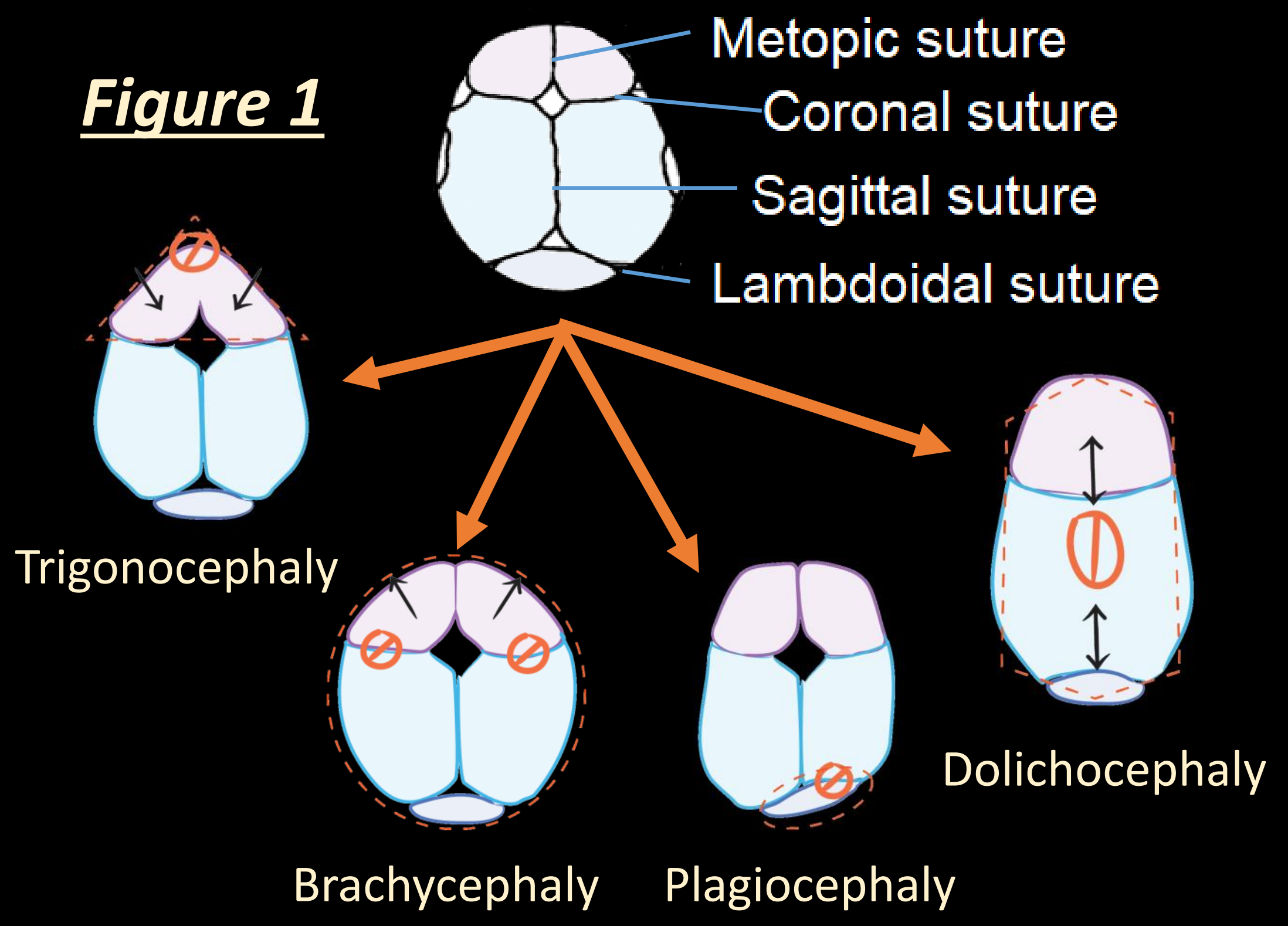
Finite element analysis of infant brain expansion and muscle activation shows the importance of cranial sutures for healthy skull growth

Louisa Hulls[1]*, Mehran Moazen*[2]*, Alana C Sharp*[3]

[1] Human Anatomy Resource centre, University of Liverpool, Liverpool, UK; [2] UCL Mechanical Engineering, University College London, UK; [3]Institute of Life course and Medical Sciences, University of Liverpool, UK

- Craniofacial sutures are unique joints consisting of soft connective tissues between the skull bones. They are important sites for bone growth during development, and for absorption of mechanical stress, but their mechanical function is not well understood.
- Craniosynostosis is a congenital condition causing premature fusion of one or more cranial sutures (Figure 1), which can lead to head malformations and brain damage.
- Corrective surgery, including cranial vault remodelling, fronto-orbital advancement or spring-mediated cranioplasty, aims to separate the fused cranial bones, restore head shape, and allow for normal cranial development.
- It is therefore important to understand the role sutures play in skull function and growth.

Figure 1



Material and Methods

1. Design

- FE skull model with fused (craniosynostosis) sutures and non-fused (normal) sutures.

2. Simulate

- Forces experienced during brain growth and activation of masticatory muscles.

- We applied finite element (FE) analysis to an infant skull model developed by Libby et al. (2017). The specimen used to create the FE model was obtained from the archaeological collection at the University of Dundee.
- The 3D FE model contained bone, suture and intracranial volume (ICV) as separate materials (Figure 2).
- ICV expansion (modelled as thermal expansion) and jaw muscle activation were simulated in Abaqus CAE 6.14 (SIMULA TM) FE software.
- We simulated "fused" sutures by applying the material properties of bone to the suture areas.
- We then compared the model with fused and non-fused cranial sutures to explore the biomechanical effect.

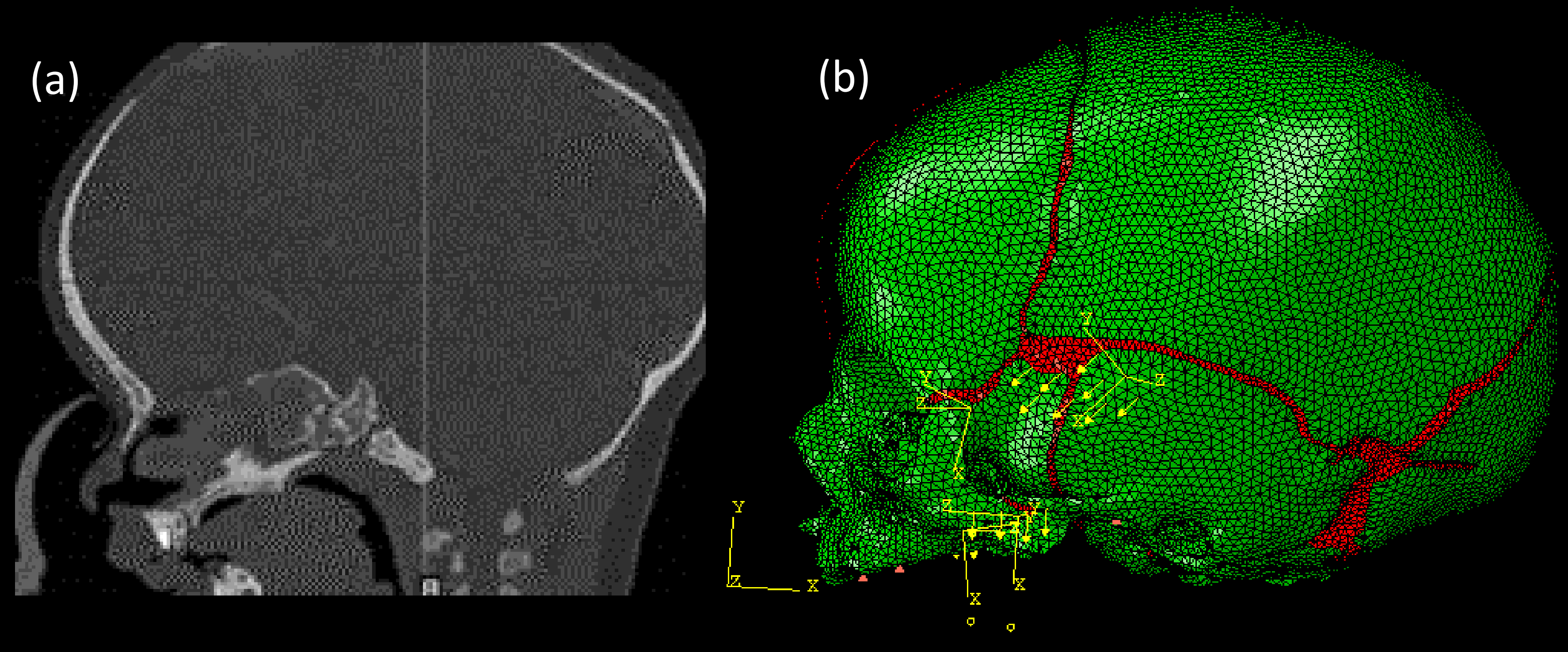


Figure 2*. (a) CT sagittal section of an infant skull; (b) 3D FE model with bone (green), cranial sutures (red) and internal ICV (unseen) materials. Mechanical loads for the temporalis and masseter are shown as arrows.*

Results

3. Compare

- Tensile strain distribution between these two scenarios in our model with and without patent sutures

- There was significantly higher strain in surrounding bone in the fused model compared to the unfused model (Figure 3) suggesting fusion of sutures causes bone deformation due to the loss of compliant soft tissue sutures.

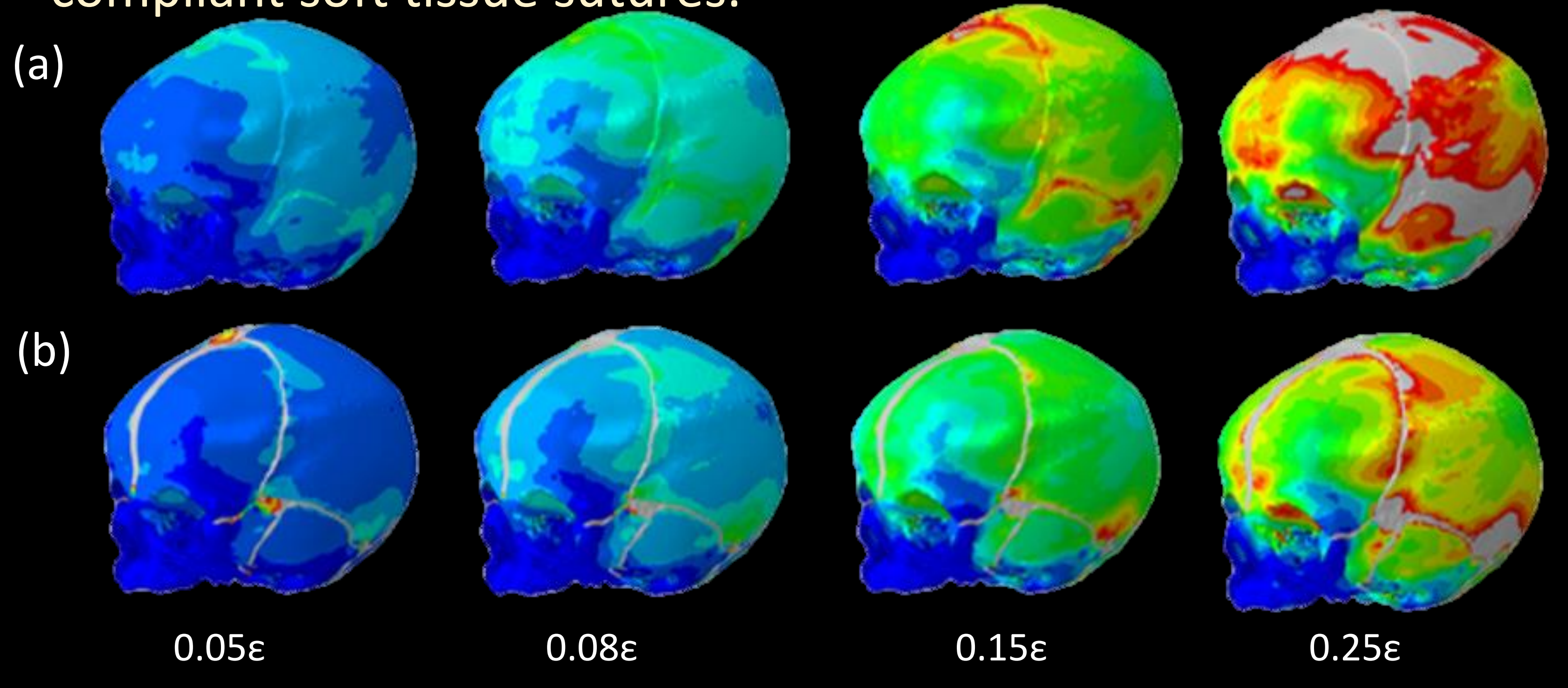


Figure 3*. Tensile strain distribution during ICV expansion for fused (a) and unfused (b) suture models. Blue shows areas of low strain, red shows high strain at respective limits and grey represents strain above this upper limit show under each model.*

- During bilateral temporalis and masseter muscles activation, tensile strain was significantly higher at the frontal suture in the unfused model compared to the fused model.

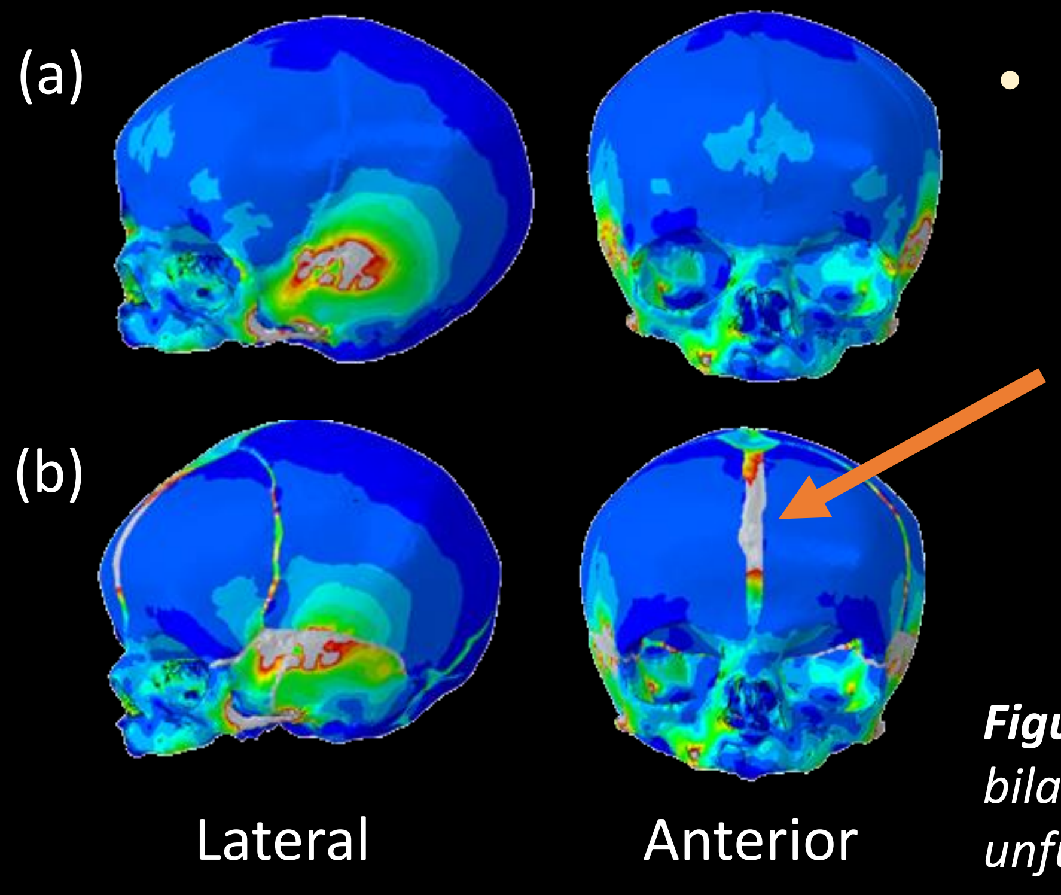


Figure 4 (left). *Tensile strain distribution during bilateral muscle activation for fused (a) and unfused (b) suture models.*

Conclusions and Future Research

- Computational modeling can reveal important biomechanical relationships between craniofacial sutures and mechanical strain.
- FE stimulations show that sutures are important sites for cranial strain during brain expansion and masticatory muscle activation in infants.
- Higher strain in the patent sutures reduced strain in the surrounding bone.
- The frontal suture is particularly important as a strain sink during jaw muscle activation.

- Further research is needed to enhance our understanding of individual suture synostosis to explore patient-specific craniosynostosis.
- Our findings suggest FE analysis has the potential to improve our understanding of the biomechanical environment of the infant skull during growth and could be used as a clinical tool for planning appropriate treatment strategy and optimising recovery for patients with craniosynostosis.

References

Libby J. et al. (2017) Modelling human skull growth: a validated computational model: Journal of the royal society interface; Cohen M, & MacLean R. (2000) Craniosynostosis: Diagnosis, Evaluation, and Management. Journal of Medical Genetics, 37:727; Malde, O. et al. (2019) An Overview of Modelling Craniosynostosis Using the Finite Element Method. Molecular Sindonology, 10:74-82.