

Investigating Embryonic Flexure and Torsion using Finite Element Analysis

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Introduction: The forces driving flexure and torsion in early embryo development are unknown but are vital for proper organ development. Embryonic flexures cause the body to bend and torsion is the rotational component (Figure 1E, F). Improper flexion and torsion could lead to birth defects. This project aims to use differential growth on a 3D computational model to show how a chick embryo bends and twists during early development. We were able to show that differential growth can produce flexion and torsion as observed in the experiment.

Materials and Methods: ABAQUS was used as the FE solver. As a first approximation, a solid cylinder was selected as the initial geometry. The part was partitioned into cranial, cervical, thoracic and caudal regions (Figure 1A). For the coordinate system to follow along the model deformation, local material orientation and nonlinear geometry were used. A fixed boundary condition was created to constrain the displacement and rotation on the bottom surface. A quadratic tetrahedral mesh was used. Previously published material properties were used. We used the chick embryo as the experimental model, staged with the system of Hamburger and Hamilton (HH) [1].

Results and Discussion: The computational model (Figure 1A-D) displayed flexures along the dorsal edge. To determine the internal growth loads, we compared our 3D model with a chick embryo (Figure 1E, F). Our results show that geometry similar to experiment could be achieved by assigning differential growth on specific sections. Half of the thoracic region was assigned 30% growth and to achieve both flexure and torsion simultaneously, the upper dorsolateral region was assigned 70% growth. We observed torsion by element tracking; only the yellow marked element was visible in the rotated model (Figure 1C), similar to the experiment (Figure 1F).

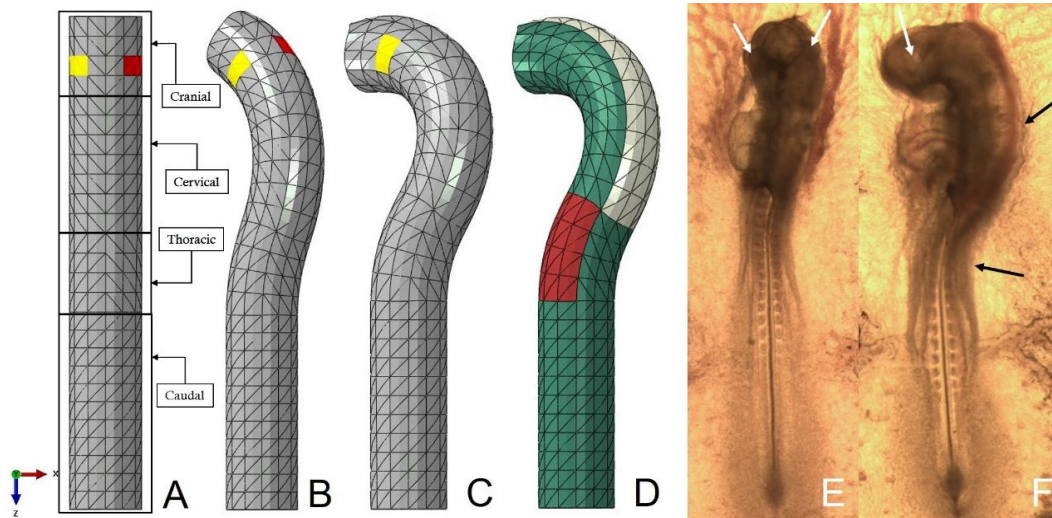


Figure 1: (A-C) Flexure and torsion with differential growth; (D) active (growth) and passive (no growth) sections; green is passive, red is 30% growth, gray is 70% growth, both along the longitudinal direction; (E) stage 12 embryo with flexure and torsion just starting. Note that both eyes are visible here (white arrows); (F) stage 14 embryo showing dorsal flexures (top and bottom black arrows denote cervical and thoracic flexures, respectively) and completed rotation in the cranial section. Note that only one eye is visible in the rotated embryo (white arrow). The yellow and red marked elements represent the position of the left and right eyes, respectively (A). Flexure development (B-C) bends the body into a flipped 'S' shape. (C) shows that only the left eye (yellow) is visible after torsion, as in the experiment. The total length of the embryo is about 7 mm.

Conclusion: Our results show that it is possible to obtain flexion and torsion similar to that seen in the experiment using differential growth. Using chemical perturbations, other research in our lab investigates if the differential growth patterns suggested by the model do indeed occur in the developing embryo.

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References: [1] Hamburger, V & Hamilton, H L, *J. Morph*, 1951, 88: 231-272