Reverse Bio-Engineering: Structural and Mechanical Modeling of Tadpole Teeth through FIB NanoTomography and Finite Element Analysis

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Engineering lessons from nature abound, but unfortunately the objects from nature do not come with their own CAD files to allow us to interrogate and analyze their structure easily. In order to effectively model these naturally engineered marvels we must capture their form across various scales. Means to accomplish this task will vary according to the requirements of size and resolution. Investigations of biological structures benefit from a hierarchical approach to probe from the millimeter range down to fine ultra-structure on the nanometer scale. Tools suitable for this approach include the recent innovations of micro-CT within an SEM in combination with FIB-SEM nanotomography.

This work will describe our efforts to characterize keratinized tadpole teeth through a combination of micro-CT, FIB-SEM nanotomography, finite element modeling and stereolithographic printing. Tadpole teeth are shovel-shaped structures typically ABOUT 35 um across at the base and 50 um tall (FIG 1). The Micro-CT performed within the SEM chamber allows initial non-destructive capture of the overall form of the structure. The FIB-SEM nanotomography is a destructive process that can provide detail on the scale of a few nanometers. The data from these techniques can be combined to form a hybrid tomographic three-dimensional reconstruction model of the tadpole tooth architecture. Using these quantitative data, we can construct a finite element model to more accurately probe the mechanical properties of the structure. Finally, these tomographic data may be used to generate a macroscopic three-dimensional solid model of the tadpole tooth with a stereolithographic printer. The macroscopic model serves as a visual and educational aide and can be used to test removal capabilities against an artificial substrate. In the future, this methodology should become a more common means to reverse engineer the secrets from biological architecture. Tadpole teeth, constructed of reasonably hard keratin but fastened in a flexible tissue, could be a good model for the design of certain microtools or abrasive surfaces.

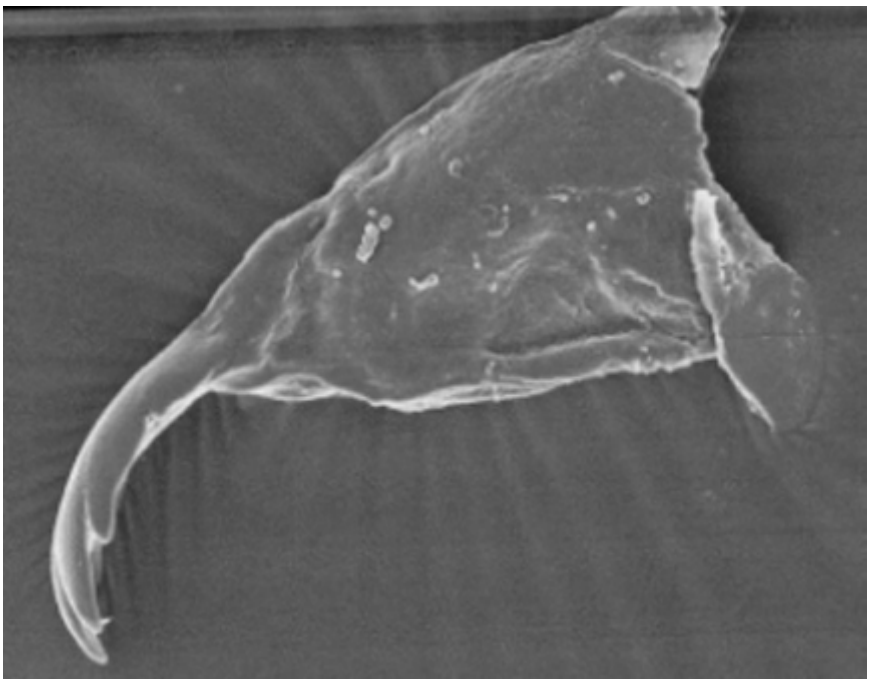

Fig 1. A tadpole tooth lying on its side on top of a carbon support film.