

RESEARCH ARTICLE

Development of a Solvent-cast Direct-write 3D Printer System for Polymeric Stent Fabrication

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ABSTRACT - Polymeric stents can be produced using three-dimensional (3D) printing methods. The most commonly used 3D printer is fused deposition modeling (FDM), as it is cost-effective and easy to use. However, the solvent-cast printing (SCP) method has more advantages as it offers material versatility and can print products with complex geometries. Combining these two techniques to build a solvent-cast direct-write 3D printer will enable better production of polymeric stents. This study proposes a concept for creating a solvent-cast direct-write 3D printer by combining FDM and SCP 3D printing systems, aiming to enhance the production of polymeric stents. However, some challenges need to be addressed. Firstly, stents have complex network-like structures that require support during the printing process. Secondly, the stent will have a better quality if the polymeric material is printed from its solvent form. Therefore, three design concepts for the printing axis and printer nozzle are proposed and carefully selected to tackle the challenges. Then, to test the 3D printer, a sample stent is fabricated using thermoplastic polyurethane (TPU). Even though the 3D printer has several limitations, it is the initial step for designing an affordable way to fabricate in-house medical stents.

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1. INTRODUCTION

A medical stent is a tube that can be inserted into the lumen of a blood vessel to open the blood passageway [1-3]. The stent is usually used to reopen blocked arteries by holding the arterial walls from collapsing [1-4]. The stent is made from material, such as metal [1, 2] or polymer [5, 6]. However, the polymeric stent is more favorable due to many advantages such as having mechanical flexibility, not producing artifacts during medical imaging, and bioresorbable [6]. The manufacturing process of stents depends on the material used. Metallic stents are fabricated using laser micro-cutting technology [7], which is expensive and requires technical skills in handling the procedure. Meanwhile, polymeric stents can be manufactured using three-dimensional (3D) additive manufacturing techniques [8], which is a more economical solution. Additive manufacturing, also known as 3D printing, is an effective way to fabricate low-volume and customized products with complex structures [9] and has been widely utilized for the fabrication of medical products such as syringes and stents [8]. To date, a number of 3D printing techniques have been used to fabricate polymeric stents, including selective laser melting (SLM) [10, 11], stereolithography (SLA) [10], and fused deposition modeling (FDM) [10, 12]. Solvent-cast printing (SCP) is another alternative of the 3D printing approach, which is suitable for solid product fabrication using fluid-based polymers [13].

FDM is a low-cost and a high-efficiency manufacturing method [14]. In FDM, polymer fibers are extruded through a printhead at a temperature higher than the melting temperature to form liquid-like filaments [15]. With the movement of the printhead, filaments are deposited layer by layer based on the designated paths and solidified rapidly to form 3D structures, especially in the environment with the ambient temperature much lower than the melting temperature [15]. One of the biggest advantages of FDM 3D Printing is scalability [16], as it can be easily scaled to any size. One of the more obvious benefits of having an easily scalable design is the cost-to-size ratio. FDM printers are continually being made bigger and less expensive, due to low part costs and simple designs. However, traditional melt-based techniques require high processing temperatures and pressures to achieve continuous flow, which limits the type of polymer suitable for the printing process [13].

Meanwhile, SCP has various advantages, including the ease with which it may be employed in labs for small-scale applications [13, 17]. The polymer is dissolved in one or more volatile solvents (organic or water) to produce a homogenous, low-viscosity solution [13, 18]. The solution can be spread over a surface or poured into a mold. The produced structure is a composite substance made of polymer and solvent particles [13]. The fundamental advantage of this method is that a liquid on a surface is dried without any external factors such as temperature or mechanical stress in solvent-cast films [13].

Despite the availability of the various 3D printing techniques, combining FDM and SCP will enable a better production methodology for stents. This new technique, also known as the solvent-cast direct-write 3D printing, is expected to function similarly to an FDM, but instead of using the temperature and pressure, the solvent will be printed out as a polymeric stent through the nozzle similar to an FDM printer head. However, some challenges need to be addressed. First, stents have complicated structures, which are composed of some overhang sections or holes in between [19, 20]. Therefore, using traditional FDM, a support or a holder must be included to hold the overhang sections of the stent. The removal of these supports may cause some damage and deformations to the printed stents [19, 20]. Secondly, the dimensions and structure of the stents vary depending on the patient's anatomy [21]. Hence, precision is also important when designing the printer head.

In this study, the solvent-cast direct-write 3D printing system is proposed through a combination of FDM and SCP techniques for polymeric stents fabrication. Firstly, the 3D printer system is designed, in which the new design for the two main parts of the printer, namely the printing axis and printer nozzle are proposed. The printing axis is used as a support to hold the overhang structure of the stent, while the printer nozzle is designed to exude polymeric solution for stent fabrication. Then, to test the capabilities of the 3D printer, a simple stent design will be fabricated. Several limitations and improvements for the 3D printer will be presented. The solvent-cast direct-write 3D printing system is expected to produce a stent structure before being applied for producing medical grade stents.

2. METHODS

This section describes the process of designing the 3D printer. Firstly, the design concepts for the printing axis and printer nozzle are discussed. Then, to test the usability of the 3D printer, simple stent designs are proposed, and the fabrication processes are discussed.

2.1 Printing Axis

There are four criteria for building the printing axis: (1) printing axis structure stability; (2) fabrication durability, which depends on how the stent fabricated on the printing axis can maintain its structure until the fabrication process ended; (3) ease of assembly of the printing axis on the overall 3D printer; and (4) printing axis fabrication cost. Figure 1 shows three design concepts for the printing axis. Figure 1(a) shows the Design 1. In this design, the printing axis will rotate vertically and controlled by a motor. The stent structure will be drawn vertically around the printing axis. This process applies the concept knitting for nitinol stent fabrication [22]. Meanwhile, Figure 1(b) shows the Design 2. Here, the printing axis will be positioned horizontally with the printer nozzle will be in a fixed position. The printing axis will rotate along the horizontal axis and translate horizontally. This concept follows the fabrication of stent using laser cutting [23]. Lastly, Figure 1(c) shows the Design 3. In this design, the printing axis will have the same position and rotation as the second design. However, the printer nozzle will move horizontally to print the stent structure.

2.2 Printer Nozzle

The criteria for selecting the printer nozzle are the precision, ease to fabricate, low cost, and leakage control. Figure 2 shows the three design concepts for the printing nozzle. Figure 2(a) shows the Design 1. This design will be like an ink-pen [24], where the stent structure can be drawn directly on the printing axis. It will be equipped with a heating element system to prevent the solvent from hardened and to ensure an easy solvent flow. Meanwhile, Figure 2(b) shows the Design 2. This design will utilize a screw pump that pushes the solvent through the nozzle for a better printing precision and to produce a one-way solvent flow [25]. Lastly, Figure 2(c) shows the Design 3. It will be a syringe-pusher system, in which it is designed to allow user to put a syringe containing the polymeric solvent, and then the system will precisely push the syringe during the printing process [26]. Regular syringe can be used as the printing tip, but a precise motor control must be developed that will push the syringe.

2.3 Test Stent Design and Fabrication Procedure

A simple test stent design will be fabricated using the 3D printer developed here. In this study, a stent shape as shown in Figure 3 will be fabricated. The arrowhead stent design is commonly used because it is suitable for compression, which is important during deployment in the blood vessels [27]. Thermoplastic polyurethane (TPU) is used to fabricate the stent. This is because it is very elastic, flexible, and may not break easily when a strong force is applied [28]. The process for stent fabrication is as follows. Firstly, the TPU pellets are dried in an oven at 80 °C for two hours to reduce the moisture content. Then, 30 g of TPU and 3 g of polyethylene glycol 400 (PEG400) are dissolved in 200 ml of methylene chloride. After that, the solution is stirred for 12 hours at room temperature using an orbital shaker. Lastly, the mixture is sealed and ready to be used for stent fabrication.

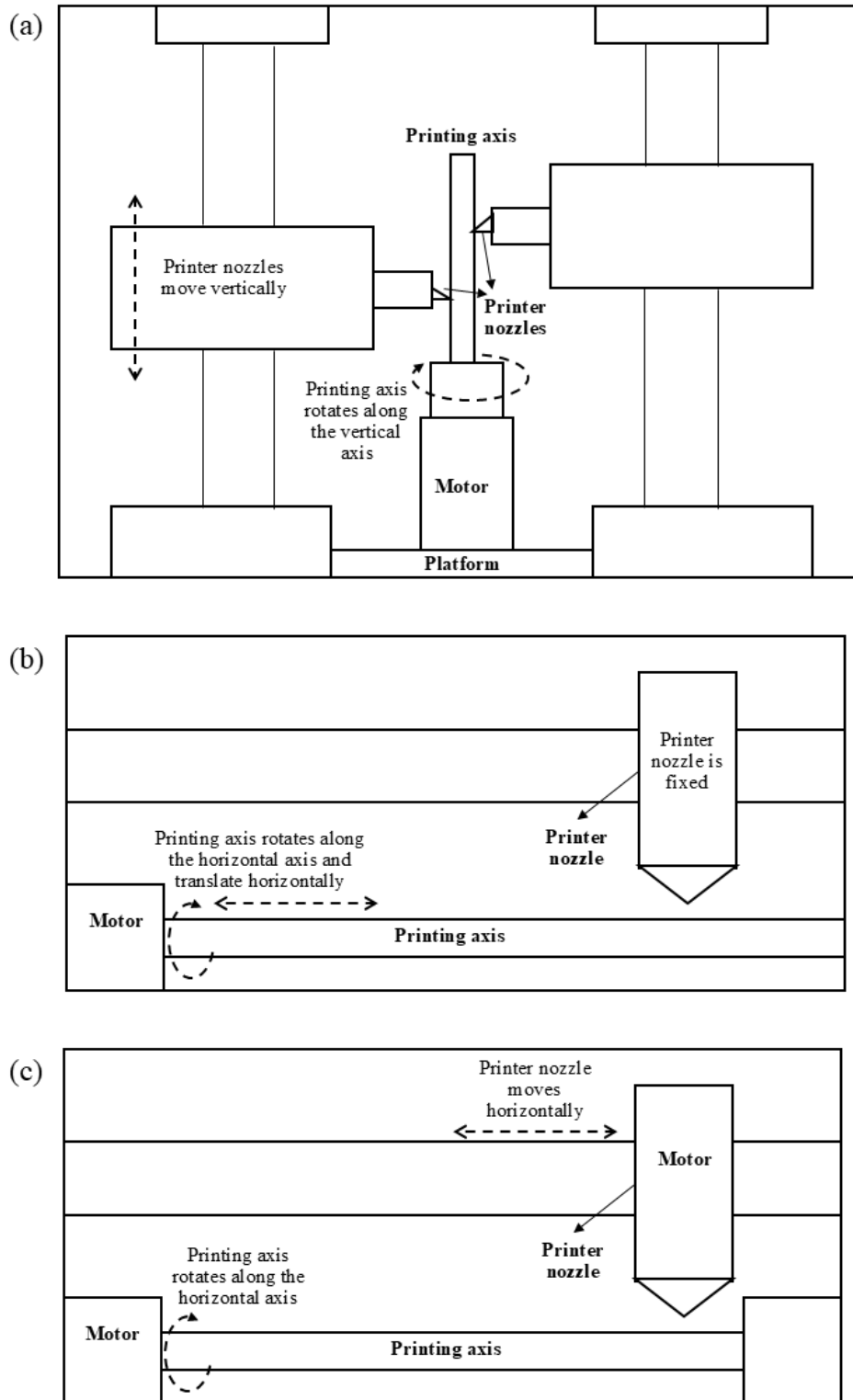


Figure 1. Printing axis design concepts: (a) Design 1, (b) Design 2, and (c) Design 3

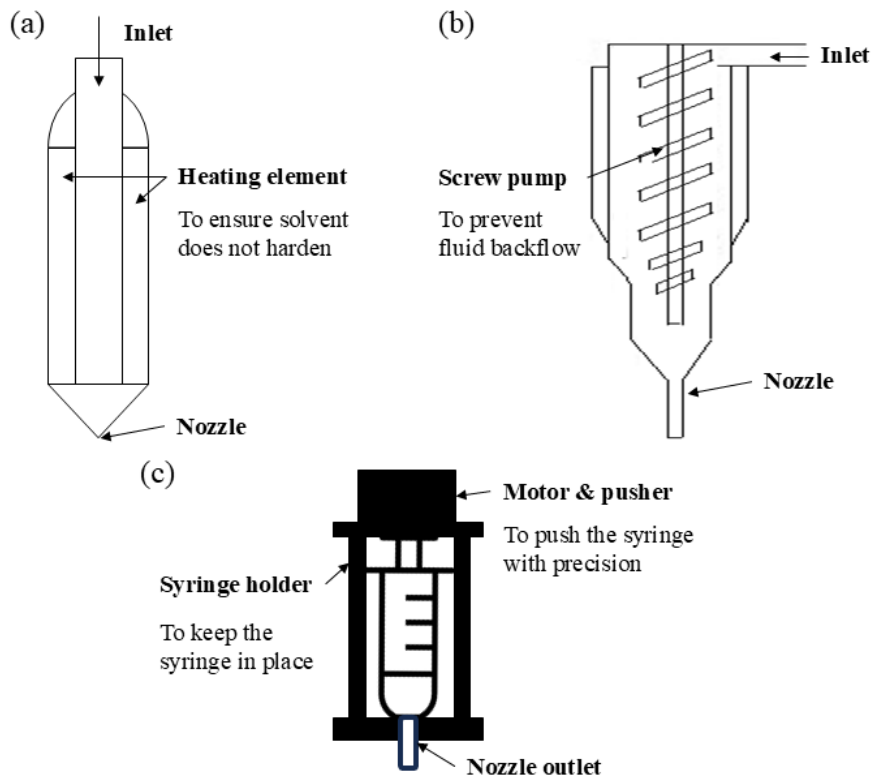


Figure 2. Printing nozzle design concepts: (a) Design 1, (b) Design 2, and (c) Design 3

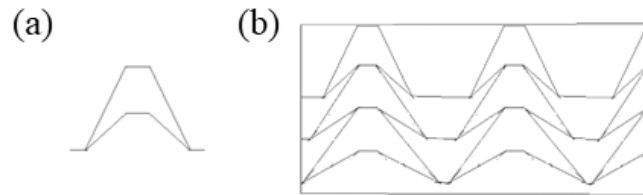


Figure 3. Test stent design with arrowhead shape: (a) a unit cell structure of the stent, and (b) a portion of a complete arrangement of the unit cell structures of the stent

3. RESULTS

In this section, the selection process for printing axis, printer nozzle, and stent design are presented. The Pugh table will be used to select for the best design concept. Throughout this section, each design criterion will be assigned the symbols + or – that represent the advantage and disadvantage of the design over the other designs, respectively. The net score is calculated by summing all criteria with + symbol minus all the criteria with – symbol.

3.1 Printing Axis Design Selection

Table 1 shows the Pugh table for the evaluation of printing axis designs. Design 1 has the best structure stability and easy to develop. However, the final product durability is expected to be a major limitation as the vertical printing will require a support structure to print a stent, which has a complicated network-like structure [10]. Meanwhile, Design 2 will be less stable due to the printing axis being held only on one side. Moreover, controlling the movements of the printing axis, which involve rotating and translating, will be difficult and is expected to incur higher cost as it will require stringent motor control. However, this design is expected to have a positive product durability because it does not require structural support compared to Design 1. Lastly, Design 3 has similar printing axis rotation as Design 2, but it is supported at both ends, which provides additionally stability. It will be easy to develop because the motor only controls the printing axis rotation. In addition, the final product durability is positive based on the same reason as Design 2. From the Pugh evaluation, it shows that design 3 scores the highest net score and hence, it is chosen for developing the 3D printer.

Design 3 is chosen as it meets all the criteria for the printing axis. Further improvement can be done by incorporating a heating system inside the rotating cylinder for a better material curing and to ensure the printed product does not slip during the printing process [10]. The components to support the printing axis could be built using FDM with polylactic acid (PLA) filament to reduce the development cost. Figure 4 shows the Solidwork drawings of Design 3.

Table 1. Pugh evaluation criteria for the printing axis

Criteria	Design 1	Design 2	Design 3
Easy to develop	+	-	+
Stability	+	-	+
Stent Durability	-	+	+
Cost	+	-	+
Sum +	3	1	4
Sum -	1	3	0
Net score	2	-2	3
Rank	2	2	1

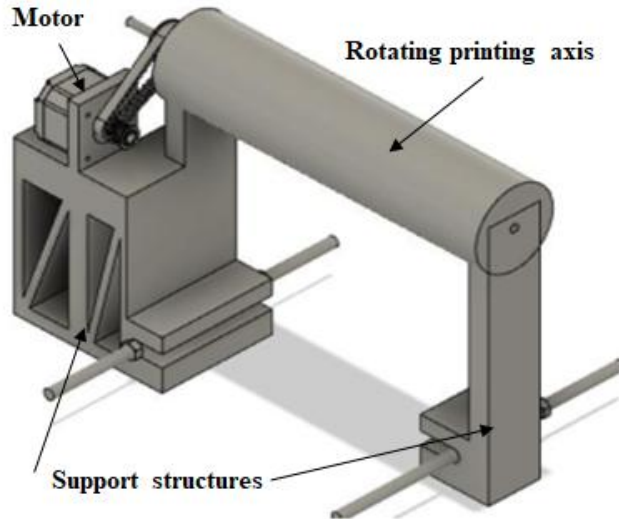


Figure 4. The final Solidworks drawing of Design 3 printing axis

3.2 Printer Nozzle Design Selection

Similarly, Pugh table is used for selecting the best printer nozzle design. Design 1 has the best precision because it can print the stent structure as easy as drawing using a pen. However, it will not be easy to fabricate and will require high cost due to the use of the heating element. Furthermore, the ink flow will depend on the heating system inside the nozzle. Meanwhile, Design 2 will have the best ink flow control due to the screw pump design. However, the design is difficult to be fabricated and is expected to be expensive due to the screw component. Lastly, Design 3 will be simple to fabricate as it only requires a precise motor control to push the syringe. The cost will be relatively cheaper than the other 2 designs. However, the flow control depends on the type of syringe used. Based on the Pugh method in Table 2, Design 3 is chosen because it has the highest net score.

Design 3 depends on the motor control to push the syringe. The polymeric solvent can then be poured into the syringe and then, the syringe can be put on the syringe holder. The syringe will be reusable, and the cleaning process is easy by just removing the syringe from the syringe-pusher system. Figure 5 shows the proposed Solidwork drawing of Design 3. Meanwhile, Figure 6 shows the final 3D printer developed using the selected designs for printing axis and printer nozzle.

Table 2. Pugh evaluation criteria for the solvent-cast nozzle

Selection of criteria	Design 1	Design 2	Design 3
Easy to fabricate	-	-	+
Precision	+	+	+
Ink flow control	-	+	-
Cost	-	-	+
Sum +	1	2	3
Sum -	3	2	1
Net score	-2	0	2
Rank	2	2	1

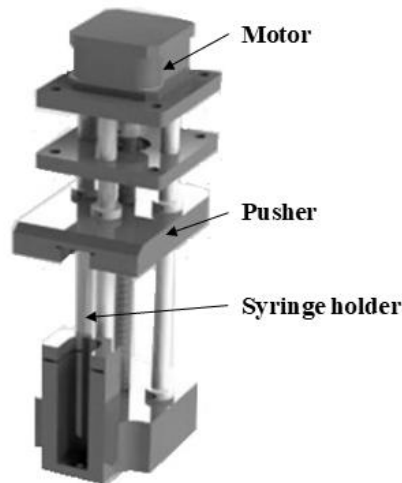


Figure 5. The final design of Design 3 for the printer nozzle

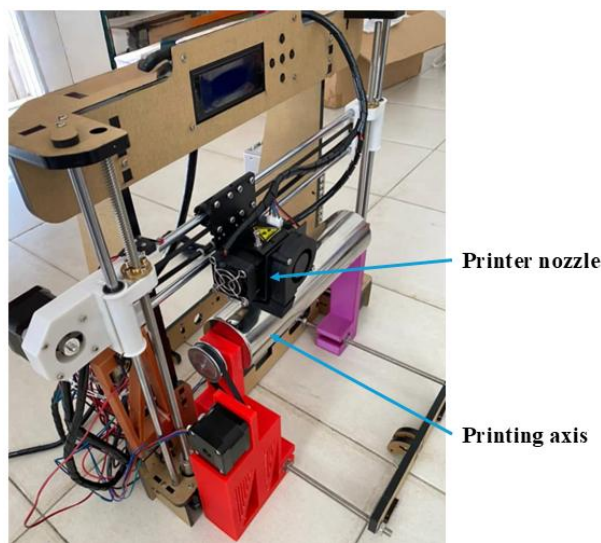


Figure 6. The final solvent-cast direct-write 3D printer developed

3.3 Stent Fabricated using the Solvent-cast Direct-write 3D Printer

The 3D printer developed in Figure 6 is then be used to fabricate the stent design as proposed in Figure 3. The stent fabricated, however, is not for used in the human body, and it is larger than the real stent. It is fabricated for the purpose of validating the 3D printer developed. Further improvements of the 3D printer are needed so that it can be used to fabricate stents for the use in the human body. Figure 7(a) shows the CAD drawing of the stent. Meanwhile, Figure 7(b) shows the stent fabricated using the 3D printer developed. The TPU materials were deposited onto the surface of the printing axis as it is rotating to form a cylindrical stent shape. After the printing is completed, the stent can be removed from the printing axis. From Figure 7(b), it can be observed that the stent is easily compressible due to the mechanical properties of the TPU. However, the network-like structure produced is not smooth. This requires post-processing to ensure that the stent produced has a smooth surface.

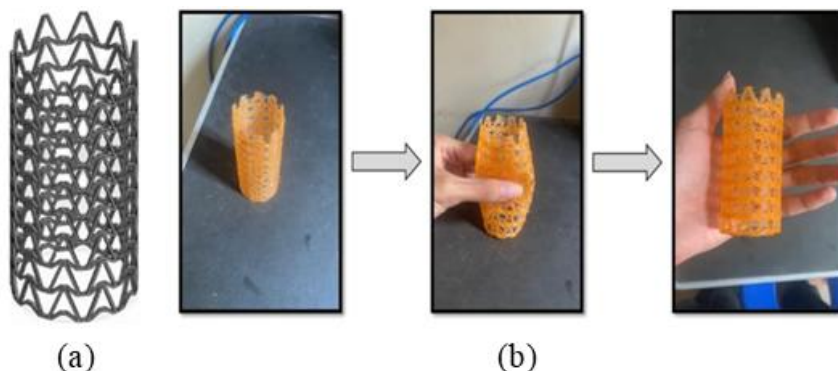


Figure 7. (a) 3D drawing of the stent; (b) Stent fabricated using the 3D printer

4. DISCUSSION

Polymeric stents have become favourable over metallic stents due to their characteristics such as light weight, good bioresorbable, easy fabricability, and low cost [6, 29]. With the advancement of the 3D printing techniques, the manufacturing process of polymeric stents have been more efficient with lower material cost and more complex 3D structures can be created [30]. The 3D printer developed here was modified from an ordinary 3D printer by changing the printing axis and printer nozzle. Several proposed designs have been presented and the final solvent-cast direct-write 3D printer developed here has a rotating printing axis and printer nozzle that precisely push a syringe containing the polymeric material. Then, a sample stent is fabricated using the 3D printer developed. The rotating printing axis reduces the need for the use of unnecessary support structures to fabricate the network-like structure of the stent [8, 19, 27]. Meanwhile, the syringe-pusher printer nozzle ensures for a precise solvent flow during the fabrication process. The solvent-cast direct-write 3D printer developed here could provide a way for an affordable in-house medical stent fabrication. However, the final stent produced has several limitations that need to be addressed for further improvement.

The stent produced here is rough and needs post-processing. Several post-processing procedure to improve the roughness are mechanical polishing [30] and chemical etching [30, 31]. However, care must be taken as this post-processing procedure may cause damage to the final product [32]. Previous studies on the printing process using solvent-based ink have suggested various crosslinking mechanisms to ensure for a smooth stent product, such as by using ionic solutions [33-35], ultraviolet (UV) radiation [36-38], and evaporation [39, 40]. Modification of the 3D printer may also be done by adding a heating element on the printing axis that will enhance the mechanical properties and removability of the stent from the axis [30].

Furthermore, the current study enables the fabrication of different sizes of stent for different blood vessels diameter such as small arteries (i.e. coronary artery) [41], bigger arteries (i.e. aorta) [42], and also may be used for fluid flow study during stent insertion [43]. This can be done by changing the printing axis with different diameter. This advantage allows for the fabrication of customized stents with different sizes, which are very important so that the stent can fit within the blood vessel. However, the limitation of this printing axis design is that only straight stents can be fabricated. In some cases, branched stent is needed [30], and this will require the use of a specific printing axis.

Finally, the stent material also plays important roles in determining the quality of the final product fabricated using the 3D printer. In this study, TPU was used to test the ability of the 3D printer developed. Various polymers have been used to fabricate stents using 3D printing, including PLA [19, 44], poly-vinyl alcohol (PVA) [27], polycaprolactone (PCL) [44, 45], methacrylated poly (dodecanediol citrate) (mPDC) [46], and poly L-lactic acid (PLLA) [44, 47]. For future improvements of the 3D printer efficiency, the use of these polymers should be taken into consideration for the stent fabrication.

5. CONCLUSION

A solvent-cast direct-write 3D printer has been developed for polymeric stent fabrication. The printer utilized a rotating printing axis as the platform, and a syringe-pusher to precisely exude the polymeric solvent. A thermoplastic polyurethane (TPU) stent with arrowhead design is printed using the developed 3D printer. The stent fabricated has poor surface roughness, which demands a further improvement of the fabrication process, including adding a post-treatment procedure, using a better polymer, and improving the printing precision. Despite the limitations, the solvent-cast direct-write 3D printer developed here could provide an affordable way for producing in-house medical stent.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHORS CONTRIBUTION

W. N. Wan Ab Naim (Writing – editing and proofreading; Design and Data Collection)

M. J. Mohamed Mokhtarudin (Writing - review & editing; Project administration; Supervision)

I. Ishak (Conceptualization)

REFERENCES

- [1] N. S. C. Amdilah, Y. S. Lau, Y. M. Liew, W. N. W. A. Naim, and M. J. M. Mokhtarudin, "Computational fluid dynamics of patient-specific coronary artery during stent treatment," in *IET Conference Proceedings CP808*, vol. 2022, no. 22, pp. 216-220, 2022.

- [2] W. T. Tan, Y. M. Liew, M. J. Mohamed Mokhtarudin, S. Pirola, W. N. Wan Ab Naim, S. Amry Hashim, et al. "Effect of vessel tortuosity on stress concentration at the distal stent–vessel interface: Possible link with new entry formation through biomechanical simulation," *Journal of Biomechanical Engineering.*, vol. 143, no. 8, p. 081005, 2021.
- [3] M. A. Seidman, R. F. Padera, and F. J. Schoen, "Cardiovascular Medical Devices: Stents, Grafts, Stent-Grafts and Other Endovascular Devices," in *Biomaterials Science*, pp. 1033-1050, 2020.
- [4] A. F. A. Ahmad Azahari, W. N. Wan Ab Naim, N. A. Md Sari, E. Lim, and M. J. Mohamed Mokhtarudin, "Advancement in computational simulation and validation of congenital heart disease: A review," *Computer Methods in Biomechanics and Biomedical Engineering*, pp. 1-14, 2024.
- [5] Y. Shen, X. Yu, J. Cui, F. Yu, M. Liu, Y. Chen, et al. "Development of biodegradable polymeric stents for the treatment of cardiovascular diseases," *Biomolecules*, vol. 12, no. 9, p. 1245, 2022.
- [6] S. McMahon, N. Bertollo, E. D. O'Ceirbhail, J. Salber, L. Pierucci, P. Duffy, et al. "Bio-resorbable polymer stents: A review of material progress and prospects," *Progress in Polymer Science*, vol. 83, pp. 79-96, 2018.
- [7] C. S. Chen, S. Y. Lin, N. K. Chou, Y. S. Chen, and S. F. Ma, "Optimization of laser processing in the fabrication of stents," *Materials Transactions*, vol. 53, no. 11, pp. 2023-2027, 2012.
- [8] A. Guerra, A. Roca, and J. de Ciurana, "A novel 3D additive manufacturing machine to biodegradable stents," *Procedia Manufacturing*, vol. 13, pp. 718-723, 2017.
- [9] J. A. Hisam, M. Y. Salehudin, M. I. M. Lizah, M. I. A. Suhaimi, M. H. M. Hisham, I. Ishak, et al., "Fabrication of aneurysm biomodel using 3D printing technology," in *Advances in Intelligent Manufacturing and Mechatronics: Selected Articles from the Innovative Manufacturing, Mechatronics & Materials Forum (iM3F 2022)*, Pahang, Malaysia, pp. 163-173, 2023.
- [10] R. Khalaj, A. G. Tabriz, M. I. Okereke, and D. Douroumis, "3D printing advances in the development of stents," *International Journal of Pharmaceutics*, vol. 609, p. 121153, 2021.
- [11] V. Finazzi, A. G. Demir, C. A. Biffi, C. Chiastra, F. Migliavacca, L. Petrini, et al. "Design rules for producing cardiovascular stents by selective laser melting: Geometrical constraints and opportunities," *Procedia Structural Integrity*, vol. 15, pp. 16-23, 2019.
- [12] M. A. Cortez, R. Quintana, and R. B. Wicker, "Multi-step dip-spin coating manufacturing system for silicone cardiovascular membrane fabrication with prescribed compliance," *The International Journal of Advanced Manufacturing Technology*, vol. 34, no. 7, pp. 667-679, 2007.
- [13] J. W. Tolbert, D. E. Hammerstone, N. Yuchimiuk, J. E. Seppala, and L. W. Chow, "Solvent-cast 3D printing of biodegradable polymer scaffolds," *Macromolecular Materials and Engineering*, vol. 306, no. 12, p. 2100442, 2021.
- [14] I. Durgun and R. Ertan, "Experimental investigation of FDM process for improvement of mechanical properties and production cost," *Rapid Prototyping Journal*, vol. 20, no. 3, pp. 228-235, 2014.
- [15] Z. Zhou, I. Salaoru, P. Morris, and G. J. Gibbons, "Additive manufacturing of heat-sensitive polymer melt using a pellet-fed material extrusion," *Additive Manufacturing*, vol. 24, pp. 552-559, 2018.
- [16] S. C. Daminabo, S. Goel, S. A. Grammatikos, H. Y. Nezhad, and V. K. Thakur, "Fused deposition modeling-based additive manufacturing (3D printing): Techniques for polymer material systems," *Materials Today Chemistry*, vol. 16, p. 100248, 2020.
- [17] R. Jani and D. Patel, "Hot melt extrusion: An industrially feasible approach for casting orodispersible film," *Asian Journal of Pharmaceutical Sciences*, vol. 10, no. 4, pp. 292-305, 2015.
- [18] X. Dong, D. Lu, T. A. L. Harris, and I. C. Escobar, "Polymers and solvents used in membrane fabrication: A review focusing on sustainable membrane development," *Membranes*, vol. 11, no. 5, p. 309, 2019.
- [19] D. Zhao, R. Zhou, J. Sun, H. Li, and Y. Jin, "Experimental study of polymeric stent fabrication using homemade 3D printing system," *Polymer Engineering & Science*, vol. 59, no. 6, pp. 1122-1131, 2019.
- [20] F. Garcia-Villen, F. López-Zárraga, C. Viseras, S. Ruiz-Alonso, F. Al-Hakim, I. Diez-Aldama, et al., "Three-dimensional printing as a cutting-edge, versatile and personalizable vascular stent manufacturing procedure: Toward tailor-made medical devices," *International Journal of Bioprinting*, vol. 9, no. 2, p. 664, 2023.
- [21] F. Auricchio, M. Conti, M. De Beule, G. De Santis, and B. Verheghe, "Carotid artery stenting simulation: From patient-specific images to finite element analysis," *Medical Engineering & Physics*, vol. 33, no. 3, pp. 281-289, 2011.
- [22] N. Korei, A. Solouk, M. Haghbin Nazarpak, and A. Nouri, "A review on design characteristics and fabrication methods of metallic cardiovascular stents," *Materials Today Communications*, vol. 31, p. 103467, 2022.
- [23] A. Guerra and J. de Ciurana, "Fibre laser cutting of polymer tubes for stents manufacturing," *Procedia Manufacturing*, vol. 13, pp. 190-196, 2017.

- [24] P. Bernard and J. D. Mendez, "Drawing in 3D: Using 3D printer pens to draw chemical models," *Biochemistry and Molecular Biology Education*, vol. 48, no. 3, pp. 253-258, 2020.
- [25] P. Zeleny and V. Ruzicka, "The design of the 3D printer for use in gastronomy," *MM Science Journal*, vol. 500, no. 1, pp. 1744-1747, 2017.
- [26] S. Baas and V. Saggiomo, "Ender3 3D printer kit transformed into open, programmable syringe pump set," *HardwareX*, vol. 10, p. e00219, 2020.
- [27] Wu Z, Zhao J, Wu W, Wang P, Wang B, Li G, et al. "Radial compressive property and the proof-of-concept study for realizing self-expansion of 3D printing polylactic acid vascular stents with negative poisson's ratio structure," *Materials*, vol. 11, no. 8, p. 1357, 2018.
- [28] Q. Guo, P. T. Knight, and P. T. Mather, "Tailored drug release from biodegradable stent coatings based on hybrid polyurethanes," *Journal of Controlled Release*, vol. 137, no. 3, pp. 224-233, 2009.
- [29] S. Bangalore, B. Toklu, N. Amoroso, M. Fusaro, S. Kumar, E. L. Hannan, et al., "Bare metal stents, durable polymer drug eluting stents, and biodegradable polymer drug eluting stents for coronary artery disease: Mixed treatment comparison meta-analysis," *BMJ: British Medical Journal*, vol. 347, p. f6625, 2013.
- [30] W. Hua, W. Shi, K. Mitchell, L. Raymond, R. Coulter, D. Zhao, et al., "3D printing of biodegradable polymer vascular stents: A review," *Chinese Journal of Mechanical Engineering: Additive Manufacturing Frontiers*, vol. 1, 2, p. 100020, 2022.
- [31] W. Zhang, Z. Li, C. Xu, M. Chai, dan P. Dong, "Surface characteristics of NiTi cardiovascular stents by selective laser melting and electrochemical polishing," *The International Journal of Advanced Manufacturing Technology*, vol. 130, no. 1, pp. 623-634, 2024.
- [32] K. K. Guduru and G. Srinivasu, "Effect of post treatment on tensile properties of carbon reinforced PLA composite by 3D printing," *Materials Today: Proceedings*, vol. 33, 5403-5407, 2020.
- [33] F. E. Freeman and D. J. Kelly, "Tuning alginate bioink stiffness and composition for controlled growth factor delivery and to spatially direct MSC fate within bioprinted tissues," *Scientific Reports*, vol. 7, no. 1, p. 17042, 2017.
- [34] Y. Jin, A. Compaan, W. Chai, and Y. Huang, "Functional nanoclay suspension for printing-then-solidification of liquid materials," *ACS Applied Materials & Interfaces*, vol. 9, no. 23, pp. 20057-20066, 2017.
- [35] T. Jiang, J. G. Munguia-Lopez, S. Flores-Torres, J. Grant, S. Vijayakumar, A. D. Leon-Rodriguez, et al., "Directing the self-assembly of tumour spheroids by bioprinting cellular heterogeneous models within alginate/gelatin hydrogels," *Scientific Reports*, vol. 7, no. 1, p. 4575, 2017.
- [36] C. B. Highley, C. B. Rodell, and J. A. Burdick, "Direct 3D printing of shear-thinning hydrogels into self-healing hydrogels," *Advanced Materials*, vol. 27, no. 34, pp. 5075-5079, 2015.
- [37] Ouyang L, Highley CB, Rodell CB, Sun W, Burdick JA. "3D printing of shear-thinning hyaluronic acid hydrogels with secondary cross-linking," *ACS Biomaterials Science & Engineering*, vol. 2, no. 10, pp. 1743-1751, 2016.
- [38] Y. Jin, C. Liu, W. Chai, A. Compaan, and Huang Y. "Self-supporting nanoclay as internal scaffold material for direct printing of soft hydrogel composite structures in air," *ACS Applied Materials & Interfaces*, vol. 9, no. 20, pp. 17456-17465, 2017.
- [39] S. Bodkhe, G. Turcot, F. P. Gosselin, and D. Therriault, "One-step solvent evaporation-assisted 3D printing of piezoelectric PVDF nanocomposite structures," *ACS Applied Materials & Interfaces*, vol. 9, no. 24, pp. 20833-20842, 2017.
- [40] S. Z. Guo, F. Gosselin, N. Guerin, A. M. Lanouette, M. C. Heuzey, and D. Therriault, "Solvent-cast three-dimensional printing of multifunctional microsystems," *Small (Weinheim an der Bergstrasse, Germany)*, vol. 9, no. 24, pp. 4118-4122, 2013.
- [41] G. Mani, M. D. Feldman, D. Patel, and C. M. Agrawal, "Coronary stents: A materials perspective," *Biomaterials*, vol. 28, no. 9, pp. 1689-1710, 2007.
- [42] H. Eggebrecht, C. A. Nienaber, M. Neuhäuser, D. Baumgart, S. Kische, A. Schmermund, et al., "Endovascular stent-graft placement in aortic dissection: A meta-analysis," *European Heart Journal*, vol. 27, no. 4, pp. 489-498, 2006.
- [43] M. F. Hubakri, M. A. S. Zamri, M. N. A. Hamzah, R. A. Roslan, W. N. Wan Ab Naim, and M. J. Mohamed Mokhtarudin, "Design and development of a flexible test rig for biomedical engineering PIV Experiment," in *Enabling Industry 4.0 through Advances in Manufacturing and Materials: Selected Articles from iM3F 2021, Malaysia*, pp. 99-107, 2022.
- [44] Wan Ab Naim WN, Junid R, Mohamed Mokhtarudin MJ, Nik Mohamed NA, editors. "Design and development of polymeric ink material for a solvent-cast direct-write 3D printer," *Proceedings of the Annual Congress of the Asia-Pacific Society for Artificial Organs*, pp. 289-299, 2024.

- [45] C. Wang, L. Zhang, Y. Fang, and W. Sun, "Design, characterization, and 3D printing of cardiovascular stents with zero poisson's ratio in longitudinal deformation," *Engineering*, vol. 7, no. 7, pp. 979-990, 2021.
- [46] M. F. de Oliveira, L. C. E. da Silva, and M. G. de Oliveira, "3D printed bioresorbable nitric oxide-releasing vascular stents," *Bioprinting*, vol. 22, p. e00137, 2021
- [47] C Flege, F Vogt, S Höges, L Jauer, M Borinski, VA Schulte, et al., "Development and characterization of a coronary polylactic acid stent prototype generated by selective laser melting," *Journal of Materials Science: Materials in Medicine*, vol. 24, no. 1, pp. 241-255, 2013.