# Accelerating Traumatic Brain Injury Modeling with Neural Operators: Toward Personalized Protective Gear Design

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## Motivation

- In 2020, there were approximately 214,110 TBI-related hospitalizations, and in 2021, 69,473 TBI-related deaths—averaging over 586 hospitalizations and 190 deaths per day [1].
- Wearing a well-fitted helmet can greatly reduce the risk of traumatic brain injuries by absorbing impact and protecting the brain during falls, crashes, and collisions.
- Helmet options are limited to a few standard sizes, while personalized designs are computationally expensive to assess for feasibility.

**Our vision: Revolutionize helmet design by leveraging scientific machine learning to enable personalized helmets with virtually no overhead costs.**

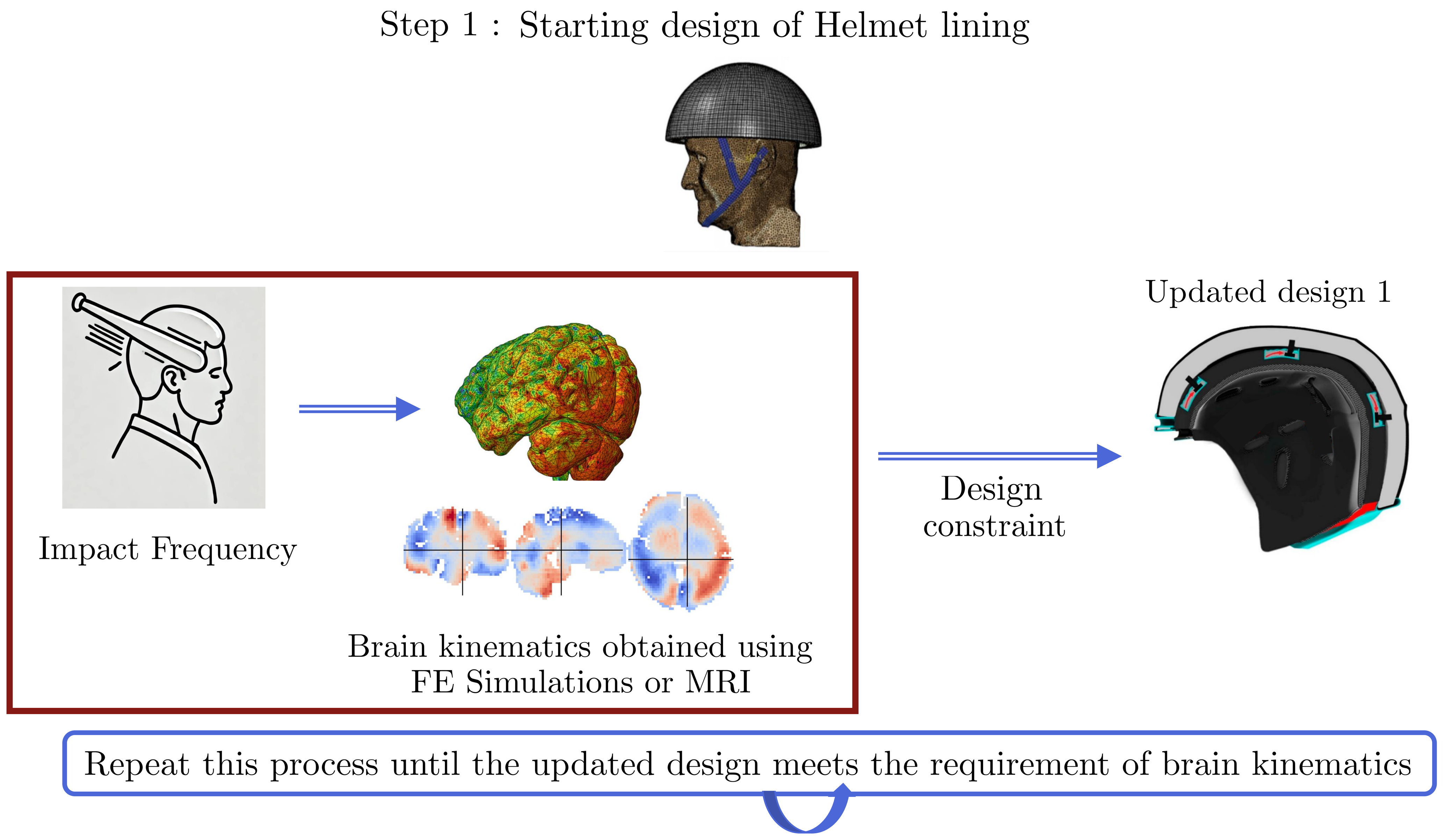



Figure 1: Optimization procedure of Helmet lining design

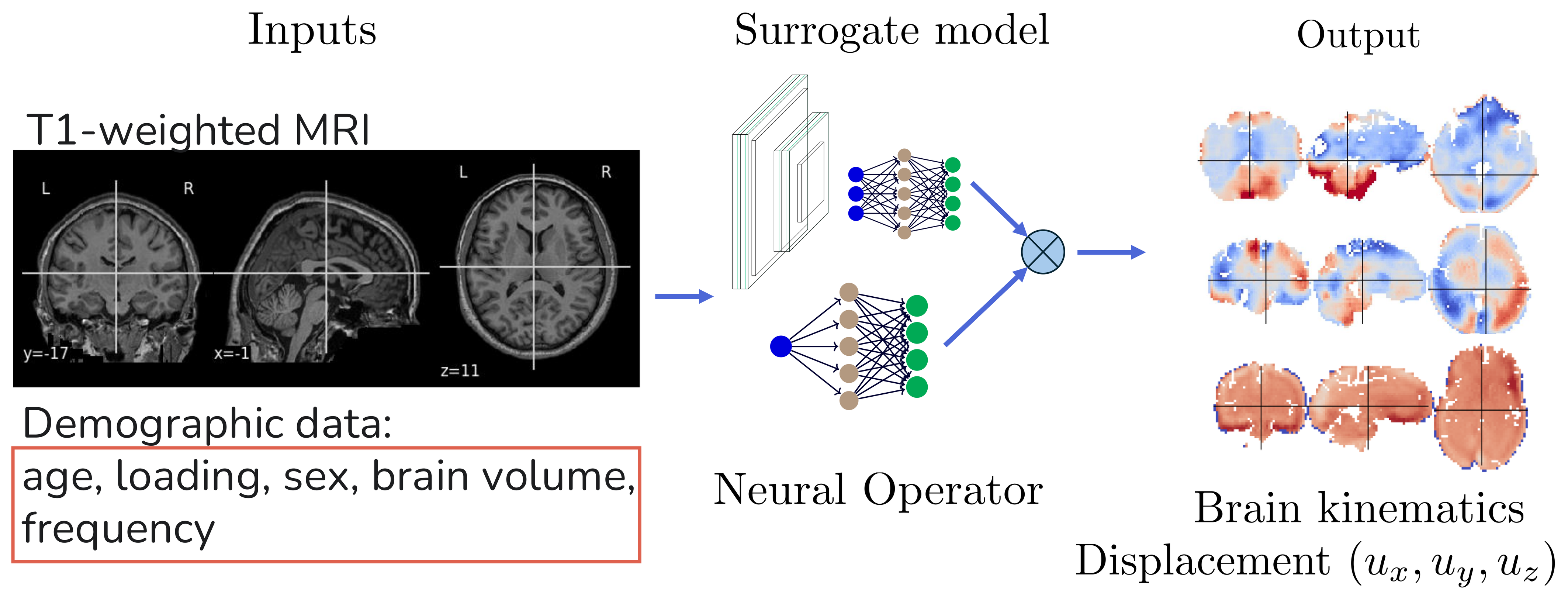
## Challenges

- Determining personalized brain kinematics using Finite Element Modeling (FEM) is computationally expensive.
- The high computational cost of obtaining the most appropriate personalized design parameter of the helmet using inverse modeling restricts the ability to explore multiple design variations.

## Proposed solution

- Our NO-based surrogate model can approximate patient-specific brain kinematics with an average absolute error of 0.16 on test cases.
- It has the potential to transform personalized helmet design optimization by enabling design updates in seconds— a significant advancement over traditional approaches that require hours of high-fidelity FEM solutions.
- The model is trained on MRE data of 228 samples from Washington University in St. Louis [3].

## Proposed framework

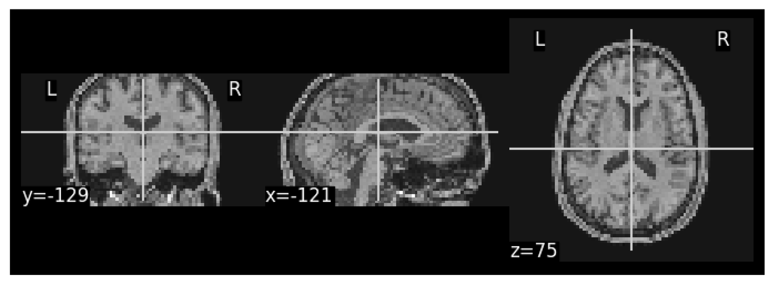



Neural operators (NOs), like DeepONet [2], use deep neural networks to approximate mappings between infinite-dimensional functional spaces.

## Results

Sample 1

T1-weighted MRI



Age: 55, Loading: Lateral, Sex: Male, Frequency: 90 Hz, Brain volume: 1258 cm$^3$

Average absolute error: **0.1817**

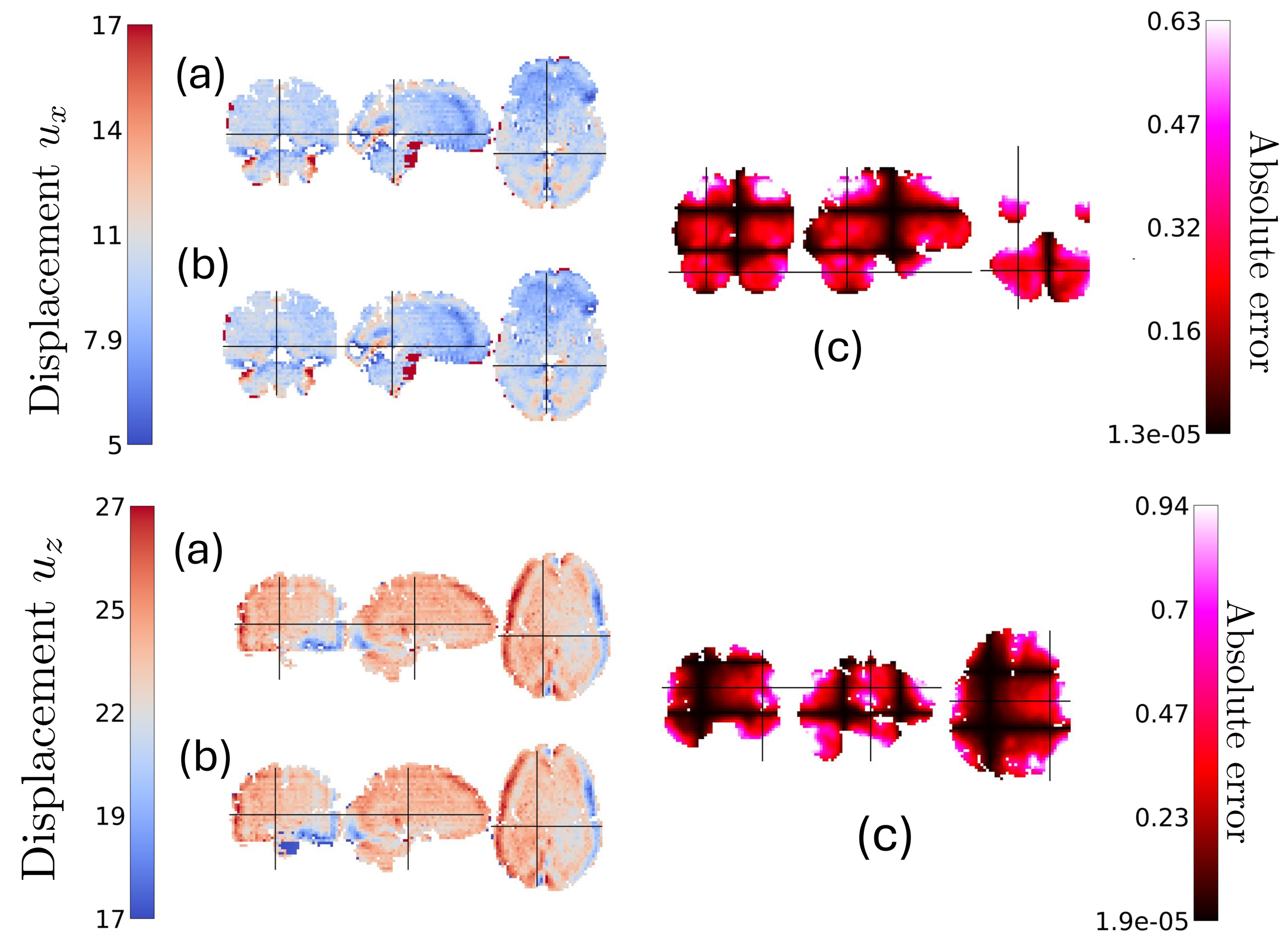
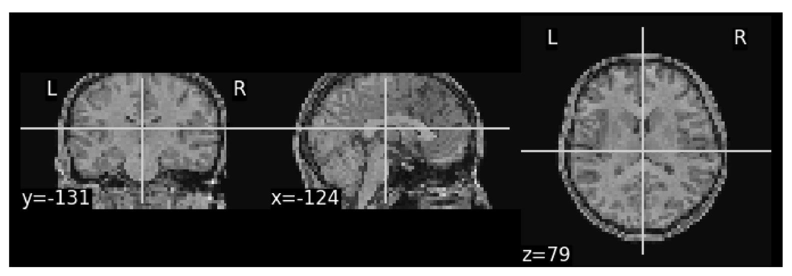



Figure: (a) Ground truth, (b) Predicted displacement, and (c) Absolute error.

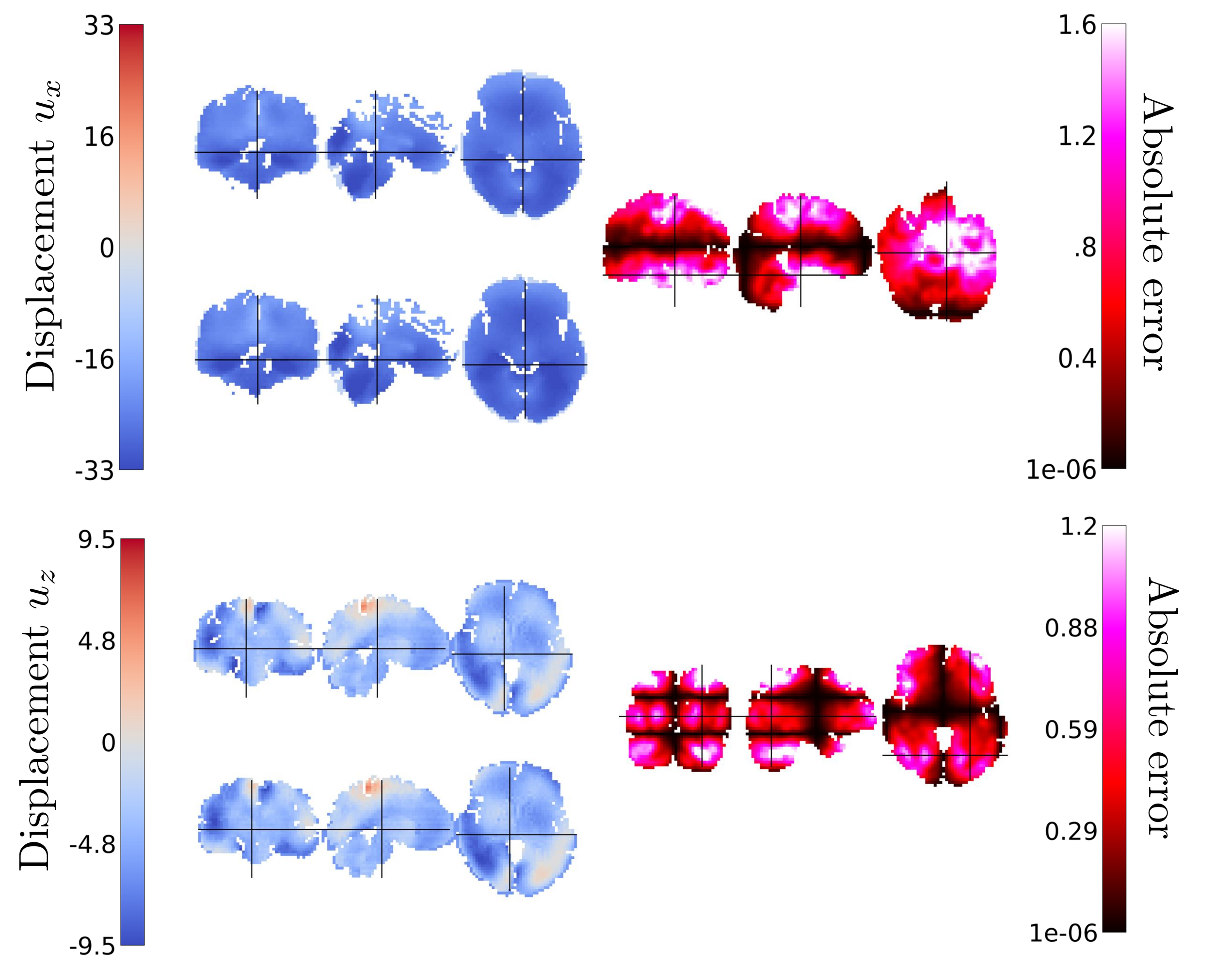
Sample 2

T1-weighted MRI



Age: 22, Loading: Occipital, Sex: Female, Frequency: 30 Hz, Brain volume: 1313 cm$^3$

Average absolute error: **0.3754**




## Reference

1. Centers for Disease Control and Prevention. National Center for Health Statistics: Mortality Data on CDC WONDER. Accessed April 2023.
2. Lu, Lu, et al. "Learning nonlinear operators via DeepONet based on the universal approximation theorem of operators." Nature machine intelligence 3.3 (2021): 218-229.
3. Bayly, Philip V., et al. "MR imaging of human brain mechanics in vivo: new measurements to facilitate the development of computational models of brain injury." Annals of biomedical engineering 49 (2021): 2677-2692.

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