Modeling the pelvic suctorial region of *Eumicrotremus orbis*

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Zoo-bot Apprenticeship 2011
Spring 2011

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Abstract

The rocky intertidal zone is a stressful environment inhabited by many organisms with specialized adaptations. One adaptation seen in several families of fish is to use a pelvic suctorial organ to attach to the substrate. This suction mechanism has been detailed in numerous fishes, but there is yet work to be done with how these structures are organized internally. My goal was to produce a three-dimensional model that could readily interact current knowledge of sucker disk morphology, development, and function. I used the software Amira to generate a 3-D model of the elements comprising the suctorial region of *Eumicrotremus orbis.* This model is easily manipulated and can be reproduced and studied to determine the function of each element. Comparisons with models of different stages of this species as well as models of other species will help us begin answering the question of how such an adaptation originated.

Keywords: Sucker fish*,* 3-d model, PSO, sucker disk, Cyclopteridae, intertidal zone adaptations

Introduction

The high wave energy of the rocky intertidal zone of marine habitats proves to be an important factor in determining what organisms may inhabit these regions. There are many different groups of organisms that have adapted to deal with this energetic habitat. Interestingly, certain families of fish have developed specialized bony pelvic regions that allow them to adhere to rock and other substrates, via suction, adhesives, surface tension, or physically latching to surfaces (Gibson 1969). Usage of a derived region of pelvic muscles and bones for substrate attachment is seen in gobies (Gobiidae), snailfishes (Liparidae), clingfishes (Gobiesocidae), and lumpsuckers (Cyclopteridae) (Green and

Barber 1988, Budney and Hall 2010). These four groups have adapted their pelvic region, including bones, muscles, skin, nervous system, soft rays, and more, resulting in a region used for suctioning onto surfaces termed the pelvic suctorial organ (Budney and Hall 2010).

Liparidae and Cyclopteridae have an unusual asymmetry of the widths of the two halves of soft ray tissue composing the suction cups (Budney and Hall 2010). This is curious as asymmetry is uncommon in ray pairs in fish, and the question arises as to what unique developmental and evolutionary pathways led to these pelvic sectorial organs. Gibson (1969) determined pelvic suctorial organs are useful primarily in the fast moving waters of the littoral zone, closer to shore, rather than in deeper waters. Liparidae and Cyclopteridae both live in the relatively calm deep sub littoral zone while the species *Cyclopterus lumpus* of Cyclopteridae swim closer to shore to reproduce. The young remaining in the higher wave zones with the father for several months to develop before returning to deeper waters (Gibson 1969). Gibson (1969) tested the breaking forces for removing the two types of suckerfish, *Liparis liparis,* an entirely subtidal, soft sediment dwelling snailfish, and *C. lumpus* and found *C. lumpus* to be stronger, in accordance with its reproductive habitat. Davenport and Thorsteinsson (1990) found that adult males of *Cyclopterus lumpus* have larger suckers than females of equal weight, indicating the importance of the size of the sucker for surviving inshore environments.

The mechanics and physics of such pelvic suctorial organs have been well studied (Green and Barber 1987, Davenport and Thorsteinsson 1990, Budney and Hall 2010), however the developmental and evolutionary origins of the differentiation of pelvic suctorial organs and the required neurology, bone structures or ray shape that craft it are still topics for further research (Budney and Hall 2010). My project was to make a three-dimensional model of the pelvic suctorial organ of a local species *Eumicrotremus orbis,* a member of the Cyclopteridae that possesses a characteristic pelvic suctorial organ. A mature *E. orbis* is about 4 centimeters long and has a pelvic suctorial organ that is about a third of its length. They can be found inshore attached to rocks that are exposed during periods of low tides, or at greater depths down to around 200 meters (Gibson 1969). An individual from this species has been CT scanned. I used imaging software to analyze CT images of *E. orbis,* resulting in a 3-D model reconstruction of the pelvic suctorial disc, which will provide a useful tool for understanding the morphology and development of this species.

Methods

For this project, I used a compilation of CT images of cross sections that had a resolution of 35µm of a specimen of *E. orbis,* taken by Thomas Kleinteich at the Seattle Research Institute. I used a specialized 3-D CT reconstructing program called Amira 5.2.2 (Visage Imaging, Inc.). I used the volume rendering function of this software to automatically generate a three-dimensional model of the entire internal and external anatomy of the fish. Next, I segmented (i.e. assigned materials to the different data-points – voxels- in the dataset) the sucker disk related parts of the fish one element at a time. This entailed looking at the cross sections of the fish head on and tracing the edges of the material until they ended. This process resulted in separated elements that can be visualized independently from the remainder dataset. The rendered elements entailed some ‘noise’, where faint tissues or other unidentified materials are grouped with the desired element because they are so close or the boundary of the desired material is hard to decipher. I can return to the volume rendering option and select to view only a completed element or set of completed elements in three dimensions. Once I rendered volumetrically all related elements, I used a feature of Amira to generate surfaces to the structures I segmented. I altered these surfaces to obtain a desired "smooth" appearance to prevent 'noise' from becoming part of the final product. I used ZPrint 7.10.3-7 (Z Corporation) software to organize each surfaced element to be sent to the rapid prototyper (ZPrinter 310). The rapid prototyper was able to print these structures in three dimensions by applying a binding solution to an extremely thin layer (0.085mm) of extremely fine powder, covering this with another layer of powder, applying binding solution, and continuing until it finishes printing from the bottom up, in accordance with what I had sent it from ZPrint. After printing, I depowdered each modeled element and infiltrated them with Cyanoacrylate to strengthen the piece. I used the volume-rendering tool to focus on elements I was gluing together and built the model following the computer-generated model.

Results

I segmented each bone, muscle, ligament, and tendon that was related to the sectorial region of *E orbis.* The computer-generated version is color-coded to reflect the different materials (Figures 1&2). I printed the model at 20 times life-size. There were 58 separate elements in the pelvic sectorial region (Figures 1&2). Each half contained 28 materials (2 muscles were in the center between them), 8 were bones, 1 was a tendon, and the remaining 16 were muscles.

Discussion

Previous studies have quantitatively shown how effective the pelvic sucker disk is at attaching to a surface (Davenport and Thorsteinsson 1990, Schoenfuss and Blob 2003) and the osteology and morphology of the pelvic suctorial organ (Budney and Hall 2010). Budney and Hall (2010) provide a detailed description of the suctorial organ of two other fish in the family Cyclopteridae, *Eumicrotremus spinosus* and *Cyclopterus lumpus*. However, the ability to look at a model and interact with it – removing and adding muscles or bones to see a structure better, looking at every angle of how muscles and bones connect, seeing where elements begin and end, etc. – can be much more useful.

With the computer-generated model, it is now easier to observe the structures related to the sucker disk and understand its composition. Future experiments might want to replicate this process with varying sizes and each gender of *E. orbis* to observe any differences that might exist in sucker morphology and development. Now that I have created a model, we can start asking questions about the functions of each element the pelvic sucker disk comprises. The model can be duplicated and then various elements removed to test the suction effectiveness, thus quantifying the necessity and function of various parts. These manipulations can lead to an understanding of what internal manipulation of muscles and bones occur to allow effective suction to various substrates among different species. Understanding the suctorial mechanisms may help uncover how this organ developed evolutionarily, and ultimately help us understand how some organisms have adapted to the rough intertidal zone.

Acknowledgments

I express my gratitude for the Mary Gates Foundation for helping fund my research. I am grateful for the mentorship and support of Thomas Kleinteich who made this project possible. I also thank the invaluable input of Megan Dethier, Hilary Hayford, Robin Wright, and Mary Krauser.

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Figures

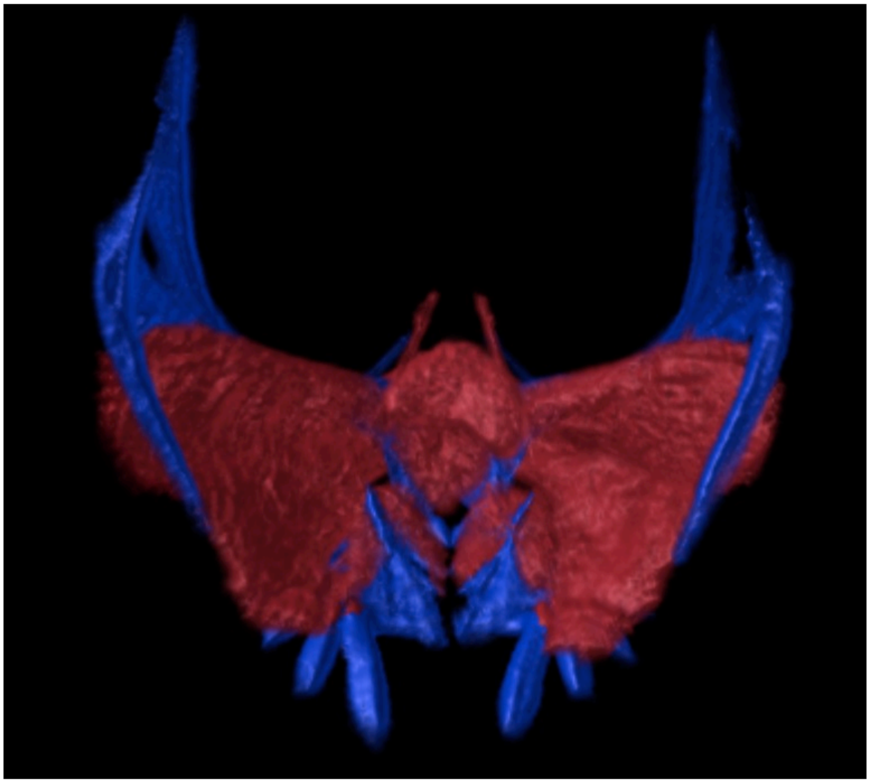

Figure 1. The anterior view of the 3-D computer generated model of structures related to the pelvic sucker disk. Red denotes muscle and blue denotes bone.

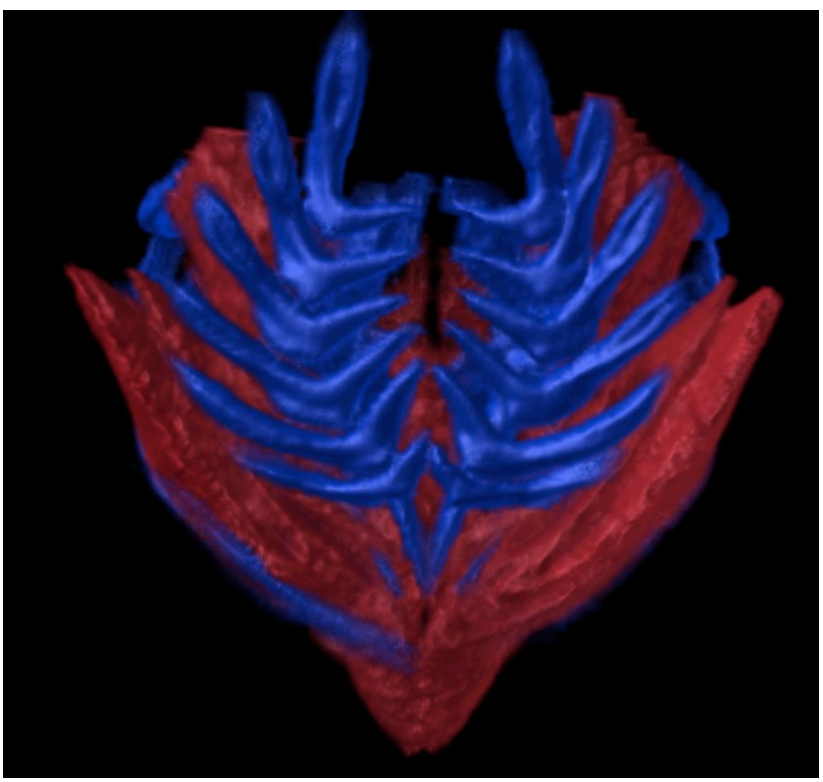

Figure 2. The ventral view of the 3-D computer rendered model of the sucker disk. Red denotes muscle and blue denotes bone.