Innovation/Impact: This mechanism is innovative in the following respects: (I) the mechanism is entirely made out of mechanically-compliant parts so that it can be adopted for motion compensation in both MRIs (given its non-magnetic components) and LINACs (given its radiation-transparent actuators); (ii) being a parallel mechanism, it can generate precise head manipulation upon air inflation to aid stable and prehensile grasp of the patient's head; (iii) its quick-connect, quick-disconnect modular construction eases the logistical setup workload of current systems; and (iv) it is minimally-invasive so that it provides the patient with comfort unlike frames and thermoplastic masks currently used in radiation therapy or stereotactic radiosurgery. As far as we are aware, **no currently available technology exists today that can perform real-time head position stabilization without dose attenuation in an online adaptive fashion while guaranteeing patient safety similar to our proposed MRI-compatible non-magnetic soft robot.**

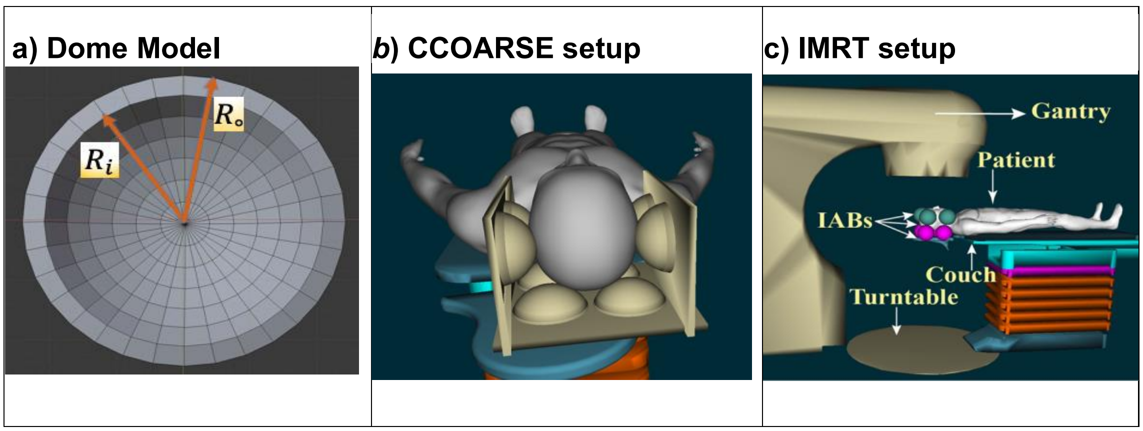

Fig. 1: Geometrical model of actuator types and overall system prototype

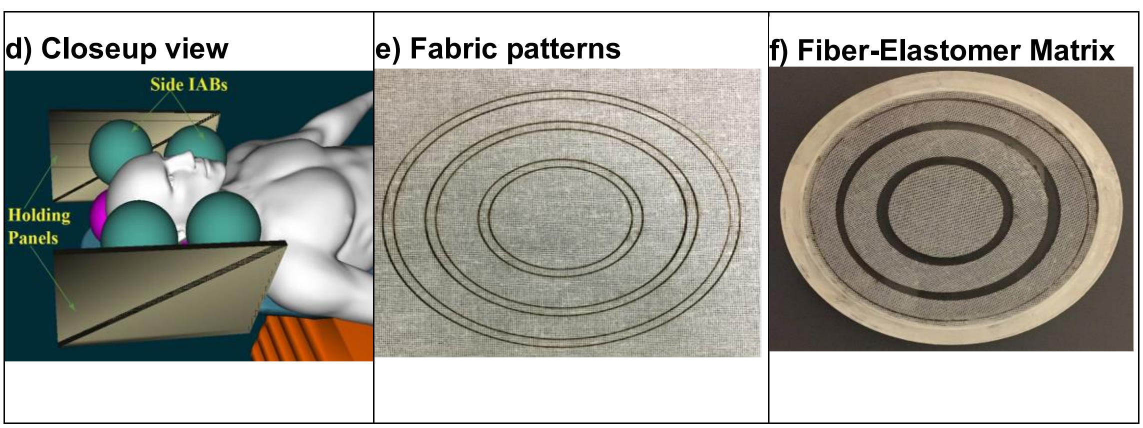

Fig. 2: Constraints and freedoms

Design and Construction: Fig. 1 shows the geometry of the proposed prototypes. Soft robots are notoriously difficult to control due to their many freedoms. Since we seek mathematically tractable models for precise control of the actuators, we constrain the circumferential stretch of the spherical actuators of Fig. 2a before inflation. This is done by laser-cutting fibers (Fig. 2a), removing the cut meshes and laying them on uncured rubber in a mold (Fig. 2b) before allowing the rubber to cure (Fig. 2c). Upon air actuation, the rubber deforms based on a Circumferentially Constrained and Radially Symmetric

Elastomer property (CCOARSE), expanding along the radial direction only (Fig. 1b). An IMRT setup of the patient motion correction with spherical actuators around the patient's head on a treatment table (Fig. 1c).

(e) illustrates the Cephalopods-inspired actuator model which reaches full

actuation in < 3 seconds (see video proofs in this link). To prevent radiation-attenuation, we carve low-temperature planar PVC foams and encase them in carbon fibers to hold the actuators in place around the head.

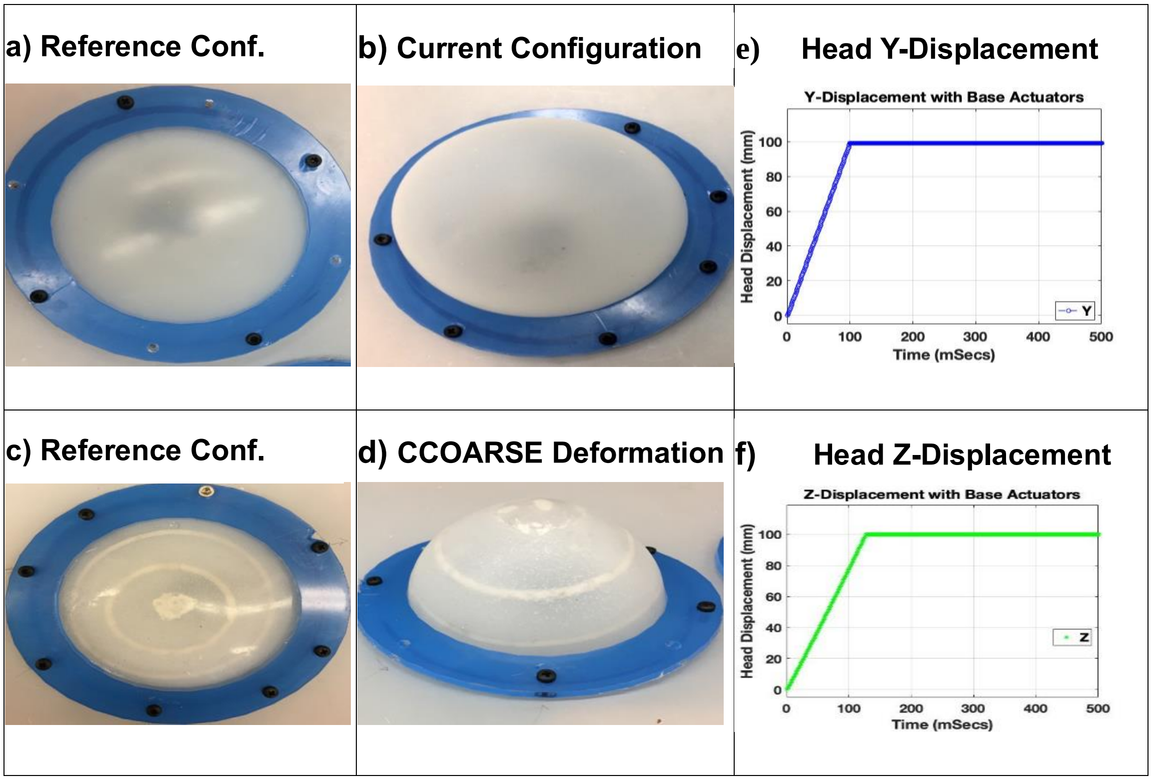

Fig. 3: CCOARSE Deformation and Head Translation Experiments

In Table II, the effect of the fabric matrix within the elastomeric solid is evident as the elastic material in (a)-(b) shows a circumferential and radial deformation. This complicates the analytical model and makes the mathematical constitutive stress laws intractable. To circumvent this, we constrain the deformation with a fiber matrix whose deformation along the radial axis is illustrated in (b) and (d).

Key results: We simulate the task of controlling the head motion of a patient in simulation using the SOFA framework. We modeled the domes as inflatable chambers which deform in a CCOARSE manner upon actuation. The head lies on the actuators as shown in Table I. We apply a pressure of 3psi at every time step to the base actuators. TO measure head position on the treatment table, we find the maximal coordinate of the axis of motion being controlled in the illustrated patient mesh. Since the patient lies supine, this corresponds to the tip of the nose. The results of independent axes of motion raising of the head above a treatment table in an ***open-loop*** control setting are illustrated in charts (e) and (f) of Table II. The head reaches desired translation positions along in less than 10 seconds (x-motion is left due to space but more results are available here). This demonstrates a proof-of-concept study that the proposed mechanism allows precise and fast head manipulation along available axes of head motion.