Re-imagining Radiotherapy Bolus as a Soft Robot: A Preliminary Investigation

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ABSTRACT

This study investigates a novel jamming-style soft robotic bolus for radiotherapy, stepping towards improved surface dosimetry through adaptive contouring and non-adhesive fixation.

Prototypes were fabricated using Ecoflex-30 silicone cured in 3D-printed molds, featuring a 6cm × 6cm grid region, filled with granular materials of glass microbeads, coarse sugar, and ground coffee, and evaluated for radiological homogeneity under a 6MV beam. EPID analysis revealed that a 60/40 sugar/glass bead mixture achieved the most uniform transmission (max/min ratio: 1.017). Mild suction enabled temporary, non-adhesive fixation.

Results establish a viable fabrication process and candidate filler materials, advancing the concept of a patient-agnostic, reusable robotic bolus as an imaginative upgrade to a long-used radiotherapy technology.

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INTRODUCTION

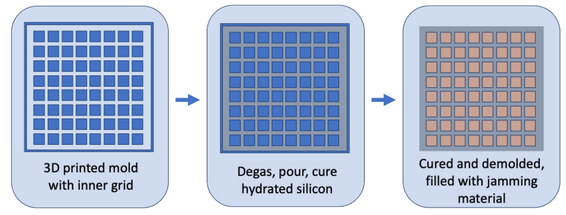
Robotic bolus has potential to enhance surface dosimetry by reducing air gaps through adaptive surface contouring while also providing immobilization for treatment regions.

This study evaluated filler materials for a jamming-style robotic bolus as an initial proof-of-concept.

Jamming was selected as a mechanism because it enables passive shape conformity and stiffness without complex actuation. The work supports development of patient-agnostic, reusable, homogeneous, non-adhesive, robotic bolus using simple pneumatic control.

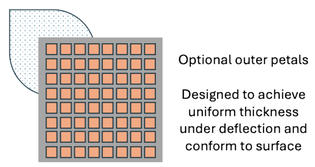
METHODS AND MATERIALS

1. Fabrication



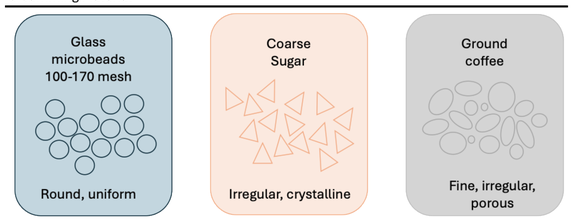
Prototype devices were fabricated with hydrated silicone (Smooth-On Ecoflex-30), degassed and cured in 3D printed molds.

2. Device Design



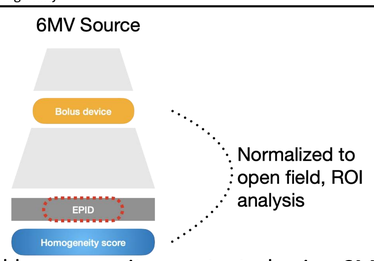
Molds had an inner 6cm x 6cm grid region with optional outer petal to enhance fixation, designed to maintain uniform thickness over a treatment region under deflection and use granular jamming for stabilization and shape conformity to the surface.

3. Jamming Material



Jamming materials and mixtures of round glass microbeads (100-170 mesh), coarse sugar, and ground coffee were evaluated.

4. Radiological homogeneity



Radiological homogeneity was tested using 6MV EPID measurements normalized to an open field and analyzed within central ROIs.

RESULTS

- A soft robotic prototyping method was established using curable silicone (Figure 1).
- EPID measurements (Figures 2, 3) demonstrated that none of the fillers matched hydrated silicone in 6MV transmission, although glass beads showed a small improvement (1.3%) over air (Table 1).
- A mixture of 60/40 weight percent sugar and glass beads had the lowest max/min and avg/min intensity ratios in the ROI (1.017 and 1.009, respectively).
- Evacuation enabled temporary, non-adhesive fixation, suggesting potential for reproducibility and comfort (Figure 4).

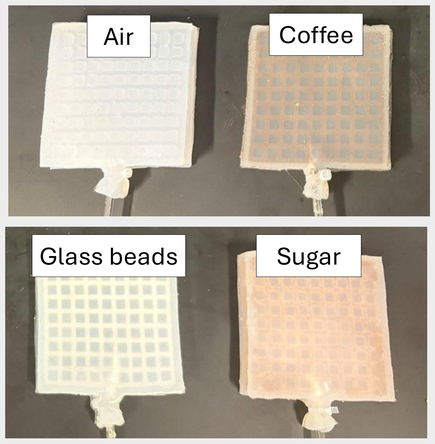


Figure 1. Sample 6cm x 6cm protypes with evaluated jamming media. Pneumatic lines allowed evacuation of air for jamming fixation.

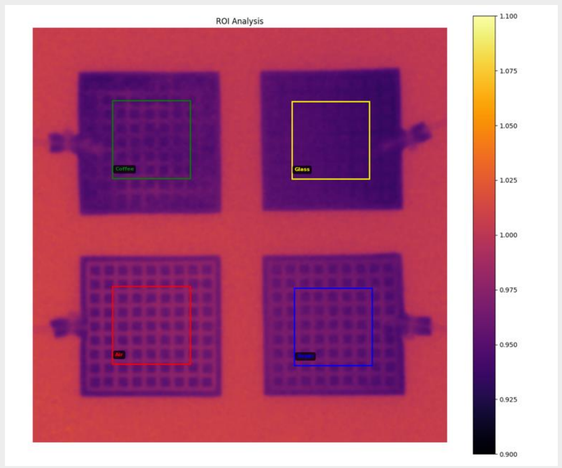


Figure 2. Filler material ROI analysis (clockwise from upper left: coffee, glass, sugar, air)

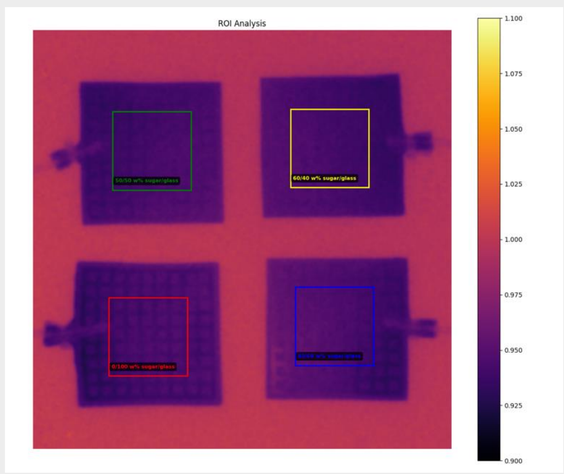


Figure 3. Mixture material ROI analysis (clockwise from upper left: 50/50, 60/40, 40/60, 0/100 w% sugar/glass)

ROI	Max/Min	Avg/Min
Air	1.0325	1.0182
Coffee	1.0232	1.0104
Sugar	1.0244	1.0135
Glass beads	1.0188	1.0100
50/50 w% sugar/glass	1.0183	1.0107
40/60 w% sugar/glass	1.0247	1.0133
60/40 w% sugar/glass	1.0168	1.0085

Table 1. Filler material comparison pixel intensity analysis

Figure 4. Example application, center uniform region with outer petal design as a first pass at mild suction.

DISCUSSION

- The 60/40 sugar/glass bead mixture achieved superior radiological homogeneity, likely due to complementary particle size and density interactions improving packing uniformity.
- While no filler matched the hydrated silicon structure, the marginal differences suggest clinical acceptability and warrants further investigation.
- Mild suction fixation demonstrated proof-of-concept for non-adhesive immobilization, a meaningful advantage over traditional adhesive bolus.
- Limitations include small prototype size and flat-surface testing only.
- Future work will address curved anatomical surfaces, pneumatic control, and cleaning protocol optimization.

CONCLUSIONS

This study steps towards transforming bolus into an active, rather than passive, system, which has the potential to improve both dose build up and immobilization in controllable and reusable ways.

- A fabrication process and candidate filler materials were established for jammed soft robotic bolus designs, using radiological homogeneity as a design constraint.
- Mixed sugar-glass bead fillers demonstrated improved uniformity relative to air.
- Temporary, non-adhesive fixation could be achieved via mild suction, with further research supporting appropriate design of hybrid systems.

REFERENCES

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