Design of weighed TPMS scaffold structures and application in hip stems via computational simulations

Soumyadeep Sarkar[1] Souptick Chanda[1],
[1]Indian Institute of Technology, Guwahati, India
Email: csouptick@iitg.ac.in, ssarkar@iitg.ac.in

Summary

Triply Periodic Minimal Surfaces (TPMS) scaffold structures are being widely researched in bone tissue engineering due to their ability to mimic trabecular bones. In this study, TPMS structures were combined, and the designed weighed scaffolds were computationally analyzed and compared based on structural and hemodynamic analysis. The structures were subsequently applied to hip stems and their biomechanical stability was checked using realistic loading simulations. Parameters like maximum Wall Sheer Stress (WSS), maximum flow velocity, average pressure drop (ΔP), permeability, compressive modulus (Ec) and yield strength (YS) were numerically evaluated for the weighed scaffolds and compared to determine their structural superiority. Based on the studies conducted, the 50% Gyroid 50% Primitive scaffold can be considered a better alternative for bone replacement, specifically in porous hip stems.

Introduction

The use of scaffold structures to repair bone defects have significantly increased in the present world since these structures allow bone ingrowth and necessary mechanical strength needed in bone tissues. Among these scaffolds, Triply Periodic Minimal Surfaces (TPMS) structures can mimic trabecular bones. [1] In this study, TPMS Gyroid and Primitive structures have been combined, and the designed weighed scaffolds have been computationally analyzed to check for their structural superiority.

Methods

The TPMS Primitive and Gyroid scaffold structures were designed initially [2], based on the formulae

$$sin\frac{2\pi x}{L_x} \,.\, cos\frac{2\pi y}{L_y} + sin\frac{2\pi y}{L_y}.cos\frac{2\pi z}{L_z} + sin\frac{2\pi z}{L_z}.cos\frac{2\pi x}{L_x} \;=\; 0 \quad (1)$$

and $$cos\frac{2\pi y}{L_y} + cos\frac{2\pi z}{L_z} + cos\frac{2\pi x}{L_x} \;=\; 0 \quad (2)$$

Then, the weighed scaffolds were designed by combining them in 30% Gyroid 70% Primitive, 50% Primitive 50% Gyroid and 70% Gyroid 30% Primitive structure combinations respectively. These structures were then computationally compared with the two existing scaffolds based on structural and hemodynamic analysis, as seen in Fig. 1; and then these scaffolds were applied to hip stems and realistic loading conditions were simulated to check their biomechanical stability.

Results and Discussion

In the hemodynamic analysis, the maximum Wall Sheer Stress (WSS), maximum flow velocity and average pressure drop (ΔP) were obtained and the permeability was calculated and compared and 70% Gyroid was scaffold was found to be least stable. In structural analysis, the compressive modulus (E_c) and yield strength (YS) were numerically evaluated and compared and 50% Gyroid scaffold showed highest YS.

Conclusions

The weighed surface-based scaffolds were designed and computationally analyzed in this study to check if they were structurally superior to the existing scaffolds. The 50% Gyroid 50% Primitive scaffold was found to be a better alternative among the weighed scaffolds designed, in the application of porous hip stems, post experimental validation.

References

[1] Dong et al. (2021) Application of TPMS structure in bone regeneration, Engineered Regeneration, 2: 154-162.
[2] Yoo et al. (2012) New paradigms in internal architecture design and freeform fabrication of tissue engineering porous scaffolds, Med. Eng & Physics, 34, 6: 762-776.

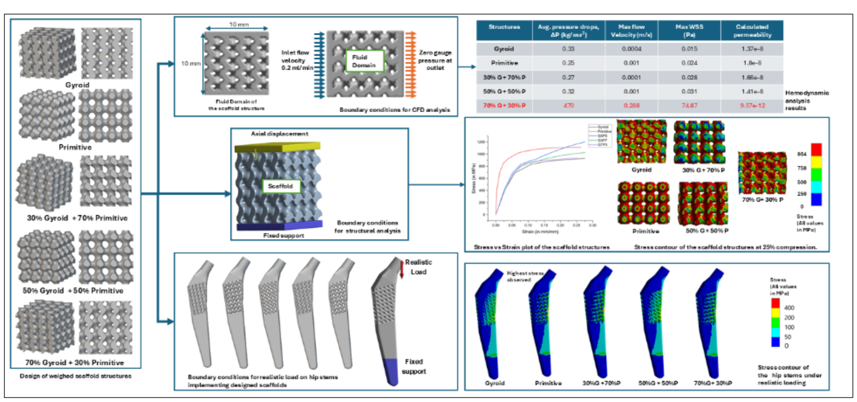

Figure 1: Flow chart of the three studies conducted