



3D Modeling of the Proximal Convoluted Tubule



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OBJECTIVE

- To develop a 3D model of the proximal convoluted tubule (PCT) using compatible biomaterials with the ability to replicate physiological structure and accomplish functionality.
- To subject the tubule to various tests that would characterize the tubule and aid in the advancement of PCT/kidney research

BACKGROUND

- The PCT is responsible for the absorption, transport, and secretion up to 80% of solutes, metabolites, and water in the kidney
- Our goal was to create a membrane that represents the interface between the PCT and surrounding capillaries. We aimed to replicate this by seeding PCT epithelial cells on one side of a membrane (mimicking the tubule's inner surface) and endothelial cells on the other side. (representing the adjacent capillaries).
- The PCT has a lumen diameter of 20–60 μm and epithelial thickness of 5–8 μm, with a surrounding interstitial space measuring 10–20 μm that contains extracellular matrix (ECM) components such as collagen and fibronectin – essential for structural support, cell adhesion, and signaling, and were considered when designing our hydrogel-based membrane to closely mimic the native environment.
- While there have been PCT models made using bioinks and seeded cells in the past, many of them failed to include vascularization of their model, introduce their model to continuous media flow, or subject their model to tests relevant to kidney research, such as glucose diffusion.

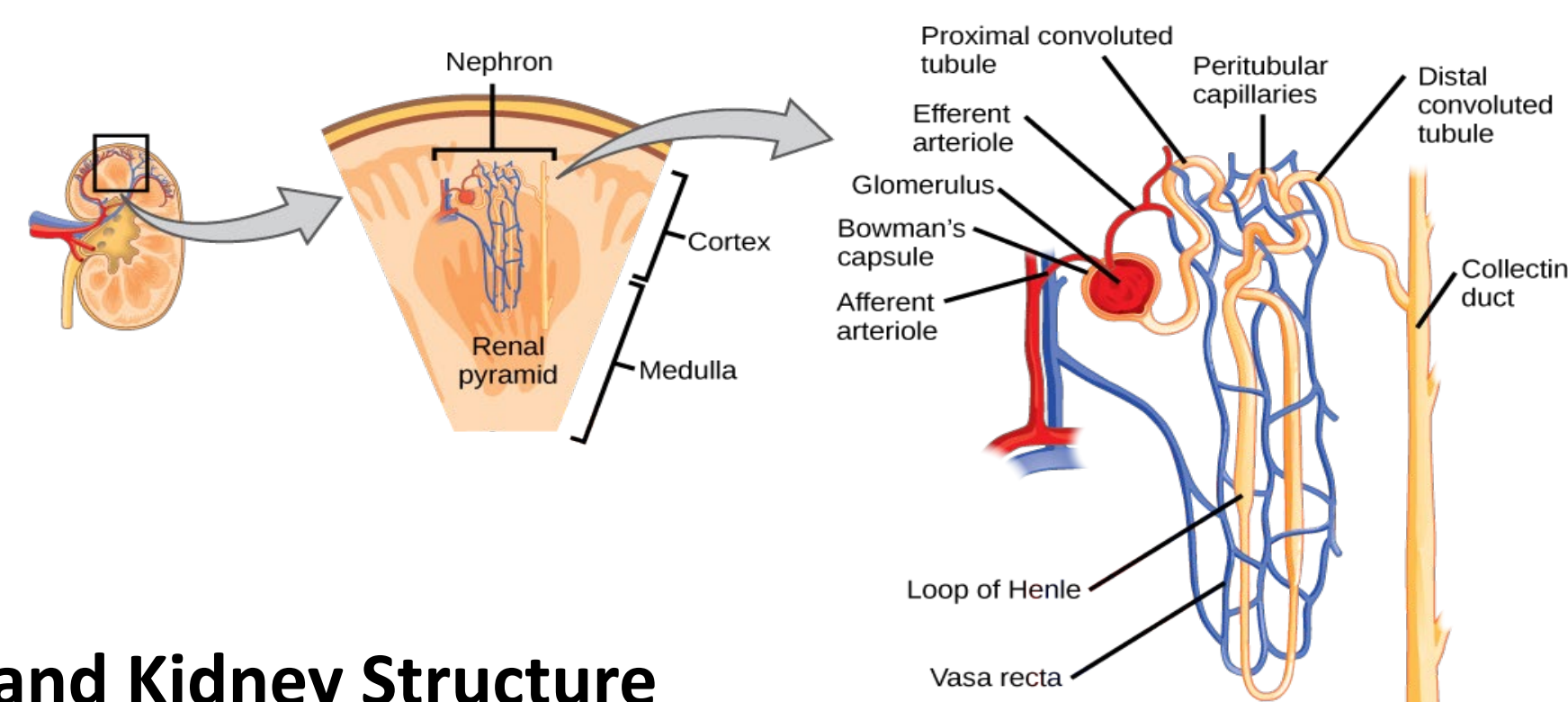


Figure 1: Nephron and Kidney Structure

METHODS AND MATERIALS

- To fabricate the membrane, we used a hydrogel-based bioink composed of 8% gelatin, 1% sodium alginate, and 2% methylcellulose, crosslinked with 2% calcium chloride. This formulation was chosen to balance printability, mechanical stability, and biocompatibility. The resulting gel supports cell adhesion and viability, making it suitable for seeding PCT epithelial cells and endothelial cells on opposite sides of the membrane.
- Solute transport was tested first by allowing the diffusion of ink across the membrane, then a glucose diffusion test was performed, with glucose levels measured over time using a ReliOn glucometer. This test helped assess the membrane's suitability for filtrate and toxin transport, mimicking native PCT functionality.
- Swelling ratios were conducted by first fabricating 1 cm by 2 cm gels. These gels were then allowed to fully dehydrate, and the weight was measured denoted as dry weight (W_d). We then submerged the gels in DI water and allowed to rehydrate. We took measurements of the weight at various time points, and this would be the swollen weight (W_s). The following equation was used to find our swelling ratios:

$$\frac{W_s - W_d}{W_d}$$

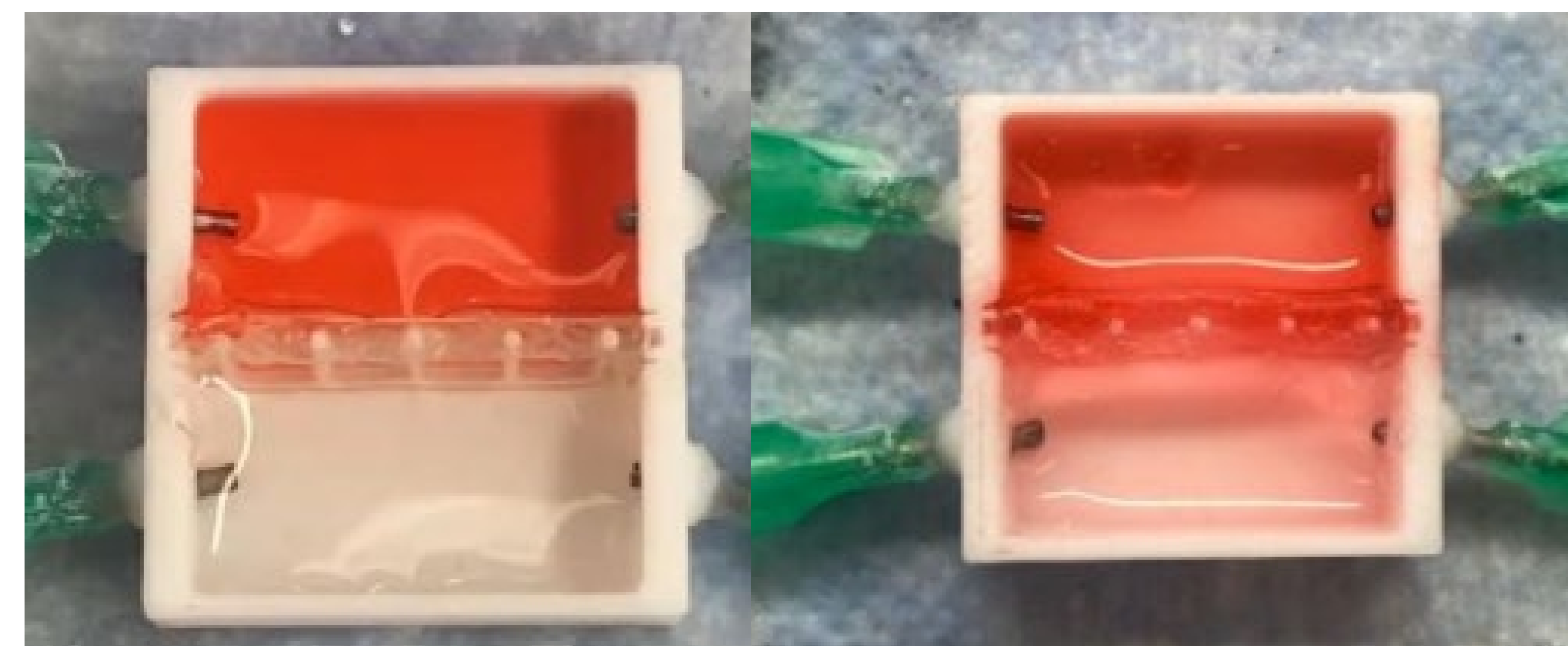


Figure 2: Ink Diffusion Across Gel

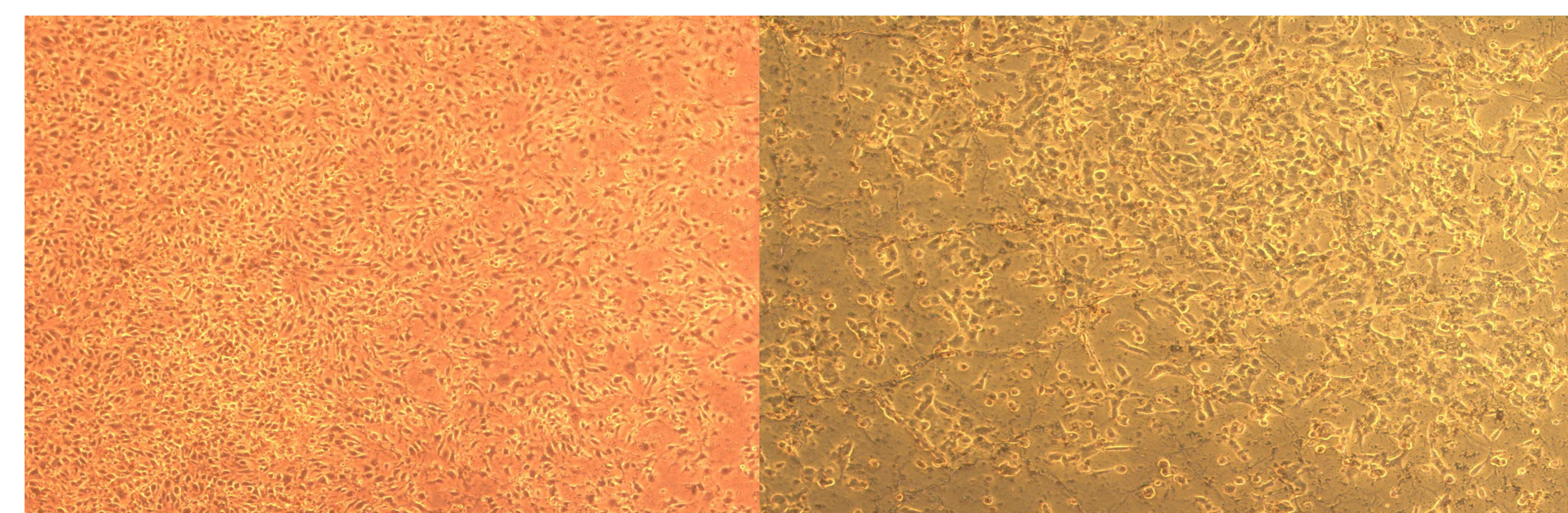


Figure 3: Endothelial and Epithelial Cell Seeding

RESULTS

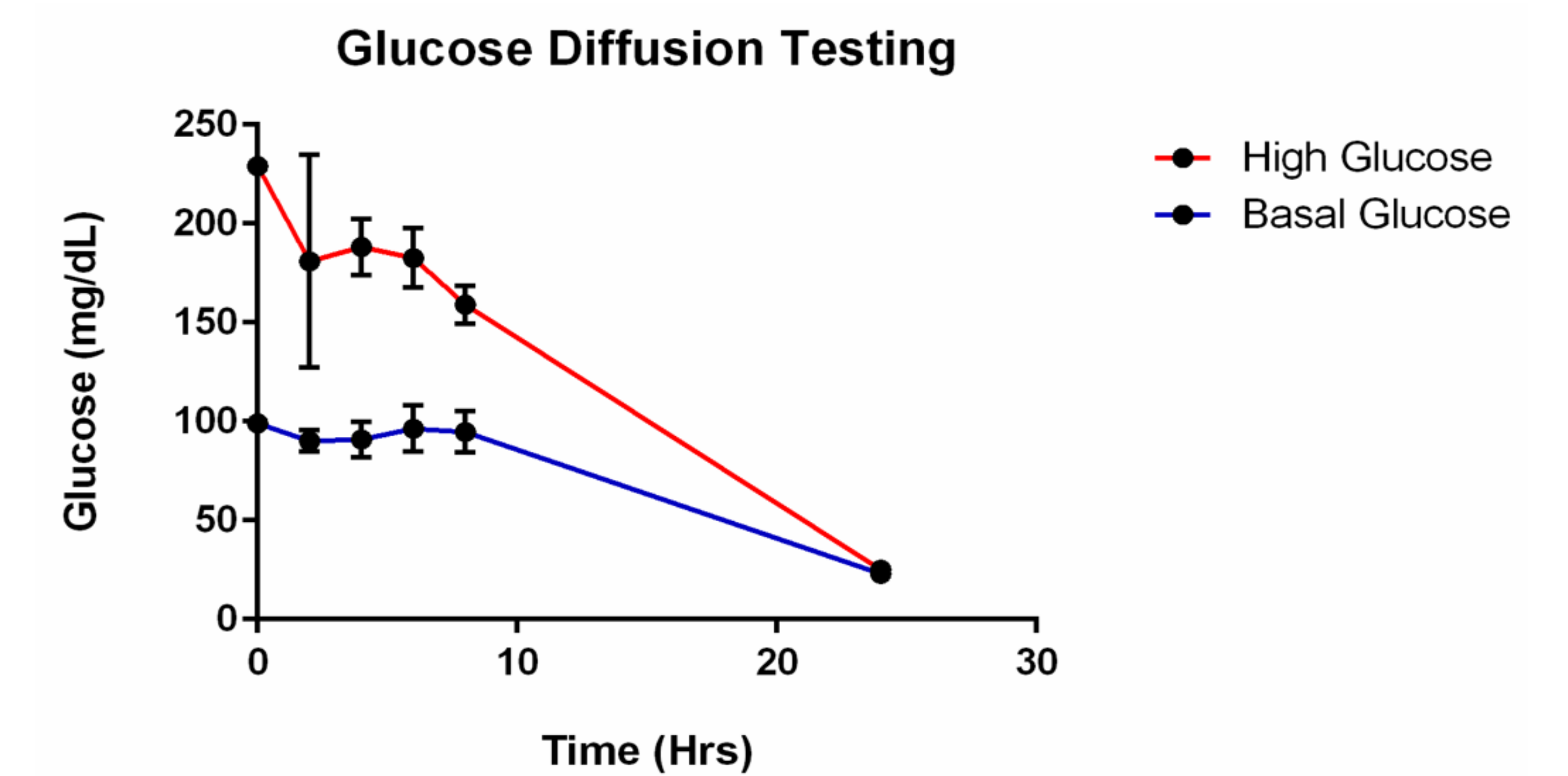


Figure 4: Glucose Diffusion Experimental Results

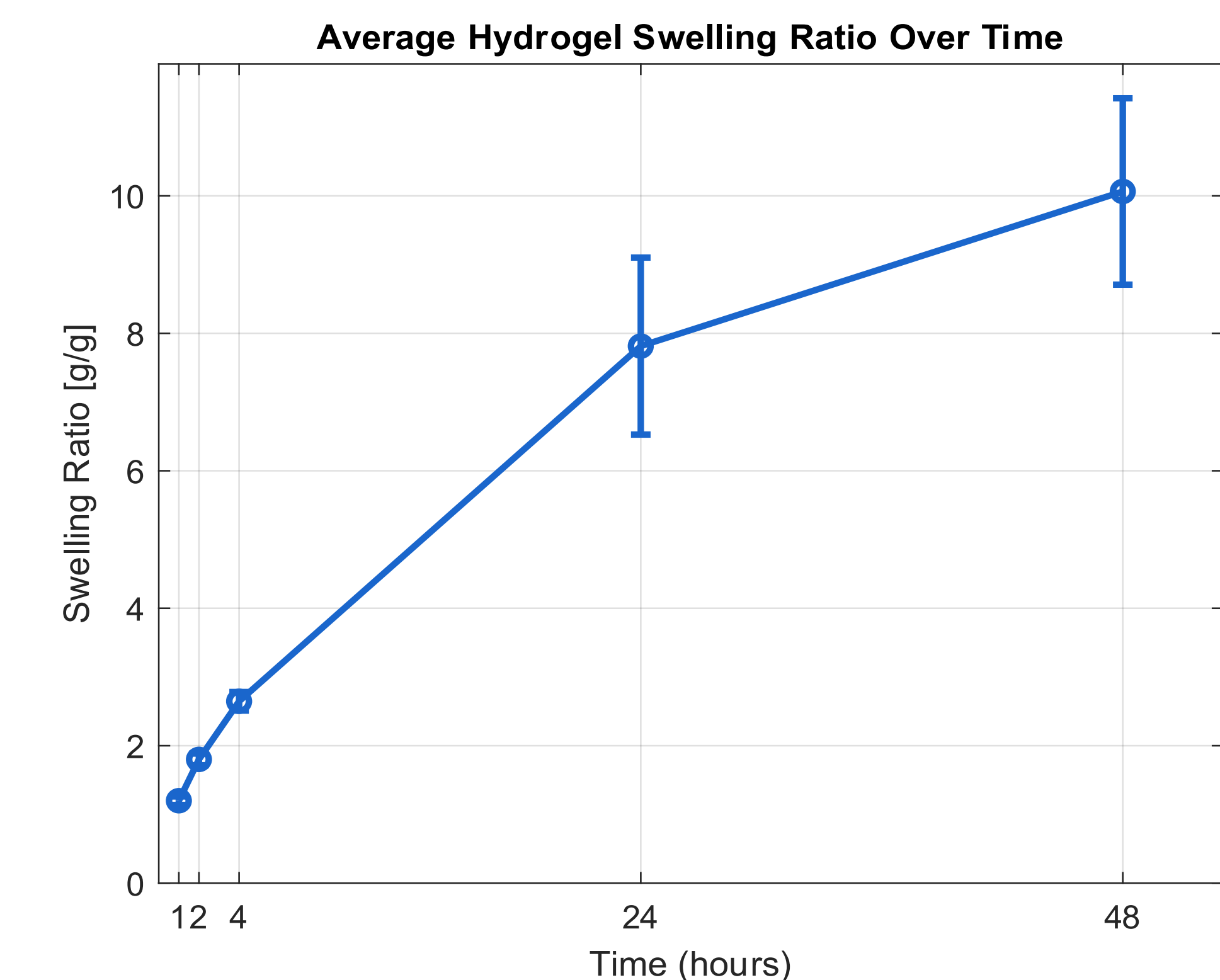


Figure 5: Hydrogel swelling ratio Over Time

CONCLUSION

We developed a 2 mm thick flat membrane gel cast within a 3D-printed PLA mold that allowed for the successful diffusion of glucose and. This setup allowed us to begin optimizing our hydrogel formulation and evaluate cell compatibility and attachment in a controlled, layered structure. Future directions of this project could focus on translating this flat-layer model into a curved or tubular geometry through 3D bioprinting, as well as minimizing the size to be closer to physiological structure (~60 μm)

ACKNOWLEDGMENTS

Our group would like to recognize Dr. Schultz and Dr. Du for their support in the development of this project, as well as Dr. Mohan and Mohan Lab members