Agent Based Modelling of the Formation Stage of Bone Remodelling

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Background

Throughout life, bones continuously undergo modelling and remodelling to facilitate growth or changes in shape. Bone modelling refers to the process through which bones adjust their size or configuration in response to physiological factors or mechanical forces. On the other hand, bone remodelling is the essential process that ensures bones retain strength and maintain mineral balance **[1][2]**.

Within the bone remodelling process, the bone formation stage plays a key role, with osteoblasts taking centre stage. These specialised bone-forming cells undergo apoptosis or differentiate after performing their primary functions **[3]**. The exact mechanisms underlying how osteoblasts collaborate to secrete new bone matrix is still under investigation, and various hypotheses have been proposed to explain this **[4]**.

This project sought to create a simulation of the bone formation stage in the bone remodelling process using an agent-based modelling (ABM) technique. It involved specifying certain assumptions and initial configurations, shedding light on the complex and intriguing world of bone physiology.

Methods

1. Bone Formation Process

Literature Review

Comprehensive research into the bone formation process and the cellular components involved.

Agent Definition

Defining agents and their functions based on pathways and biological roles identified.

2. Model Development

MESA Library

Completion of MESA introduction tutorial to gain a thorough understanding of the functions applied in the project.

Assumption and Configuration

***Model Hypothesis**:* Osteoblasts secrete bone matrix until it is embedded, after which they either differentiate or undergo apoptosis.

***Initial Configuration**:* Osteoclasts have vacated the bone site, and osteoblasts are recruited to lay down new bone matrix.

3. Simulation Implementation

Scripting

The scripting phase involved translating our agent definitions and model design into executable code.

Visualisation and Simulation

Primary agents**:* Osteoblasts (green***), Bone Matrix (***blue* & *white***) and Osteocytes (***salmon***).

Interactions: Osteoblasts move randomly until they find a damaged bone site represented by white bone matrix grid cells. Upon reaching the site, they deposit osteoid, leading to a progressive increase in the density of the white bone matrix cells until it reaches a density of 5 units.

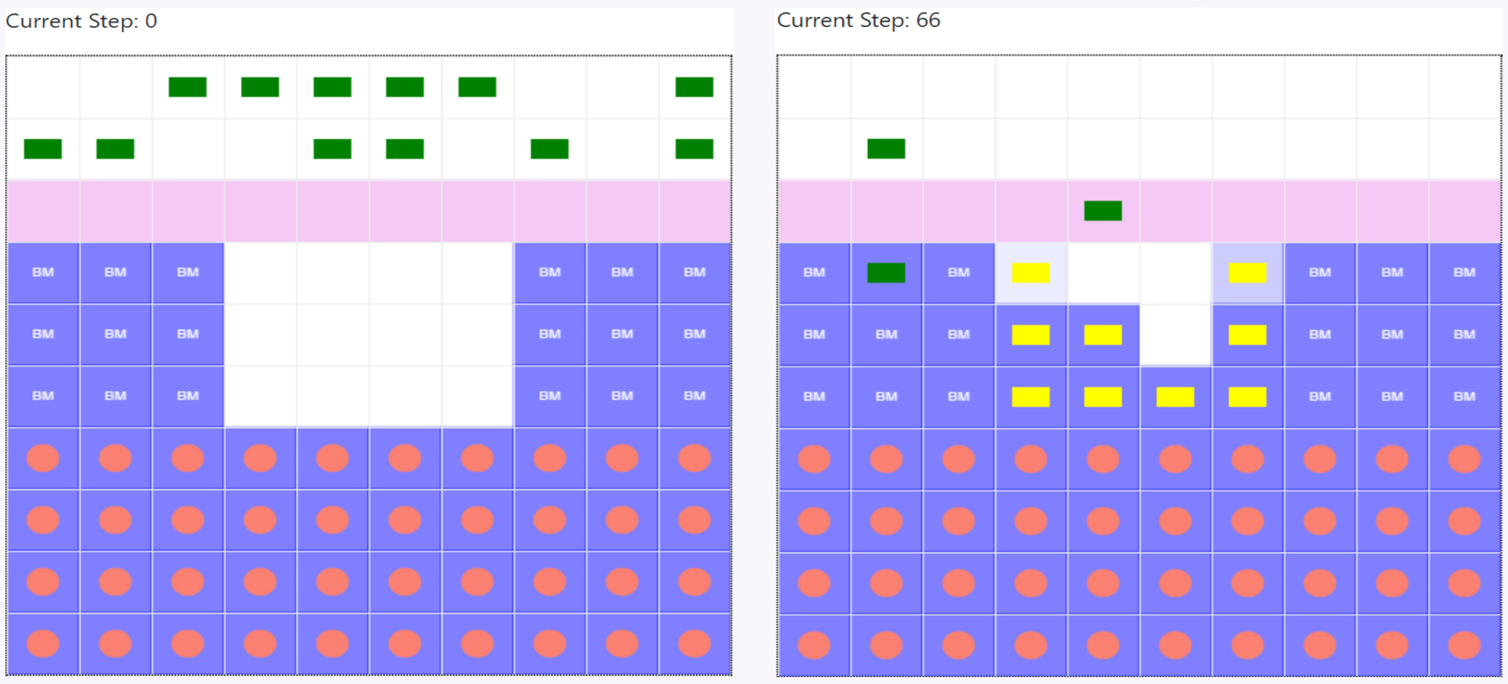

***Figure 1**: **Step 0**: Initial Visualization of Agents and Environment in the Bone Formation Simulation. **Step 66**: Simulation Progression – Interaction between Osteoblasts and Bone Matrix agents.*

Results

- **Agent Behaviour:** The simulation effectively replicated the behaviours of Osteoblasts and Bone Matrix with certain accuracy. This can be observed by the realistic movement patterns towards damaged bone sites, closely mirroring their in vivo behaviour.
- **Density Changes:** Effectively captured the process of osteoid secretion by Osteoblasts, closely resembling the biological response to areas lacking bone. This phenomenon was reflected in the gradual colour transition from light blue to a deeper blue.
- **Time Measurement:** A module to precisely gauge the duration for all Osteoblasts to fill empty spaces and secrete osteoid until reaching a new bone layer with a density of 5. Running the simulation at a frame rate of 3 frames per second (fps), an average completion time of approximately 27.5 seconds was recorded, offering valuable insights into the temporal dynamics of the bone formation process.

Future work

Our future work includes the implementation of a data collection function to measure the bone formation rate. Additionally, we aspire to refine agent behaviors, such as introducing differentiation and apoptosis for Osteoblast agents, and further empowering Osteocyte agents with advanced functionalities. These planned enhancements will not only bolster the accuracy of our model but also enable a more nuanced and detailed representation of the intricate processes governing bone physiology, fostering a deeper understanding of bone formation and repair mechanisms.

We invite all interested parties to explore and enhance our Python script, which will be provided in the poster. Your contributions and insights will be invaluable in refining and expanding the capabilities of our bone formation simulation.

Python script: https://qrco.de/boneformationscript

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Reference