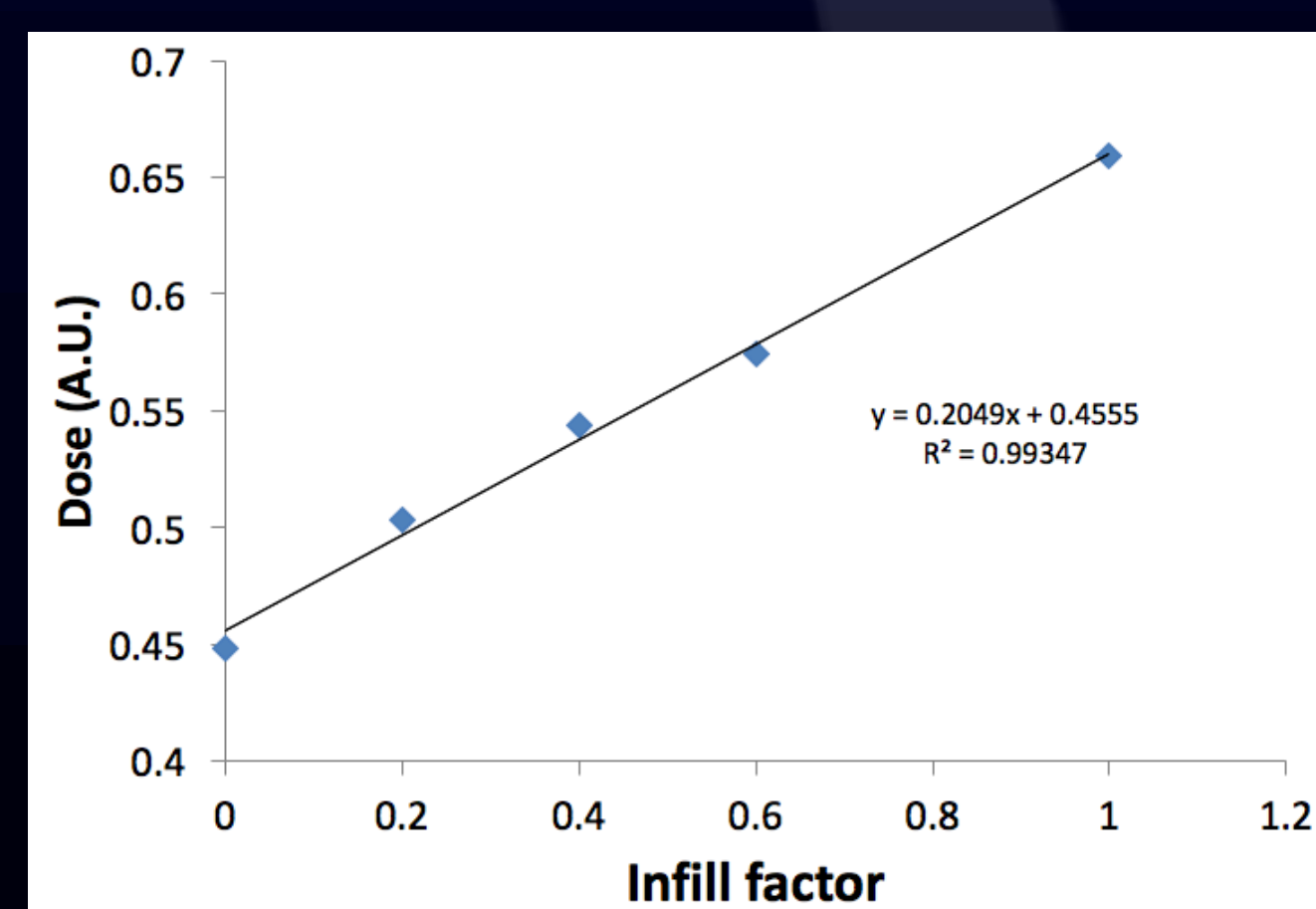

Figure 2. Variation of measured surface dose with infill factor (percentage of printed slab filled with printed media).

Results

3D printed bolus provided an improved fit for all three gel phantoms (figure 3). Volumes of air cavities were reduced with the use of 3D printed bolus by factors ranging from 1.4 to 16.3 (figure 4) compared to sheet bolus. The maximum air gap dimension normal to the surface was reduced by factors ranging from 1.0 for the simplest anatomy to 12 for the most complex. In some cases air cavities were reduced from over 1 cm in dimension to less than 2 mm. In general, greater advantages were seen for more complex chest wall anatomy, e.g., where the use of tape and linens by the therapist to compress sheet bolus could not achieve the conformity of 3D printed bolus (figure 5).

Under 3D printed bolus, OSLDs readings were within 2.0% of planned values at corresponding locations (range -1% to +4.9%).

Systematic dose differences were observed between treatment plans calculated with 3D printed bolus compared to sheet bolus proximal to air cavities (figure 6). In addition, improved uniformity of surface dose was observed for 3D printed bolus (dose standard deviation 5.3% compared to 8.1%).
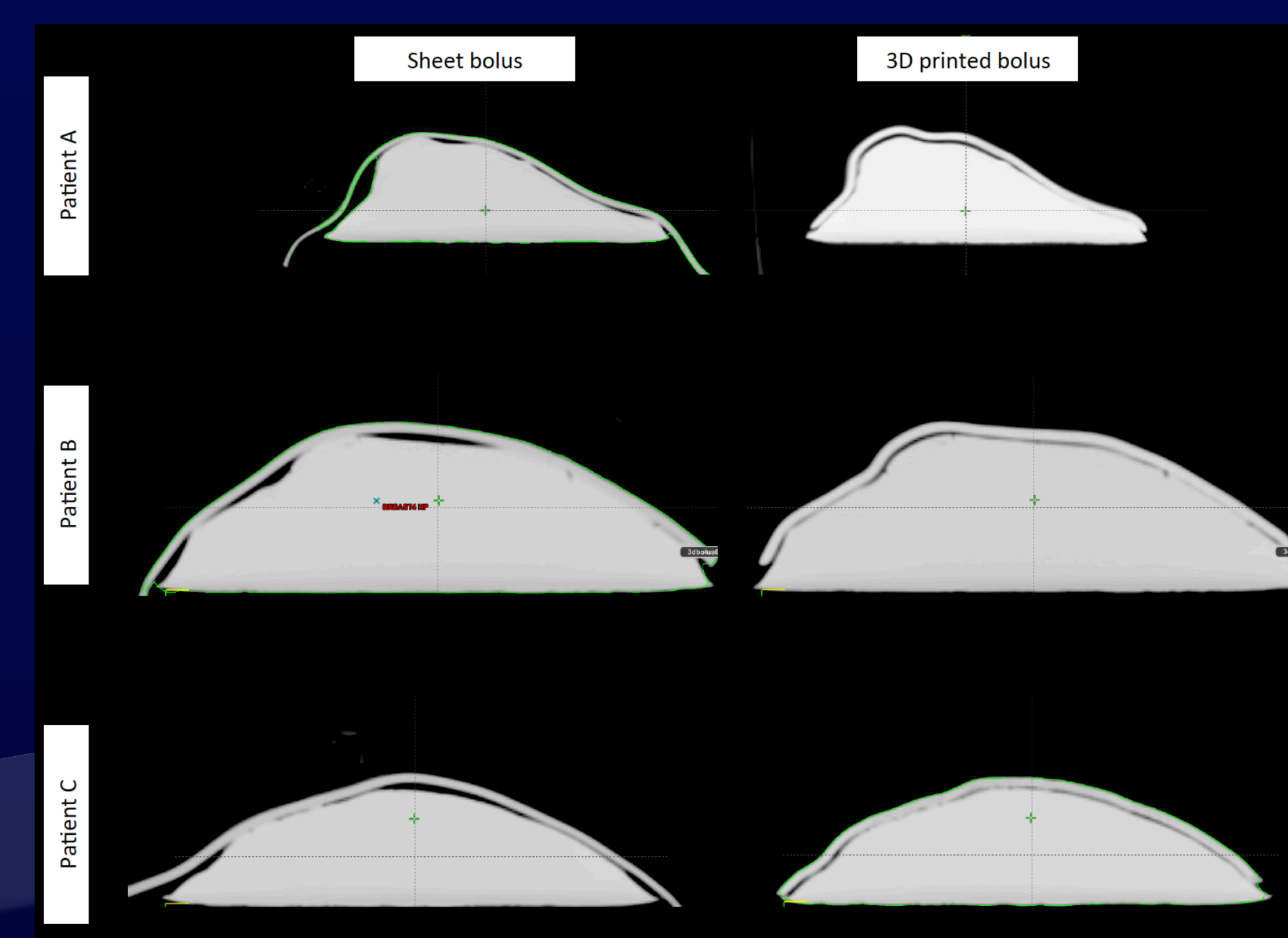

Figure 3. Comparison between standard sheet bolus and 3D printed bolus for three gel phantoms.
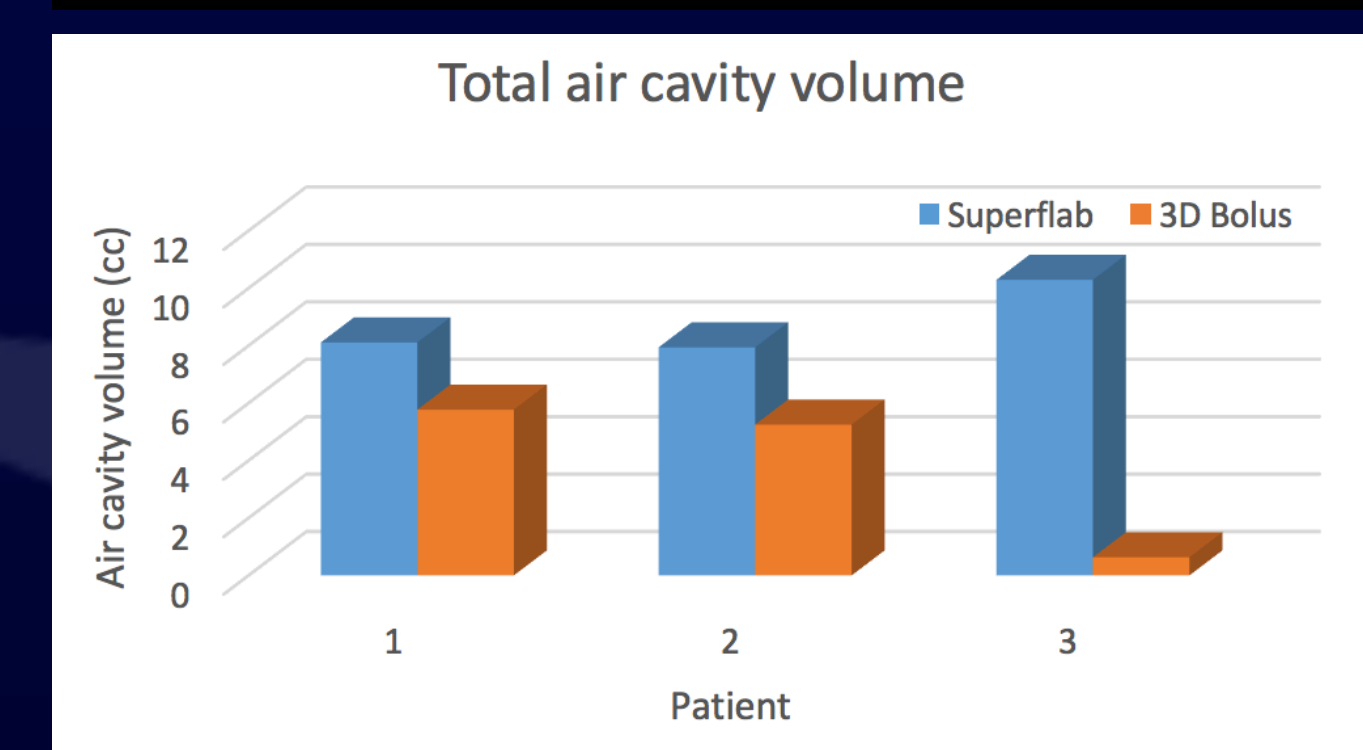
Total air cavity was reduced by 3D printed bolus by a factor ranging from 1.4 to 16.3.

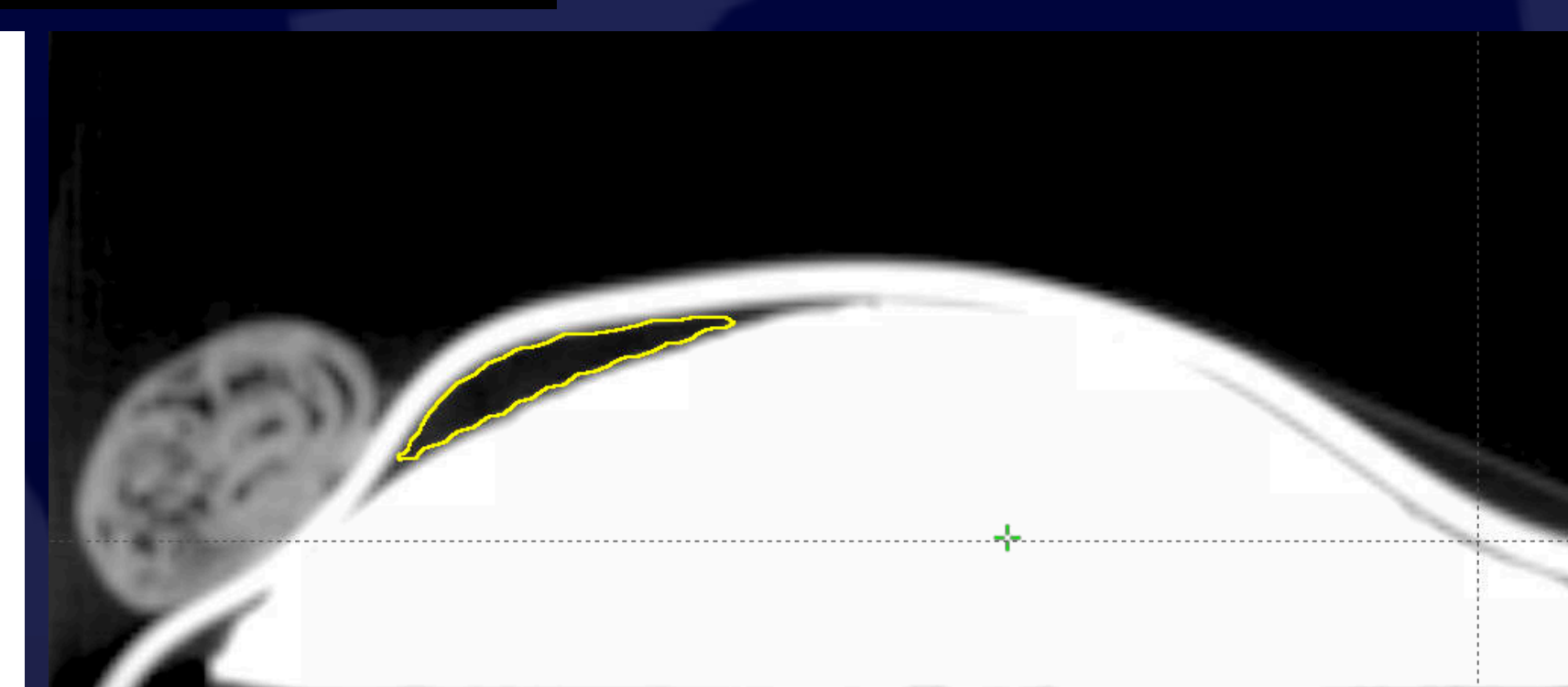**Figure 4.** Comparison of air gap volumes.

Figure 5. For sheet bolus, use of tape and linens did not produce fit comparable to that achived by 3D printed bolus.
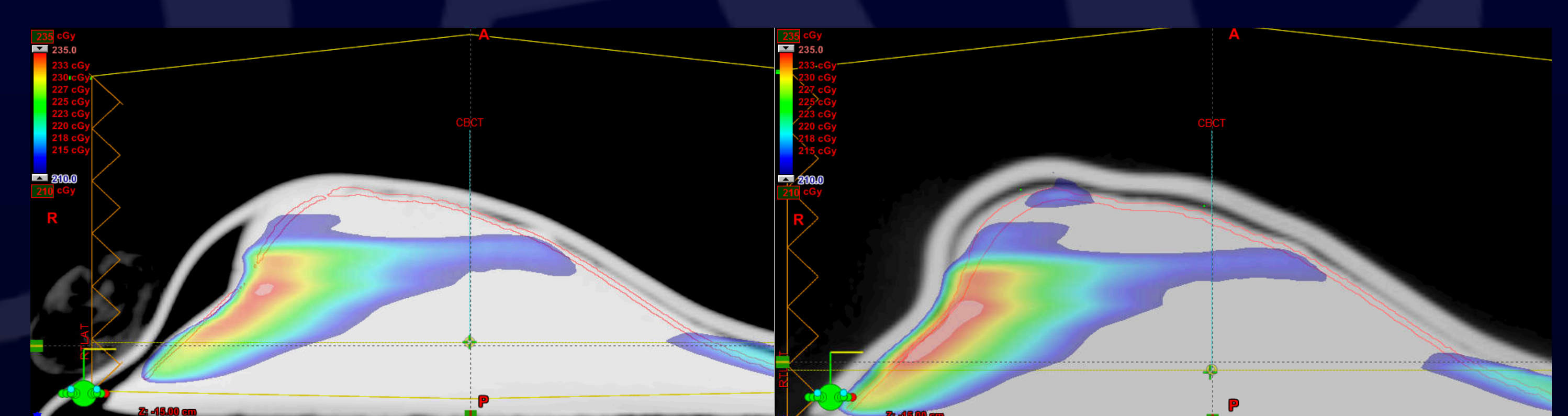

Figure 6. Systematic differences in dose distribution were observed between sheet bolus (left) and 3D printed bolus (right) when the same treatment plan was applied.

Conclusions

PLA and Ninjaflex provide appropriate printable media for chestwall bolus with regard to dose build-up characteristics. Infill factor can control surface dose if required. 3D printed bolus provides improved spatial conformity to the chestwall compared to standard sheet bolus. Improved bolus fit appears to produce more uniform surface dose.

References

1. S. Su and J. Robar, Design and production of 3D printed bolus for electron radiation therapy, JACMP 15(4), 2014.
2. S. Burleson et al, Use of 3D printers to create a patient-specific 3D bolus for external beam therapy, JACMP 16(3), 2015.

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