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The quantitative analysis method of three dimensional morphometry by segmentation of planktonic foraminifera chambers.

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Most of existing morphometric methods of planktonic foraminifera (e.g. Lohmann, 1983; Malmgren et al., 1984; Hull and Noris, 2009; Scott *et al.*, 2007) are based on 2-D specific sideviewing pictures of shells that are distorted from 3-D shape and affected by researcher's arbitrariness. In addition, various shell ontogeny 3-D models (e.g. Berger, 1969; Tyszka and Topa, 2005) suggest that shell morphology of planktonic foraminifera can be described by 3-D parameters of chamber's shape, size, and angle of connection. While size and angle of connection of chamber were dealt with by Kennett (1966) and Wei and Kennett (1988), 3-D shape of chamber was not analyzed.

Whereas, the recent computer evolution enable us to analyze biomorphology of three dimensional (3-D) shapes. 3-D specimens scanned with X-ray computed tomography (X-ray CT) have been generally available for 3-D morphometric methods. For example, Hodges and Garland (2003) visualized horned lizards 3-D skull, and Wiley *et al.* (2005) traced primate skull evolution with 3-D images. Therefore, various analytical procedures were proposed by the parametrization of closed surfaces for 3-D shape description (Brechtbuhler, 1995), the spherical mapping (Shen and Makedon, 2006), Eigensurface analysis (Polly and Macleod, 2008), and others. Speijer *et al.* (2008) applied 3-D morphological analysis to planktonic foraminifera research.

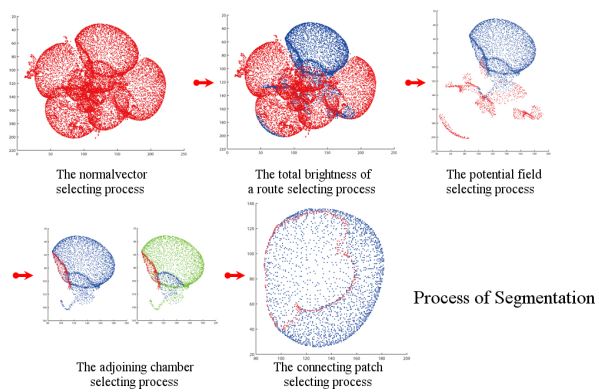
We present a new method of individual chamber segmentation procedure, quantitative analysis of chamber's 3-D parameter, and comparison of each chambers.

We applied chamber segmentation procedure to *Neogloboquadrina himiensis* and *Neogloboquadrina dutertrei* that have enough size to be scanned with our X-ray CT machine, because *Neogloboquadrina*'s chamber that has diversity of form and doesn't have particular peculiarity is competent for a sample of our method and the chamber's shape were represented by inner wall not to be affected by secondary calcification that is different from outer wall.

All processes of segmentation and analysis were carried out on numerical analysis software MATLAB (Mathworks, Inc), and shell tomographical images were converted into patch objects which surfaces are represented by an aggregate of microtriangle (patch). Each patch have eigennormalvectors that define inside and outside.

Our chamber segmentation procedure is composed of five phases that are the normalvector selecting process, the total brightness of a route selecting process, the potential field selecting process, the adjoining chamber selecting process, and the connecting patch selecting process. The normalvector selecting process chooses patches that each eigennormalvector are headed for a marker-point within selecting chamber. The total brightness of a route selecting process chooses patches that each total brightnesses between a marker-point within selecting chamber and each vertex of patches are over optional threshold. The potential field selecting process chooses patches which each vector field involve a inner wall of selecting chamber. The adjoining chamber selecting process removes outer wall's patches of adjoining chamber. Each normalvector of outer wall's patches are turned around a marker-point within adjoining chamber. The connecting patch selecting process removes patches which are satisfied with above-mentioned processes whereas don't belong to inner wall of selecting chamber.

Analysis and comparison of chamber is carried out by morphometric map that 3-D chamber specimen data is described. Morphometric map is made from a standardized griddata by the center of gravity and chamber's aperture position, and null fields of chamber's data are masked. This method enabled us to analysis the chamber shape without scale difference. In addition, output hypsographic or clinometric map is useful for morphologic comparison of chamber. These methods for polar region become warped, so we attempt to develop a new method of comparison.



Keywords: planktonic foraminifera, morphometric analysis, quantitative analysis, 3-D specimen, X-ray CT