



Uncovered

Sponge-derived silica for tissue regeneration

Bioceramics of deep-sea sponge

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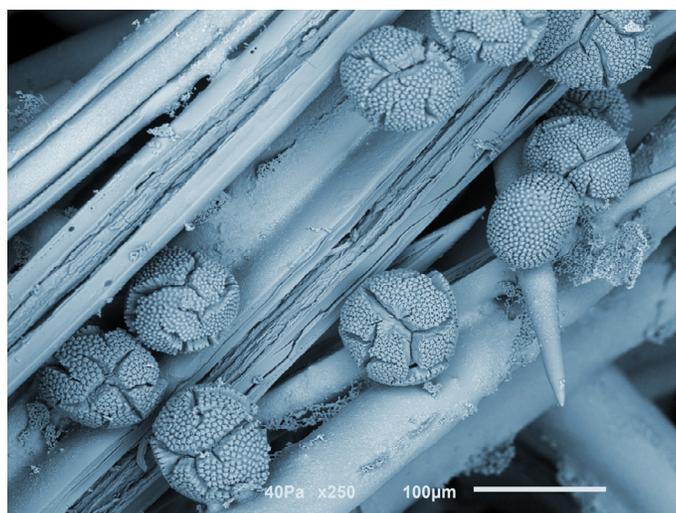
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Sponges (Phylum Porifera) are highly diverse and important members of many benthic communities in all oceans. In some areas, sponges add structure and habitat complexity, forming sponge-dominated communities known as sponge grounds, aggregations, gardens, and reefs along continental shelves, on seamounts, and on mid-ocean ridges, and also in the deepest ocean basins. In addition to habitat provision, sponges are also important players in the circulation and recycling of nutrients and elements in the ocean, including carbon, nitrogen, and silica [1].

A distinguishing feature of this taxonomic group is the production of inorganic skeletal elements composed of either



amorphous, hydrated silica (siliceous spicules) or calcium carbonate (calcareous spicules), which are then disposed to form more or less elaborate skeletal systems. Three of the four extant classes of sponges, which represent over 90% of the species, produce siliceous spicules that differ in the number of symmetry axes. While species within Demospongiae have either monaxonic or tetraxonic spicules, those in Homoscleromorpha have only tetraxonic spicules and derivatives resulting from the reduction in or ramification of the actines. Species within Hexactinellida have spicules with triaxonic (hexaradiate) symmetry or derivatives resulting from the loss of one or more rays [2]. The silica content of these sponges can amount to 75% or more of the dry mass of the animals [3].

Sponge spicules contain a central axial filament that spatially directs the deposition of silica along its entire length. These proteinaceous filaments are predominantly composed of three highly similar subunits called silicateins (silicatein α , β and γ), enzymatic biocatalysts of biosilica formation [4].

Mimicking sponge-derived silica has been a driving force for the production of novel biomaterials for biomedical context, particularly, bone replacement and regeneration strategies [5]. This is a huge arena, with healthcare being highly deficient of adequate therapies to overcome the loss of bone tissue caused by

trauma or disease. In this regard, nearly 60% of the available synthetic bone graft substitutes involve ceramic materials (as calcium phosphates or silica), either on their own or in a composite structure, and significant research efforts are being devoted to develop solutions capable to overcome the problems associated with autologous bone grafts [6].

Bioactive silica glasses have been shown to enable bonding and integration with bone tissue through the formation of a silica gel layer, which attracts and stimulates osteoprogenitor cells to proliferate and to differentiate into osteoblasts, starting the synthesis and the deposition of bone organic matrix and matrix mineralization [7]. In particular, mimics of sponge-derived silica have already been considered as potential biomaterials for bone replacement and regeneration [5]. The inclusion of other elements such as strontium and boron is of special interest, because of their important role in bone growth, namely by increasing metabolic activity in osteoblasts and decreasing osteoclast activity. Thus, the development of strontium-incorporated or borosilicate bioactive glasses has been tested for bone tissue regeneration [8], as well as their combination with polymers in composite structures [9].

On the other hand, the fabrication of biomaterials with architectures mimicking the three-dimensional interconnected porosity and hierarchical features of natural bone is a fascinating research. Barros et al. reported *in vitro* studies of ceramic structures isolated from marine sponges, revealing a non-cytotoxic behavior with potential to be used as substitutes of synthetic Bioglass [10].

Despite the increasing interest in the biomineralization mechanisms of this ancient group, the inorganic part of marine sponges' skeletal elements (spicules) and their arrangement has not yet been fully characterized nor is it well understood. In this regard, deep-sea sponges that often present complex, hierarchically arranged and, sometimes, hypersilified skeletons represent a large and yet untapped potential of research and biomimetic inspiration.

This issue's cover image of *Materials Today* is a scanning electron microscopic (SEM) image of the bioceramics of a deep-sea sponge – *Geodia atlantica* [11] – collected in a Norwegian fjord. The bioceramics were obtained from the marine sponge through a calcination process that involved heating in a furnace at 800 °C for 6 h, after washing sponge materials with fresh water to remove the salt and any other contaminants. Micrograph was collected on a JSM-6010 LV microscope (JEOL, Japan). The microscopic observation of the bioceramics allowed distinguish-

ing the different types of spicules present such as sterrasters (microscleres, spherical) and dichotriaenes (megascleres). All spicules were fractured after calcination, as a consequence of removing all organic part from them, evidencing their composite nature.

The main goal of the research being developed is to chemically characterize the biogenic silica found in a wide range of deep-sea ground-forming sponges of the North Atlantic and further assess its bioactive behavior with potential use in tissue engineering and regenerative medicine applications. Particular focus will be given to developing biomaterials capable of influencing cell fate and ultimately to developing silica-based biocomposites, inspired by the natural organization features of deep-sea sponges, capable of promoting bone tissue regeneration.



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Further reading

- [1] M. Maldonado et al., in: S. Rossi, L. Bramanti, A. Gori, C. Orejas (Eds.), *Marine Animal Forests – The Ecology of Benthic Biodiversity Hotspots*, Springer, Switzerland, 2017, pp. 145–183.
- [2] J.N.A. Hooper, R.W.M. Van Soest (Eds.), *Systema porifera: a guide to the classification of Sponges*, Kluwer Academic/Plenum Publishers, NY, USA, 2002. 1–1101, ISBN 0-306-47260-0. xix, 1103–1706 (2 volumes).
- [3] D. Barthel, *Mar. Ecol. Prog. Ser.* 123 (1995) 149–153.
- [4] J.N. Cha et al., *Proc. Natl. Acad. Sci. USA* 96 (1999) 361–365.
- [5] S. Wang et al., *Bone* 67 (2014) 292–304.
- [6] K. Rezwan et al., *Biomaterials* 27 (18) (2006) 3413–3431.
- [7] T. Odatsu et al., *J. Biomed. Mater. Res. A* 103 (2015) 2797–2806.
- [8] J.S. Fernandes et al., *Cryst. Growth Des.* 16 (7) (2016) 3731–3740.
- [9] J.S. Fernandes et al., *Acta Biomater.* 44 (2016) 168–177.
- [10] A.A. Barros et al., *Biomed. Mater.* 11 (4) (2016) 1–11.
- [11] J. Stephens, Fisheries, Ireland Scientific Investigations, 1914(4) (1915) 1–43, pls. I–V.