

1. ABOUT THE DATASET

Title: Finite element model of a rabbit skull

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Description: The dataset contains a finite element model of a rabbit skull, which contains hard (separate bones and teeth) and soft tissues (sutures and periodontal ligament). Files are provided to simulate a maximum incisor bite when considering a range of material properties for each bone in the skull. The files include: 1) a high resolution (~19million elements) mesh of the skull compatible with ANSYS; 2) input files for muscle loading, constraints and material properties; 3) a input file to run a range of simulations (compatible with ANSYS) which varies the material properties for each bone to use either i) bone-specific isotropic elastic modulus when measured in a particular orthotropic direction, ii) average isotropic elastic modulus when measured in a particular orthotropic direction, iii) bone specific orthotropic material properties with varying magnitudes of shear modulus. The material properties are taken from Wang et al (2024) (DOI: 10.1371/journal.pone.0298621). The files provided enables the user to output an image of the strain in the skull, along with averaged strain along a prescribed path through the skull (4 paths are included as a demonstration). Input files can be altered to alternative bone material properties and muscle forces.

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2. TERMS OF USE

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3. PROJECT AND FUNDING INFORMATION

Title: A new framework for computational biomechanical models and 3Rs in musculoskeletal research

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4. CONTENTS

scaled_monitoring_points_on_cranium_path_1.csv – contains the x, y and z coordinates for a path (termed path 1) on the rabbit cranium. The location of these paths can be altered to user defined coordinates.

scaled_monitoring_points_on_cranium_path_2.csv – contains the x, y and z coordinates for a path (termed path 2) on the rabbit cranium. The location of these paths can be altered to user defined coordinates.

scaled_monitoring_points_on_cranium_path_3.csv – contains the x, y and z coordinates for a path (termed path 3) on the rabbit cranium. The location of these paths can be altered to user defined coordinates.

scaled_monitoring_points_on_cranium_path_4.csv – contains the x, y and z coordinates for a path (termed path 4) on the rabbit cranium. The location of these paths can be altered to user defined coordinates.

elastic_moduli_of_individual_parts.csv - contains the elastic modulus for the individual bones, sutures, periodontal ligament and teeth for a range of simulations. These values can be altered to user defined elastic modulus values.

ratio_of_elastic_modulus_to_shear_modulus_of_bone_segments.csv – contains the shear modulus for orthotropic simulations. These values can be altered to user defined shear modulus.

muscle_forces_x.csv – the component force of muscle strands in the Fx direction. These forces can be altered to user defined forces.

muscle_forces_y.csv – the component force of muscle strands in the Fy direction. These forces can be altered to user defined forces.

muscle_forces_z.csv – the component force of muscle strands in the Fz direction. These forces can be altered to user defined forces.

MuscleOriginLocations.csv – the x, y and z coordinate of the origin of several muscle strands. These coordinates can be altered to user defined coordinates.

constraint_locations.csv – the x, y and z coordinates of constraints applied to the teeth and temporomandibular joint. The location of these constraints can be altered to user defined coordinates.

Mesh.txt – the mesh of the rabbit skull (compatible for ANSYS).

Load_file.text – script for an input file for running a simulation/s in ANSYS. This file refers to all other files as input files, and executes ANSYS commands to run a series of simulations. This file enables the user to specify how many simulations to run (these simulations correspond to the simulations stated in the elastic_moduli_of_individual_parts.csv file). This file requires the user to specify the file path for all the individual files, and a file path for the output data. Instructions on user specific aspects are annotated in the script.

5. METHODS

The FEA model of a rabbit skull was created through initially MRI scanning the head of a rabbit using a Siemens 3.0 T Prisma scanner (Siemens), with a human wrist coil (Hand/Wrist 16, A 3T Tim coil) at an isotropic resolution of 0.23 mm. Volumetric models of the skull, jaw and individual masticatory muscles were constructed to visualise muscle paths.

The same head was then μ CT scanned using a Tek HMX 160mCT scanner (X-Tek Systems Ltd, UK) with a resolution of 0.0669 mm in each direction. The μ CT scan data was segmented to identify all individual bones of the skull, along with sutures, periodontal ligament, enamel, dentine, and tooth pulp. A volumetric model was meshed with ~19.05 million tetrahedral elements, connected through ~3.76 million nodes.

The location of muscle origins were identified on the mesh through the use of the MRI scan data. Multiple strands per muscle were included. Muscle forces were applied at nodal loads at the muscle strand origin, and represented a maximum bite. A node on the left temporomandibular joint was constrained in the antero-posterior and VD directions, while a node on the right TMJ was constrained in all degrees of freedom. A node at the tip of each incisor was constrained in the ventro-dorsal direction.

The model is capable of several homogeneous, isotropic simulations based on assigning a different elastic modulus (E) to each bone (note – numbering corresponds to model numbering in elastic_moduli_of_individual_parts.csv):

- 1) bone-specific E (average E when measured in the antero-posterior direction) and teeth defined with the same E (the average across all teeth when measured in the antero-posterior direction);
- 2) each bone defined with the same E (the average across all bones when measured in the antero-posterior direction) and teeth defined with the same E (the average across all teeth when measured in the antero-posterior direction);

- 3) bone-specific E (average when measured in the medio-lateral direction) and teeth defined with the same E (the average across all teeth when measured in the medio-lateral direction);
- 4) each bone defined with the same E (the average across all bones when measured in the medio-lateral direction) and teeth defined with the same E (the average across all teeth when measured in the medio-lateral direction);
- 5) bone-specific E (average measured in the ventro-dorsal direction) and teeth defined with the same E (the average across all teeth when measured in the ventro-dorsal direction);
- 6) each bone defined with the same E (the average across all bones when measured in the ventro-dorsal direction) and teeth defined with the same E (the average across all teeth when measured in the ventro-dorsal direction);
- 7) bone-specific E (average from all three orthotropic directions) and teeth defined with the same E (average from all three orthotropic directions);
- 8) each bone defined with the same E (the average across all bones and all three orthotropic directions) and teeth defined with the same E (the average across all bones and all three orthotropic directions);
- 10) each bone defined with the same E (taken from another species) and teeth defined with E from literature.

The model is capable of several homogeneous, orthotropic simulations based on assigning a different elastic modulus (E) to each bone:

- 9) bone-specific (E_x corresponded to the average E when measured in the antero-posterior direction, E_y corresponded to average E when measured in the ventro-dorsal direction, and E_z corresponded to average E when measured in the medio-lateral direction). Orthotropic shear moduli for each bone (G_{xy} , G_{yz} and G_{zx}) was defined as 20 times lower than their respective orthotropic values;
- 11) bone-specific (E_x corresponded to the average E when measured in the antero-posterior direction, E_y corresponded to average E when measured in the

ventro-dorsal direction, and E_z corresponded to average E when measured in the medio-lateral direction). Orthotropic shear moduli for each bone (G_{xy} , G_{yz} and G_{zx}) was defined as 5.5 times lower than their respective orthotropic values;

12) bone-specific (E_x corresponded to the average E when measured in the antero-posterior direction, E_y corresponded to average E when measured in the ventro-dorsal direction, and E_z corresponded to average E when measured in the medio-lateral direction). Orthotropic shear moduli for each bone (G_{xy} , G_{yz} and G_{zx}) was defined as 3 times lower than their respective orthotropic values;

13) bone-specific (E_x corresponded to the average E when measured in the antero-posterior direction, E_y corresponded to average E when measured in the ventro-dorsal direction, and E_z corresponded to average E when measured in the medio-lateral direction). Orthotropic shear moduli for each bone (G_{xy} , G_{yz} and G_{zx}) was defined as 4 times lower than their respective orthotropic values.

Material properties for the bone were taken from Wang et al (2024) (10.1371/journal.pone.0298621). All simulations are assigned the same material property for the periodontal ligament (Rees & Jacobsen, 1997; 10.1016/S0142-9612(97)00021-5PDL), pulp (Benazzi et al. 2016; 10.1371/journal.pone.0152663) and sutures (Moazen et al. 2009; 10.1098/rspb.2008.0863).

The E values listed in `elastic_moduli_of_individual_parts.csv` in in the following order: dentine, pulp, enamel, parietal, frontal, squamosal, bulla, premaxilla, nasal, maxilla, basisphenoid, presphenoid, alisphenoid, orbitosphenoid, palatine, ethmoid and internal turbinate, vomer, occipital segment, supraoccipital, interparietal, periodontal ligament and suture.