Exploring the Untapped Potential of CT Scanning in the Quantitative Analysis of Brachiopod Long Loops

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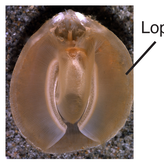
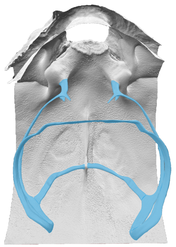
What are brachiopods?

Brachiopods are a group of marine invertebrates that superficially resemble bivalve molluscs. Despite both groups having shells formed by two valves, brachiopods are lophophorates—i.e they possess a feeding and respiratory organ called the *lophophore*—and are more closely related to phoronids and bryozoans. In terebratulide brachiopods (Order Terebratulida), the lophophore is supported by a calcareous structure known as the ***loop*** (or brachidium), which is an important character in taxonomy and phylogenetic studies.

Laqueus erythraeus



Lophophore



Internal view of dorsal valve showing the loop (*Tereberatalia transversa*).

Introduction

Brachiopods are one of the most diverse and abundant marine invertebrates in the fossil record, with over 5000 fossil genera recognized and approximately 400 extant species described. However, the taxonomic validity of named species has rarely been tested in a quantitative manner. The aim of this study is to quantify the variation of one of the most conspicuous and geometrically complex morphological features in terebratulide brachiopods—the loop—in order to test the morphological validity of living named species. Quantifying ranges of morphological variation in living brachiopod species is fundamental for the study of fossil brachiopod diversity, particularly given the common assumption in paleontology that morphology alone defines species as evolutionary biological entities. This study represents an effort to work at the species level in neontology with clear implications for paleontology—where the trend has often been to treat genera as proxies for species. Moreover, given the geometrically complex shape of loops, we generated 3D isosurface models from CT scans and analyzed them using 3D geometric morphometric methods, demonstrating that the use of CT scanning technology goes beyond purely descriptive purposes.

Methods

To analyze long loop variability in brachiopods, we chose *Laqueus*, *Terebratalia*, and *Dallinella* as exemplar genera. Of these three genera, we focused on the following species: *Laqueus erythraeus*, *L. vancouveriensis*, *L. rubellus*, *L. blanfordi*, *L. quadratus*, *Terebratalia transversa*, *T. coreanica*, and *Dallinella occidentalis.*

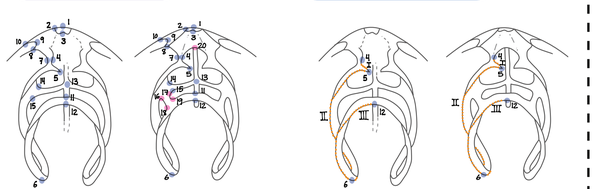
Laqueus vancouveriensis | *Laqueus erythraeus* | *Laqueus rubellus* | *Terebratalia transversa* | *Dallinella occidentalis*

3D isosurface models	- From CT scans - Amira
Landmark and semilandmark registration	- Based on proposed landmark schemes - Stratovan Checkpoint
Landmark superimposition	- Generalized Procrustes Analysis - Semilandmark sliding using bending energy
Ordination methods	- Principal Component Analysis - Canonical Variate Analysis and between-group PCAs
Statistical methods	- Procrustes ANOVA

Landmark schemes and 3D isosurface models

Landmarks

Semilandmarks



Bilateral loop *Laqueus* | Trabecular loop *Terebratalia* and *Dallinella* | Bilateral loop *Laqueus* | Trabecular loop *Terebratalia* and *Dallinella*

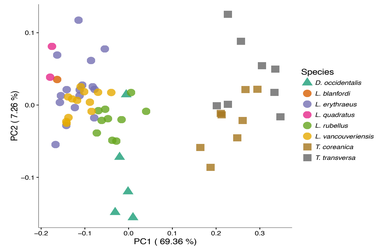
3D models

Laqueus blanfordi | *Terebratalia transversa* | *Dallinella occidentalis*

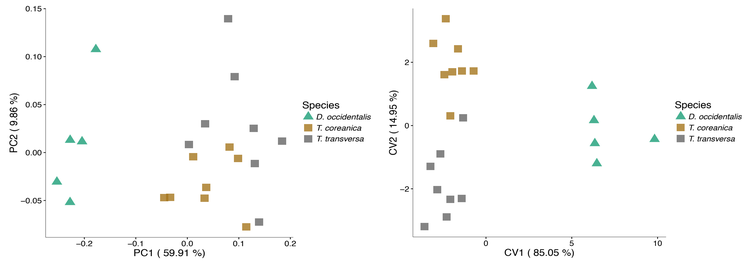
Results

General pattern of variability

Each genus forms a distinct cluster in shape space.
Laqueus and *Terebratalia* separate along PC1, forming two distinct clusters. There is some overlap between *Laqueus* and *Dallinella*. However, these two genera do not share the same loop type.

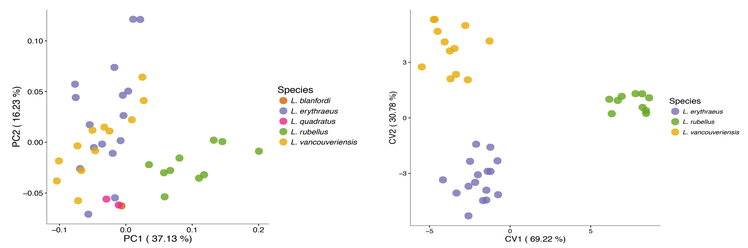


Terebratalia + Dallinella



Overall classification accuracy: 85.71%
Size does not have a statistically significant impact on shape (p=0.15).
Species are statistically different in shape (p=0.001).

Laqueus



Overall classification accuracy: 100%
Size does have a statistically significant impact on shape (p=0.001).
Species are statistically different in shape (p=0.001).

Conclusions

Is it possible to discriminate species based on loop morphology?

- Yes, each species has a statistically distinct loop.
  - Although species of Terebratalia seem to be harder to tell apart, possibly due to its highly variable loops.
- Each species cluster together in shape space.
- Given our results, the traditional approach of identifying brachiopod species using internal and external morphological character seems to be validated.

CT technology plays an important role in understanding geometrically complex morphological structures like loops.

What's next?

Loops are rarely preserved in the fossil record, how can we apply these results to fossil specimens? CT scanning of fossils? **YES**.

Is there correspondence between loop shape and shell shape?
- Outline analyses of Recent specimens + loops
- Outline analyses of fossil (Cenozoic) specimens.

Funding

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