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Short Communication

The Molecular Mechanism of Pearl Biomineralization

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Abstract

In the artificial pearl industry, the epithelial cell of mantle grafting proliferates to form the pearl sac and secret organic matrix to guide pearl biomineralization. This article summarized the process of pearl formation, the involvement of matrix proteins in calcium carbonate (CaCO3) deposition and the genetic contribution of saibo in pearl formation. At last summarizes the existing issues and discusses the problems which should be further researched.

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INTRODUCTION

From ancient times, pearl has always been a highly sought after treasure for the gorgeous luster. Pearl, because of their unique microstructure and excellent mechanical properties, has been the focus of scientific research in recent years. The formative process of natural pearl involves the forming the pearl sac by the rapid proliferation of the epithelial cell of mantle followed by $CaCO_3$ ordered deposition with a proper outside stimulation [1].

Pearls are composed of inorganic $CaCO_3$ and organic matrix. In pearl crystallizing layers, the most common mineral phase of $CaCO_3$ includes calcite, aragonite and vaterite. The content of different $CaCO_3$ mineral phases plays a decisive role in determining pearl quality. In high quality freshwater pearls, crystallizing layers are formed by aragonite crystals, and lamellaes are parallel to each other. In low quality freshwater pearls, vaterite and aragonite were found in prismatic layer in addition to aragonite nacreous layers [2]. In seawater pearl, vaterite is absent, and the prismatic layer in low quality pearls is composed by calcite [3].

There is a striking similarity between the pearl and the nacreous layer of shell with $CaCO_3$ and organic matrix component. Moreover, the saibo selected for grafting process is generally the region responsible for nacreous layer mineralization in shell formation. Therefore, it is often interpreted that the matrix protein contributing to shell nacre secreted by mantle is vital to pearl biomineralization and the formation mechanism of pearl follows a process similar to the shell. The organic matrix as the elementary element of shell accounts for 5% (w/w) in the calcified layer [4]. Recently, research on the molecular mechanism of shell promoted several matrix proteins identification and isolation. According to the solubility, matrix proteins can be broadly classified into two parts: soluble matrix proteins (SMPs) and insoluble matrix proteins (IMPs). IMPs, often referred to as framework proteins, pre-fill the space among the chitin framework during the initial nacreous layer biomineralization [5]. Generally, IMPs are multifunctional in nacre biomineralization. For example, MSI60 is a typical IMP, poly (alanine) is considered to participate in the formation of β-sheet conformation and the sequence "EYDYDDDSDDDDEWD" is responsible for calcium binding [6,7]. MSI7 involved in framework formation by C-terminal hydrophobic region and further functional study showed MSI7 could induce aragonite nucleation [8,9]. After the formation of organic framework by chitin and IMP, SMP mainly acidic protein is combined with chitin and provides nucleation sites for $CaCO_3$ deposition. Generally, SMP contains high proportion of acid amino acid residues, such as Asx and Glx. With the growth of crystal, IMP is pushed out and located between crystals, and SMP is incorporated into the aragonite crystal. Therefore, matrix proteins, the major components of organic matrix, embedded in intercrystalline for providing nucleation site, controlling crystal growth and accelerating polymorphic transformation during nacre formation [10].

In pearl industry, the standard operating procedure of grafting process is a mantle graft referred to as saibo selected from the region responsible for shell nacreous layer mineralization was implanted into the mantle of the host oyster for non-nucleated pearl production. In addition to the saibo contacted with a nucleus was implanted into the gonad of the host oyster for nucleated pearl production (Figure 1) [11]. With the proliferation of the epithelial cell, the graft tissue meshes tightly to the host tissue and eventually forms a pearl sac. The organic matrix is secreted by epithelial cells of pearl sac and then induces $CaCO_3$ deposition to make the successive formation of the prismatic and nacreous layer of the pearl. The seawater shellfish, *Pinctada fucata*, is mainly used for nucleated pearl breeding and freshwater Mollusca *Hyriopsis cumingii*, *Hyriopsis schlegelii* are more commonly used for non-nucleated pearl culturing in China [12,3].

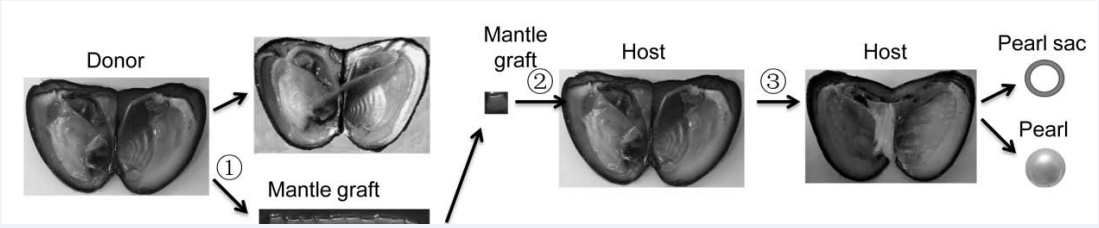

Figure 1 A sketch of the non-nucleated pearl formation. ① The mantle of donor is used to make mantle graft; ② Implantation of mantle graft; ③ Mantle graft proliferates rapidly and cohere with connective tissue to eventually form a pearl sac, then pearl sac secrets nacre and forms the pearl finally.

The mantle allografting goes through cell differentiations and rejection reaction, finally becoming a pearl sac in host oysters. To determine the genetic contribution of mantle allograft and recipient oyster in the course of pearl formation, many experimental studies in the molecular aspect have been presented to research the pearl sac. Arnaud-Haond et al., confirmed the genome of donor was detected in the pearl sac by using microsatellite genetic markers [13]. Masaoka et al., determined the type of nucleotide sequence of matrix protein N16 and N19 in pearl sac was same with those in donor mantle [8]. McGinty et al., compared the quality traits of pearls formed by mantle xenografts between *P. maxima* and *P. margaritifera* and allograft in same species, results showed several quality traits such as nacre deposition color and complexion were influenced by mantle xenografting [14]. Subsequently, McGinty et al., performed the transcriptome analysis of xenografted pearl sacs, and confirmed the putative biomineralization genes expressed in pearl sac was detected in donor oyster by species-diagnostic single nucleotide polymorphisms [15]. All the results indicate the donor mantle is survived in host oyster and involves in pearl sac formation and primarily participates in pearl biomineralization.

The molecular mechanism of pearl biomineralization is extremely complicated. The various features of pearl such as bright luster, dense structure and excellent mechanical properties are derived from the accurate control $CaCO_3$ crystal by matrix protein. Research on the regulation mechanism of matrix proteins has been increased considerably, but most studies have been predominantly concerned with the molecular mechanism of nucleated pearl biomineralization and the matrix proteins have been identified is emphasis on a narrow range of varieties, such as *Pinctada fucata* and *Pinctada maxima*. In artificial pearl industry, freshwater pearl accounted for the largest portion of the output. Future research ought to focus on exploring the mechanism of freshwater formation. Moreover, very significantly, the isolated matrix protein primarily involved in nacreous layer formation. The characteristic structure of pearls showed that it tends to have a thin prismatic layer before nacre mineralization, which provides a connecting link on nucleus and nacreous layer. More and more fatal matrix proteins need to be identified to exploring the transformation mechanism from prism to nacre biomineralization. Furthermore, the regulatory role of matrix proteins in pearl formation has gradually been known and developed, but now little research has been done to connect matrix proteins with the pearl quality traits, such as colour, shape and weight. Therefore, it is necessary to increase the connection between the mechanism study and the pearl industry.

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