



Visualizing and interpreting the dynamics of life-related crystals

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Abstract

Biominerals, such as bone, teeth, urinary stones, and vascular calcification, are crucial inorganic-organic hybrid minerals that exist at the intersection of health and disease. Our research aims to elucidate how these “life-related crystals” nucleate, grow, dissolve, and transform between phases by visualizing subtle changes in the height and shape of crystal surfaces in real time. We use high-resolution optical interference microscopy combined with light-assisted crystallization techniques to control crystallization fields while observing the process. With this approach, we study pathological biominerals and pharmaceutical crystals to identify principles that govern their formation pathways and structures.

Background & Results

Biominerals are not simple inorganic precipitates, but rather, they are hybrid materials formed through the close interaction of inorganic ions, organic molecules, and cellular processes. Minimal alterations in the local environment can result in pathological conditions, including urolithiasis, vascular calcification, and osteoporosis. On the other hand, pharmaceutical small-molecule crystals are “functional crystals,” the polymorphism and microstructure of these crystals strongly affecting solubility, stability, and bioavailability. However, the mechanisms by which these crystals nucleate, grow, dissolve, and transform under biologically relevant conditions remain unclear.

Previously, we mapped the static features of urinary stones and bone-related samples, including crystal phase distribution, organic components, and defect structures. We also identified key phenomena, such as metastable calcium phosphate phases acting as scaffolds for

calcium oxalate and phase transitions coupled with protein localization. In parallel, we have developed light-based techniques, including optical trapping, to control the structure and crystallization pathways of organic and ice crystals.

Significance of the research and Future perspective

We view biominerals and pharmaceutical crystals not as static structures, but as evolving processes over time. We believe that understanding these processes quantitatively and in a designable manner is key to future medical innovations that support healthy longevity. By clarifying how “life-related crystals” nucleate, grow, dissolve, and undergo phase transitions under biologically relevant conditions, our research will establish a foundation for predicting when and where pathological mineralization occurs and how to prevent or reverse it. This knowledge is directly linked to new strategies for predicting and preventing urinary stones and vascular calcification, as well as to the rational design of regenerative and repair materials for bone and teeth.

We will also make effort to offer a unified framework for controlling the structure and morphology of pharmaceutical crystals. The polymorphism and microstructure of these crystals critically determine drug efficacy and safety. We aim to establish guidelines that connect external conditions, crystallization pathways, and final crystal forms for both biominerals and drug substances by combining high-resolution optical methods with externally controlled crystallization fields such as light. Ultimately, we aim to contribute to “future medical innovation that supports healthy aging” by looking at the entire course of life from their birth to their disappearance, through the *lens* of crystals.

Solution-mediated phase transition effectively promotes urinary stone growth.

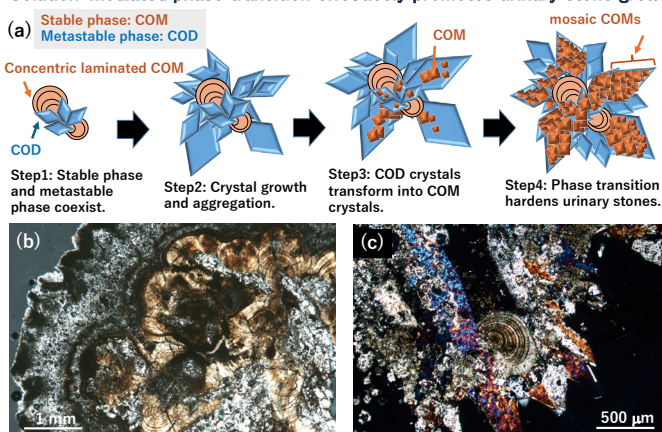


Fig. 1 (a) Schematic diagram of the formation mechanism of calcium oxalate urinary stones. (b) Transmitted light optical microscope image of calcium oxalate stone. (c) Polarized light microscope image (crossed Nicols) of calcium oxalate stone.

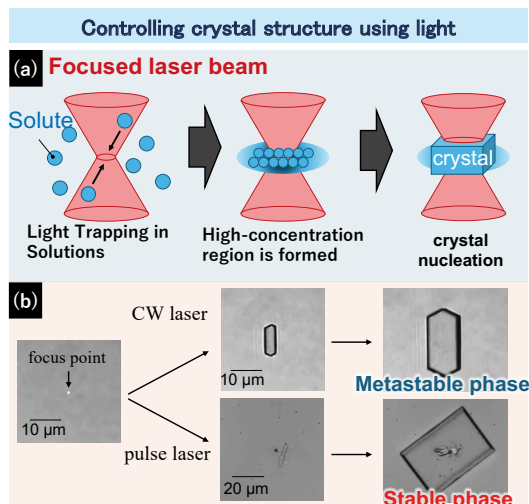


Fig. 2 (a) Overview of light-trapping crystallization. (b) Control of L-cysteine crystal polymorphism.

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Keyword crystal growth, phase transition, biomineralization, laser trapping, medical-engineering collaboration