

Cells organize in complex three-dimensional patterns by interacting with proteins along with the surrounding extracellular matrix. This organization provides the mechanical and chemical cues that ultimately influence a cell's differentiation and function. Here, we computationally investigate the pattern formation process of vascular mesenchymal cells arising from the interaction between cells, Bone Morphogenic Protein-2 (BMP-2), and its inhibitor, Matrix Gla Protein (MGP). Using a first-principles approach, we derive a reaction-diffusion model based on the biochemical interactions of BMP-2, MGP and cells. Simulations of the model exhibit a wide variety of three-dimensional patterns not observed in a two-dimensional analysis which suggests a mechanism for differences seen in cell regulation between two and three-dimensional experiments. We demonstrate the emergence of three types of patterns: spheres, tubes, and sheets, and show that the patterns can be tuned by modifying parameters in the model such as the degradation rates of proteins and chemotactic coefficient of cells. Our model may be useful for improved engineering of three-dimensional tissue structures as well as for understanding the role of three dimensional versus two dimensional microenvironments on cell organization.