Marine invertebrates are a source of bioadhesives with biomimetic interest

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INTEREST IN MARINE BIOADHESIVES

- ✓ Bioadhesives are found in several marine invertebrates that developed attachment devices to adhere permanently or temporary to various substrates. These adhesives, generally highly viscous or solid secretions, are of interest to materials science to create bioinspired-adhesives that can perform in water or wet conditions and can be applied in a variety of biotechnological and industrial fields [5].
- ✓ The well characterized marine adhesive from marine mussels (genus *Mytilus*), rich in 3,4-dihydroxyphenylalanine (DOPA), a residue formed by post-translational modification (PTM), is involved in the adsorption of the adhesive proteins to the substrate and in the formation of cross-links between these different proteins [1]. DOPA have been used as bioadhesives for cells, wound sealants and drug carriers [5].
- ✓ The molecular characterization of the adhesives secreted by other marine invertebrates have gained increase interest and the studies performed so far are revealing promising results, as they have distinctive characteristics that those found in the mussel adhesive or, being similar, can fill in the understanding of adhesive processes [2,3,4,6].

MARINE INVERTEBRATES WITH ADHESIVE PROPERTIES

Molluscs

- ✓ Oysters build extensive reef systems by producing a biomineralized adhesive material for bonding to rocks and together.
- ✓ The adhesive from the oyster *Crassostrea virginica* is composed of proteins with analogy to mussel adhesives, but has a high inorganic content [3].
- ✓ These animals gave new insights on the production of new types of organic-inorganic hybrid adhesives with comparable adhesion performance to mussel-inspired DOPA-based adhesives [3].

Polychaetes - Tube-dwelling worms

- ✓ Several polychaetes (e.g. *Phragmatopoma californica*) form reefs by the association of thousands of tubes. Each worm builds the tube by collecting materials and applying a proteinaceous adhesive.
- ✓ The adhesive is composed by repetitive and oppositely charged proteins, phosphorilated serine proteins, DOPA, sulfated polysaccharides and Mg^{2+} and Ca^{2+} ions [5, 6].
- ✓ A coacervate system is involved in the tubeworm adhesion that inspired the development of coacervate-inspired structures [5, 6].

Tunicates

- ✓ Tunicates are sac like sessile animals found attached to a variety of substrates at all ocean depths.
- ✓ The body wall is composed of proteins containing DOPA and 3,4,5-trihydroxyphenylalanine (TOPA) which contribute to underwater adhesion and rapid self-regeneration [7].
- ✓ Tunicate-mimetic adhesives revealed higher adhesion strength then mussel-mimetic adhesives and the role of PG (pyrogallol) moieties in TOPA-containing compounds for the development of functional biomaterials [8].

Crustaceans

- ✓ Barnacles, sessile crustaceans with their body enclosed in mineralized plates, are found attached to substrates by producing an adhesive (cement).
- ✓ The adhesive proteins (e.g. *Megabalanus rosa)* have no PTM indicating a different molecular system of attachment [2].
- ✓ The cement comprises hydrophobic proteins; charged proteins with hydrophilic feature; hydrophilic proteins rich in Ser, Thr, Ala and Gly residues; a hydrophilic protein rich in Cyst residues [2].
- ✓ Low complexity glycine/serine-rich proteins and multiple lysyl oxidases and peroxidases share homology to certain silk motifs and have a role in the construction of barnacle cement nanofibrils [9].

Echinoderms

- ✓ The tube feet of echinoderms produce strong reverse adhesives to adhere to the substrate.
- ✓ The adhesives from the sea star *Asterias rubens* and sea urchin *Paracentrotus lividus* are composed by proteins containing high amounts of charged (especially acidic) and uncharged polar amino acids; large amounts of cyst; phosphorylation and glycosylation were also identified, in accordance with other marine adhesive proteins [3, 10].
- ✓ Adhesives in sea cucumbers are secreted by instantaneous adhesive structures discharged by these animals as a defense mechanism.
- ✓ The identification of a C-type lectinin in the adhesive of *Holothura forskali* raise the hypothesis of involvement of glycoproteins in sea cucumber adhesion as well as the involvement of enzyme-like proteins in structural and/or ligand-binding properties [11].

REMARKS

✓ The composition and properties of adhesive secretions in marine invertebrates appears to be diverse. Is therefore important to study:

- Adhesives from other marine invertebrates (e.g. sponges and sea anemones).
- Adhesives from less known marine environments (e.g. warm or colder water temperatures).
- How organisms control the chemical environment at the interface of adhesion.
- The structure-adhesive function, cohesion and interactions of the adhesive proteins.

References:

[1]Waite JH (2017) J Exp Biol 220, 517-530; [2]Kamino K (2013) Biofouling 29,735–749; [3]Hennebert E, Wattiez R, Demeuldre M, Ladurner P, Hwang DS, Waite JH, Flammang P (2014) Proc Natl Acad Sci USA 111:6317–6322; [4]Li A, Jia Y, Sun S, Xu Y, Minsky BB, Stuart MAC, Cölfen H, von Klitzing R, Guo X (2018) ACS Appl Mater Interfaces 10(12), 10471-10479; [5]Cui MK, Ren SS, Wei SC, Sun CJ, Zhong C (2017) APL Materials 5, 116102; [6]Stewart RJ, Wang CS, Shao H (2011) Adv Colloid Interface Sci 167(1), 85-93; [7]Taylor SW, Kammerer B. Bayer E (1997) Chem Rev 97,333–346; [8]Cho JH, Lee JS, Shin J, Jeon EJ, An S, Choi YS, Cho S-W (2018) Adv Funct Mater 28, 1705244; [9]So CR, Fears KP, Leary DH, Scancella JM, Wang Z, Liu JL, Orihuela B, Rittschof D, Spillmann CM, Wahl KJ (2016) Sci Rep 6,36219; [10]Lebesgue N, da Costa G, Ribeiro RM, Ribeiro-Silva C, Martins GG, Matranga V, Scholten A, Cordeiro C, Heck AJR, Santos R (2016) J Proteomics 138:61–71; [11]Peng YY, Glattauer V, Skewes TD, McDevitt A, Elvin CM, Werkmeister JA, Graham LD, Ramshaw JAM (2014) Mar Biotechnol 16:695–706.

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