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Abstract

Dual-concentration PVA hydrogel brain phantom for neurosurgical training

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Neurosurgical training demands realistic tissue phantoms that replicate mechanical and imaging properties of human brain tissue. This work presents a polyvinyl alcohol (PVA)-based phantom simulating healthy and pathological brain tissue by exploiting the material properties of different PVA concentrations. The phantom enables a training system that offers accurate mechanical behavior and ultrasound visualization.

A three-part casting system was developed using 3D-printed Acrylonitrile Butadiene Styrene (ABS) molds to produce brain phantoms with an insertable tumor component. Two PVA formulations were prepared: 10% concentration representing healthy brain tissue and 15% concentration simulating pathological tissue. After one freeze-thaw cycle, the specimen underwent mechanical characterization according to ISO 7743:2017-10 and an ultrasonic evaluation using clinical imaging equipment.

Compression testing revealed distinct mechanical behavior between PVA concentrations. At 25% strain, 15% PVA exhibited stress values of 1.92 ± 0.08 kPa while 10% PVA demonstrated 1.25 ± 0.03 kPa, mimicking the reported mechanical properties of brain tissue [1,2]. Ultrasound examination showed material differentiation with boundary artifacts in between layers. Dimensional analysis comparing the ultrasound images with the original design demonstrated a difference within 3%.

Clinically relevant mechanical differences between simulated tissue types were successfully created using the multi-concentration approach. The system provides anatomically accurate phantoms suitable for neurosurgical education and ultrasound imaging, representing advancement in tissue-mimicking technology for medical training applications.

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