Fabrication of Shape-Memory Polymer-Based Drug Delivery Platforms: Design and Process Parameter Optimization

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Introduction

The combination of 3D printing and shape-memory materials has provided new insights into the development and customization of pharmaceutical products with tailored properties. This approach enables the fabrication of drug delivery platforms with distinct properties, notably the ability to temporarily maintain a specific shape that patients can easily swallow and ability to revert to their original predesigned shape within the stomach upon exposure to specific external stimuli, such as body temperature and gastrointestinal pH.

Thus, the purpose of this work was to investigate the feasibility of utilizing fused deposition modeling (FDM) 3D printing to fabricate a shape-memory polymer-based drug delivery platforms and influence of 3D model design parameters and process parameters on shape fidelity and shape memory behavior of the platform.

Methods

3D Model Designing and 3D Printing

Predesigning in CAD software

Model 1
Helix diamter = 8 mm
Helix height = 10 mm
No. of turns = 3
Base height = 0.50 mm

Model 2
Helix diamter = 8 mm
Helix height = 8 mm
No. of turns = 3
Base height = 0.25 mm

Model 3
Helix diamter = 8 mm
Helix height = 6 mm
No. of turns = 2
Base height = 0.25 mm

Setting the parameters in Slicer software

- Layer height = 0.05 mm
- Perimeters = 3
- Infill = 0%
- Printing speed = 30 mm/s
- Gap fill speed = 20 mm/s
- Filament diameter = 1.75 mm
- Nozzle temp. = 200 °C
- Bed temp. = 60 °C
- Nozzle diameter = 0.4 mm
- Filament type: Polylactic acid (PLA)

Fused deposition modeling (FDM) 3D Printing

Programming of the Temporary Shape

Placing the models in 50, 60, or 70 °C distilled water for 1 min

Compressing them into the tablet-like shape

Placing in room temp water to fix the temporary state

Evaluation of the drug delivery platforms

1. **Weight variation**
2. **Printing quality and accuracy assessment**
3. **Shape-memory property**
   - Recovery percentage of the original shape was analyzed by measuring the change in thickness of platforms before and after immersion of the tablet-like model into gastric condition (900 mL of 0.1 N Hydrochloric acid) at 37 ± 0.5 °C.

Results and Discussion

3D printing of drug delivery platforms with different model design parameters

After printing, all models with varying helix heights and number of turns were found to be white in colour and to have great structural fidelity, with the ability to be constructed in helical shape without any need for supports and without structural deformation or collapsing issues.

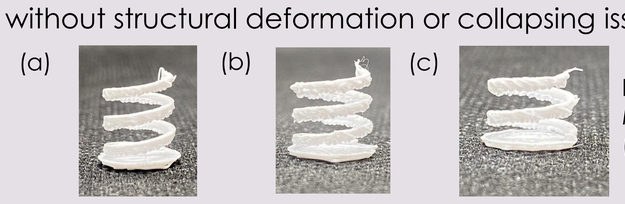

Figure 1. Macroscopic appearance of Model-1 (a), Model-2 (b), and Model-3 (c).

Weight variation and Printing Accuracy

Table 1. Weight and Printing accuracy

Model	Weight (mg±SD)	Thickness (mm±SD)
Model-1	133.7 ± 1.4	10.85 ± 0.21
Model-2	102.5 ± 1.6	8.90 ± 0.13
Model-3	74.0 ± 1.3	6.85 ± 0.05

The thickness of all models closely approximated that of pre-designed model (10.5, 8.5, 6.5 mm), and a narrow SD was observed in all models' weights. This suggests that the process of fabricating these 3D models through FDM printing exhibited a high level of reproducibility which indicates the potential for reliably producing drug delivery platforms with a high degree of accuracy.

Shape memory property

Table 2. Shape memory property of the models with programming temp of 60°C

Model	Shape memory recovery rate (%)
Model-1	33.84 ± 4.68
Model-2	59.54 ± 4.27
Model-3	0.77 ± 0.11

- The findings demonstrated that platform with helix shape was most effectively transformed into a tablet-like shape when the programming temperature was close to the glass transition temperature (T_g) of PLA or 60°C
- When the temperature exceeded T_g (70°C), the platform became too soft, thus resulting in 3D structure distortion and shape recovery that could not be analyzed.
- The developed platforms with three helical turns and programming temp. of 60°C could revert to their original shape with a recovery ratio of up to 60% in 30 min when subjected to 0.1N HCl at 37 °C.
- On the other hand, platform with two turns hardly revert to their original shape during the same period. This could be because the structure of this one is more lighter than the other two, allowing it to fix the shape strongly when it was compressed and making it difficult to revert.

Conclusion

Overall, the findings of this study demonstrated a strong influence of the 3D model design parameter and 3D printing process parameter adjustments on the structural properties and shape-memory properties of the developed drug delivery platforms via FDM 3D printing technique. The platforms with three helical turns demonstrated the ability to temporarily be fixed into tablet-like shape for patients to easily swallow before reverting back to its original shape in stomach with the shape recovery rate of approximately 60% in 30 min.

Thus, the findings in this present work provide crucial insights for future research on utilizing this platform for stomach-specific drug delivery, particularly in gastroretentive approaches

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Acknowledgements

This research project was supported by the Department of Pharmaceutical Sciences, Faculty of Pharmacy, Chiang Mai University, Chiang Mai, Thailand.