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Testing the role of bivalve shell shape as defensive adaptation against crushing predation with Finite Element Analysis

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Bivalve shells have been hypothesized to aid organisms to better withstand the attack of a durophagous predator and some morphological aspects of the valves have been tested experimentally for their contribution to the structural stability of bivalve shells. However, due to limitations of experimental set-ups, data on the function of shell shape under crushing predation remains scarce. We use the Finite Element Analysis (FEA) to examine if different shell shapes act as as defensive adaptation against crushing predation.

Our models are based on feeding experiments and measurements of the stone crab Menippe mercenaria and three bivalve taxa, the hard clam Mercenaria mercenaria, the soft clam Mya arenaria, and the blue mussel Mytilus edulis. We analyze over 25 models varying sizes and shell thicknesses and examining stress distribution patterns across the shells.

Our models show that the hard clam models have the lowest stress accumulation distributing stresses evenly across the shell. While hard and soft clam shapes accumulate most of the stress in the contact areas between crab claw and shell surface, blue mussel shells distribute the stress peaks alternating from the inside to the outside of the shells. Scaling the shapes to explore the impact of shell size shows that soft clams experiences the most dramatic decrease in stress maxima when the shells are larger. Examining the performance of shell shapes varying the thickness of the shells shows that blue mussels accumulate the least stresses when the shells are thin, but hard clams start to outperform blue mussel shapes when shell thickness reaches 0.5 mm.

Nanoindentation tests of the three species' shell materials indicate a relationship between their properties and the performance of their shapes under crushing pressure. The hard clam develops a heavy, brittle shell with a high Young's modulus making it stiff and well suited to withstand loads evenly distributed across the valve. The soft clam is 0.6 times thinner than the hard clam with a lower Young's modulus, responding to the localized load peaks with deformation rather than dispersion. Blue mussel valves are only a quarter the thickness of the hard clam. The alternating stress distribution pattern exhibited by these shell shapes combined with the low Young's modulus of its material facilitates the valves ability to respond to pressure with high degree of ductile deformation.

In sum, we find that the material properties of the shells correspond with the results of our FEA models. The characteristics of the material complement the shapes response to crushing predation and this seems to indicate that the shell shapes can be interpreted as a defensive adaptation.