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Platynereis dumerilii chaetae: mechanical loading estimation from kinematics in larva stage

Luis ZELAYA-LAINEZ[1], Giuseppe BALDUZZI[1], Kyojiro N. IKEDA[2], Florian RAIBLE[3], Christian HELLMICH[1]
[1]Institute for Mechanics of Materials and Structures - Vienna University of Technology
[2]Department of Microbiology, Immunobiology and Genetics - University of Vienna, [3]Max F. Perutz Laboratories - Vienna Biocenter

Motivation

Chaetae (B) are well tailored extracellular structures typical of *Polychaeta* (marine bristle worms) [1]

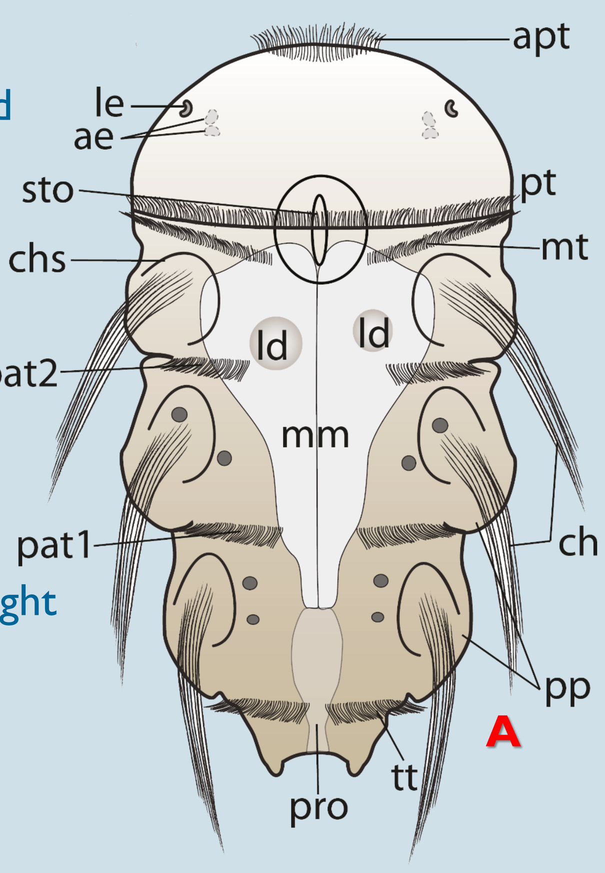
- Complex geometries & internal structure (highly-optimized structures)
- Made by basal apposition of material (reminiscence of 3D printing) (C, picture from [3])
- Unclear function e.g., in *Platynereis dumerilii* larvae (A, picture from [2]) propulsion is given by ciliary bands (apt, pt), however chaetae are also present (ch)
- Critical length scale, standard experimental techniques and models may not be effective

Bio3DPrint project aims

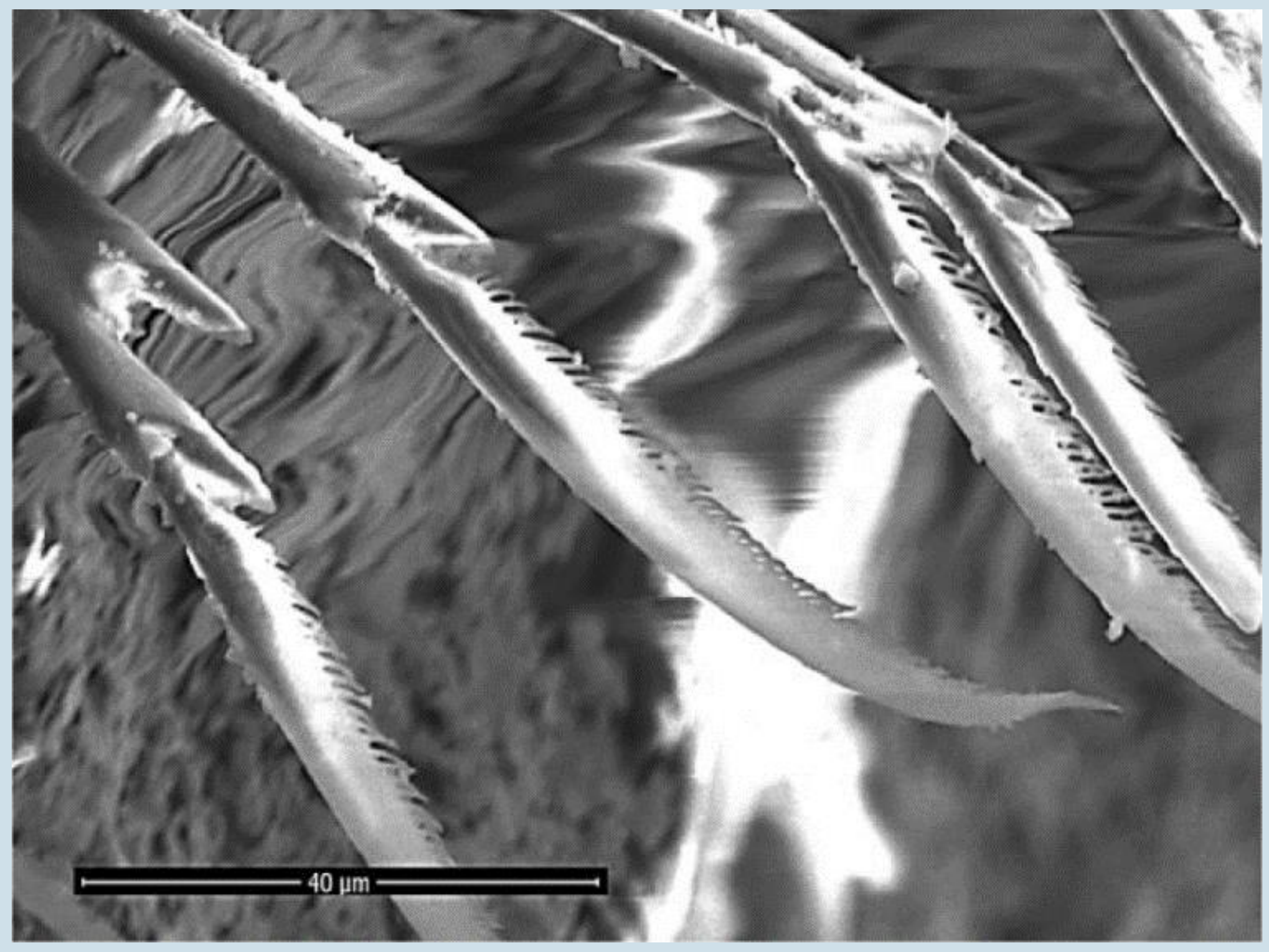
- Deciphering the 3D printing process.
- Understand bio-mechanical function of chaetae.

Project tasks:

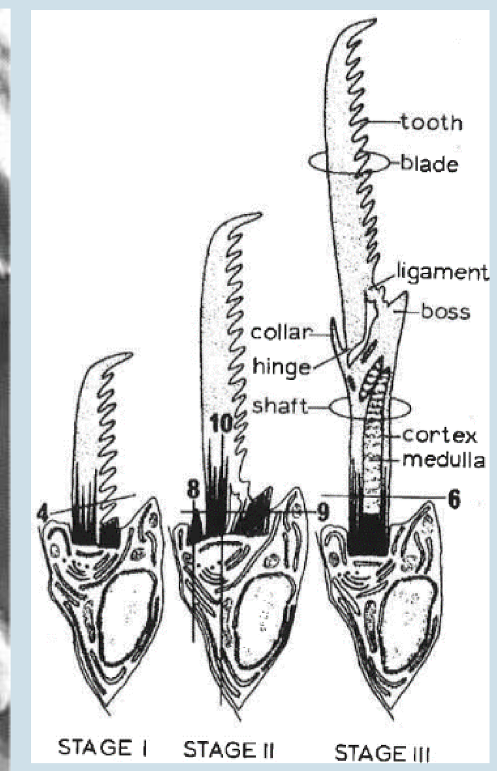
- Internal structure and external geometry ↔ imaging (light microscopy, scanning electron microscopy, synchrotron computed tomography)
- Material (ß-chitin) characterization ↔ pico-indentation
- Function and load ↔ kinematic analysis



A



B



C

Material and Experimental Methods

Chaetae function and larvae behavior

Qualitative analysis of swimming larvae have highlighted two different swimming strategies: (i) slow crawling-like movements, when larvae swim using chaetae and (ii) fast torpedo-like movements, when larvae swim using cilia. In particular, during torpedo-like swimming, chaetae are tightly attached to the animals bodies (A), while larvae stretch chaetae apart from the body for effective deceleration and swerve actions (B, C).


A B C

Data acquisition & elaboration

Swimming *Platynereis dumerilii* early nectochaete (i.e., the development stage of larvae at 72 hours post fertilization) were filmed. Images were recorded with a frequency of 5 frames per second ($\Delta t = 0.2$ sec) with a 5x magnification and a resolution of 1920 x 1080 pixels.
The positions $\boldsymbol{p}_i = (x_i, y_i)$ of the early nectochaete at time t_i (for $i = 1 \ldots Nf$, being Nf the total number of frames) have been recorded using a semi-automatic tracking procedure.
The instantaneous velocity $\boldsymbol{v}_i$ and acceleration $\boldsymbol{a}_i$ are estimated using finite difference formulas of second order of accuracy.

$$\boldsymbol{v}_i = \frac{1}{2\Delta t}(\boldsymbol{p}_{i+1} - \boldsymbol{p}_{i-1})$$

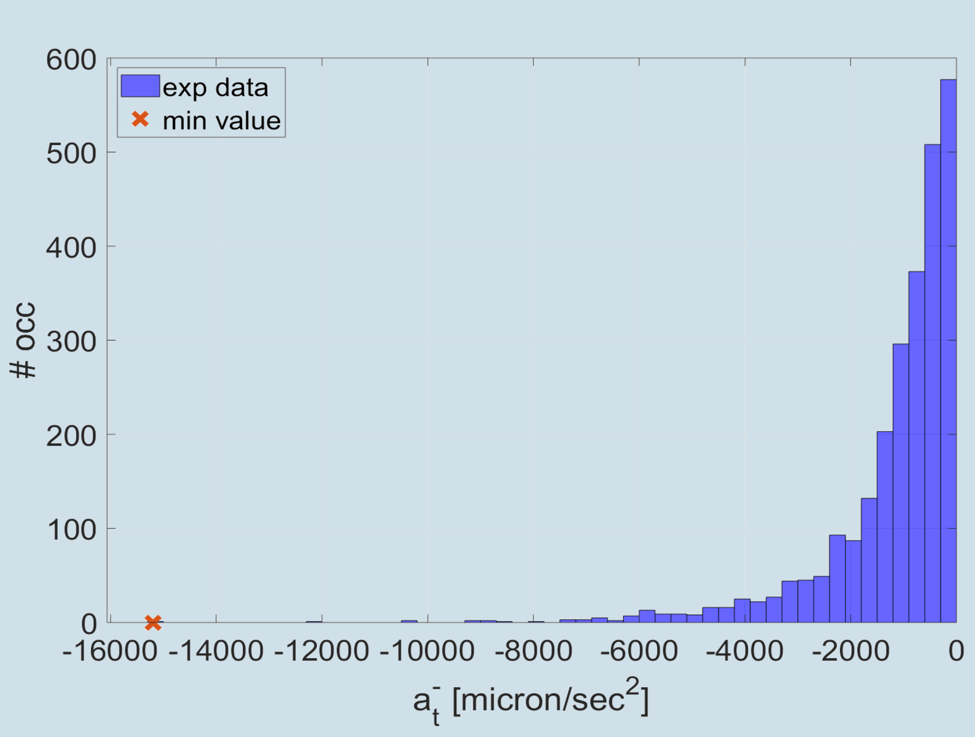
$$\boldsymbol{a}_i = \frac{1}{\Delta t^2}(\boldsymbol{p}_{i+1} - 2\boldsymbol{p}_i + \boldsymbol{p}_{i-1})$$

The unit vector tangent to the trajectory is evaluated as $\boldsymbol{t}_i = \boldsymbol{v}_i / |\boldsymbol{v}_i|$ and the tangential component of the acceleration was computed as $\boldsymbol{a}_{t\,i} = \boldsymbol{a}_i \cdot \boldsymbol{t}_i$.

Results & Discussion

Accelerations

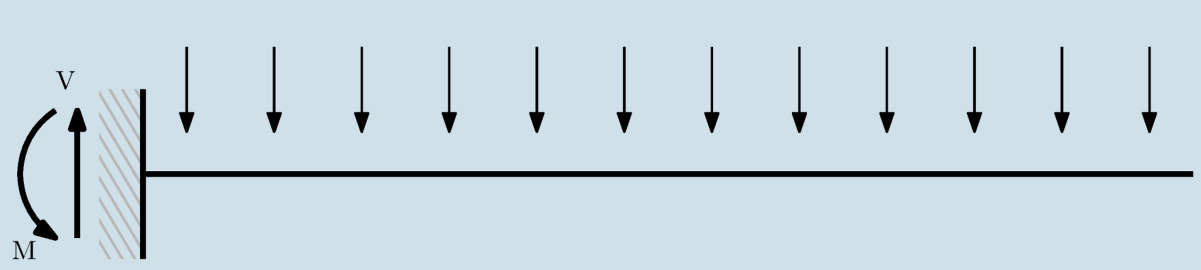
Globally, 5220 velocities and accelerations have been recorded and analyzed. Since we are interested in the deceleration mechanism, we limited the statistical analysis to negative tangential accelerations $a^-_{t\,i}$.



Maximal recorded deceleration resulted equal to 15 191 µm/sec^2.

Maximal stress

The body of the lava has been approximated as a spheroid with diameter d_l = 150 µm and length l_l = 280 µm.
The average density of larvae body has been experimentally determined, resulting in ρ=1.04 g/cm3.
The average larva mass (m = 3.44 µg) and the maximal inertial force (F_{max} = 52.22 pN) have been calculated.
It has been assumed that inertial forces are uniformly distributed among two chaetae bundles (24 chaetae).
The chaeta has been modeled as a cantilever with a uniformly distributed load (length l_c = 102 µm and circular cross-section diameter d_c = 1.4µm have been measured),



The maximal bending moment is equal to 111.3 aNm and the associated maximal axial stress is 446 Pa.
The obtained the maximal stresses looks small in comparison with the strength of chitin (ranging from 0.4 to 400 MPa, according to data available in literature [4]), however detailed information concerning chaetae internal structure and real material strength is not still available.

Discussion

The proposed methodology has allowed to analyze fundamental kinematic quantities associated to the swimming of *Platinereis dumerilii* early nechtochaetae. The adopted analysis has the capability to provide accurate and quantitative information on empirically observed phenomena, allowing for a simple preliminary analysis of the magnitude of loads acting on chaetae.
Future research will include the extension of the proposed analysis to other development stages of *Platinereis dumerilii* and more realistic life conditions, aiming at identifying conditions inducing highest stresses.

Acknowledgements

This work was supported by grant Bio3DPrint from the Austrian Academy of Sciences (OeAW).

References:
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36th DANUBIA-ADRIA SYMPOSIUM on Advances in Experimental Mechanics, September 24–27, 2019, Pilsen, Czech Republic