Computational fluid dynamics of sponge aquiferous systems

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Background

The aquiferous system of sponges is one of their main anatomical features by structural as well as functional means. As sessile filter feeding organisms all physiological processes in sponges rely on their ability to pump high volumes of water through their body in order to retrieve the required nutrients and oxygen. Until the discovery of bypass elements (Bavestrello et al. 1988) in the complex 3D network of incurrent and excurrent canals the sponge aquiferous system has been understood as a unidirectional fluid transport system powered by the high number of choanocyte chambers (flow generating units) distributed within the entire mesohyl. So far the biological function of bypass elements and their impact on flow in sponges is not understood. This is mainly due to the fact that quantitative data on the 3D morphology of the canal system and bypass elements therein are not available for most sponge canal systems. Besides those bypass elements our earlier studies on the canal system in sponges already revealed a higher complexity of canal system architectures than previously assumed [1]. With respect to both findings the standard model of flow [2] requires a refinement. However, so far it was not possible to resolve information on all relevant structures needed for CFD modeling with the available tomography setups at DESY. With the newly available imaging Beamline P05 @ Petra III we aim at overcoming these limitations to obtain the required sub-micrometer resolution.

Methodology

We imaged critical point dried specimens of the marine demosponge *Tethya wilhelma* and the freshwater sponge *Spongilla lacustris* fixed in a solution of 2.5 % glutaraldehyde and contrasted in 1% OsO_4 to extract virtual corrosion casts *in silico* from the microtomography data sets [1,3]. Microtomography was operated by HZG using the beamline P05 at the storage ring PETRA III at DESY. Canal system models were generated from high resolution 3D reconstructions using a workflow including ImageJ/Fiji, VG StudioMax, MeVisLab and AMIRA [modified from 1]. Computational fluid dynamic simulations were performed using Comsol Multiphysics 4.3a and ANSYS FLUENT 14.5. The geometric model of the canal system for CFD simulations was developed based on a virtual canal system cast using Autodesk MAYA and Robert McNeel Rhino. Grid generation was done using ANSYS ICEM CFD.

Results and discussion

The new imaging beamline P05 at the storage ring PETRA III @ DESY enabled us to obtain high density and spatial resolution 3D image data sets of our sponge species studied. Based on the microtomography image stacks, we have extracted virtual corrosion casts of *Tethya wilhelma* and *Spongilla lacustris* canal systems. The aquiferous system models have been used to set up computational fluid dynamic simulations using a custom developed workflow for image based grid generation. Therefore the studied canal system models are as close as possible to the actual biological study. In order to reduce the complexity and computation time we have introduced some slight simplifications. On the basis of the computational fluid dynamic models we are able to study the prevailing flow conditions in the respective canal systems. A preliminary qualitative analysis of the flow conditions in bypass elements of *T. wilhelma* revealed no recirculation caused by the presence of the anastomoses forming bypass elements. An analysis evaluating the possibility whether bypass elements play a role in the use of passive flows induced by environmental flows in *T. wilhelma* is currently tested in our simulation model.

In summery with our previous experiments the information gathered on canal system functional morphology, internal fluid dynamics, the relation of canal system architecture to hydrodynamics and in future studies nutrient distribution will not only increase our knowledge about the sponge canal system, it might even more provide important aspects in the context of understanding physiological processes in sponges in general. This will help to improve cultivation techniques which is of great interest for evolutionary research in general (i.e. the field of evo-devo) as well as for marine biotechnology.

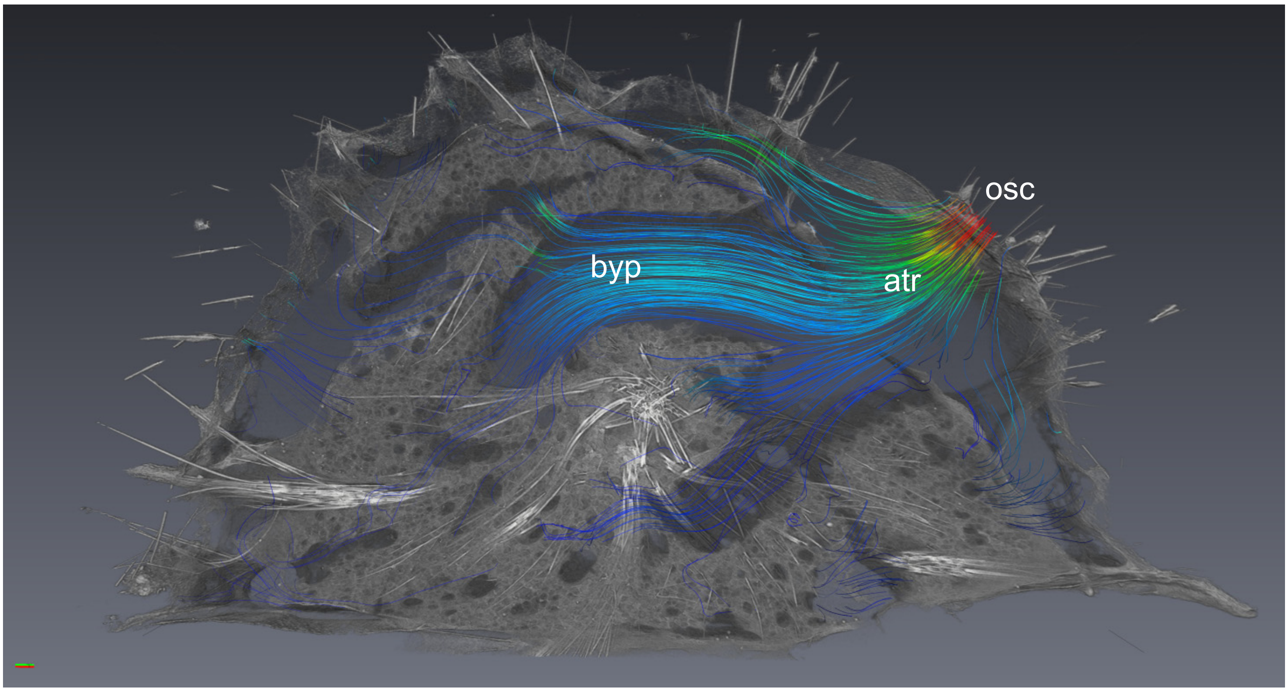

Fig. 1. Combined visualization of a SRµCT volume data and a stream line plot from CFD simulation results. For the ease of understanding only a subvolume of the microtomography data set is shown by the use of two parallel clipping planes. The volume displays the area near the osculum (osc) including part of the atrium region (atr), parts of a bypass element (byp) as well as other canals of the incurrent and excurrent canal system, soft tissue and skeletal elements (bright white). Streamlines from the CFD simulation experiment are color coded for velocity magnitude ranging from blue to red (slow to fast). In accordance to visualization of image data we applied two prallel clipping planes to the streamline plot as well.

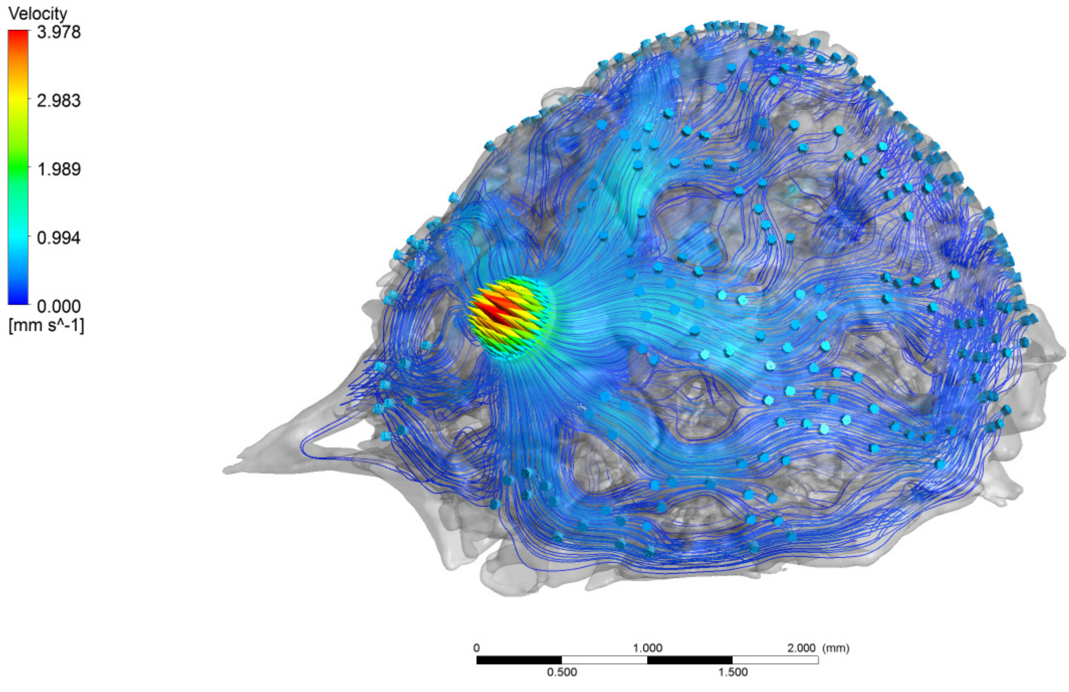

Fig. 2. Streamline plot of a fluid dynamic simulation in the canal system of *Tethya wilhelma*. The geometry model of the canal system for CFD simulation is based on a high resolution SRµCT data set.

References

1. Hammel JU et al. (2012) Acta Zoologica 93: 160-170.
2. Reiswig HM (1975) Journal of Morphology 145: 493-502.
3. Nickel M et al. (2008) Proceedings of SPIE 7078: 7078W.