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Formation of Turing structures in an agar matrix under stratospheric conditions

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Introduction. As humanity expands its presence into space and the stratosphere, astronauts and pilots face a critical challenge: the degradation of bone mineral density. The bone density is found to decrease approximately 1 wt.% to 2 wt.% per a month at the microgravity environment. These conditions lead to osteoporosis, possessing a substantial health risk during and after space missions [1,2,3]. Thus, it's crucial to address the bone loss caused by microgravity. Research has shown that bones may have evolved an adaptation to gravity for the skeleton maintenance. Thus, it's crucial to address the bone loss caused by microgravity. In this regard, the study of bone formation at nonequilibrium conditions. The Liesegang rings formation[4] is a convenient model for studying these processes.

Main part. The study included two experiments of growing hydroxyapatite (HA) crystals in an agar matrix during a stratospheric high-altitude balloon rising 23 km above sea level. For these experiments, CubeSats were utilized. The CubeSats include several small research stations comprised of one or several cubic modules. Each CubeSat was equipped with equipment necessary for collecting data on external temperature, the balloon's repositioning, and flight height. It's important to note that the CubeSat-1 does not have an inner thermal control system, while the CubeSat-2 was able to maintain a stable internal temperature of 25°C. The collected data from both CubeSats provided valuable parameters such as temperature, pressure, radiation, high etc. for analyzing the experiment conditions. After the stratospheric launch, tube holder blocks were removed from the CubeSats and transported to a laboratory for physical-chemical analysis of the crystals. The purified and dried hydroxyapatite crystal powder underwent various analysis methods, including XRD, FITR, SEM, and TEM.

Turing structures are observed to form at the first stratospheric experiment without thermal control. Turing structures are stationary patterns formed by nonlinear reaction-diffusion dynamics under nonequilibrium conditions, affecting the HA crystal deposition process. In contrast, the inner thermal control in the CubeSat-2 leads to the pattern’s growth at the testtube bottom. It indicates a temperature influence on the formation of Turing structures. The xrd analysis has showed that nonequilibrium conditions significantly impact crystal lattice integrity. The HA crystals from the first stratospheric launch exhibited calcium deficiency, a result of lower temperatures and unique stratospheric conditions.

The SEM images show large, shapeless conglomerates crystals grown in both stratospheric experiments. These crystals have no well-defined crystal morphology compared to laboratory samples. The TEM images have shown the HA conglomerates are consisted of nanocrystals with an average size of 150 nm.

Conclusions. The study focused on the growth of HA crystals in the stratosphere's non-equilibrium conditions. This research revealed that non-stationary conditions, particularly temperature, play a key role in influencing the formation and morphology of these crystals. Significant differences were observed in the structures of crystals grown in the stratosphere without thermal control. In contrast, crystals grown in the stratosphere with thermal control showed different structural characteristics. Comparatively, crystals grown in laboratory conditions displayed distinct structural features, highlighting the impact of these varied conditions.

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Literature:

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