Low Profiled Angiographic Catheter with Enhanced Pushability and Flexibility: A Novel Design, Fabrication, and *in-Vitro* Analysis

Hafsa Inam, Murtaza Najabat Ali and Aimen Arshad
Biomedical Engineering and Sciences Department, School of Mechanical and Manufacturing Engineering (SMME), National University of Sciences and Technology (NUST), Islamabad, Pakistan

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Abstract: The diagnostic angiographic catheter (DAC) available in the market have improved the survival rate and are the result of extensive R&D, but there's still room for improvement in terms of catheter profile, enhanced pushability, and trackability therefore, the current research focuses on the development of laser-cut reinforced shaft catheters in an attempt to design a low-profile DAC with enhanced pushability and trackability. A new 'I' hollow geometry has been used to fabricate reinforced shafts. Stainless Steel 304 was selected as a material to fabricate a laser-cut reinforced shaft and PTFE and PEBAX® for inner lumen and catheter jacketing. This study analyzes and reports the design, performance, and behavior of laser-cut reinforced shaft catheters. The 'I' geometry of laser-cut reinforced shaft catheter differed from braided catheters based on ovality retention, enhanced flexural rigidity, and pushability; the pushability force analysis results prove that laser-cut reinforced shaft catheter exerts a minimal resistive force which is approximately 1/3rd times less than the braided catheter. This study also endeavored to manufacture a significantly lower wall thickness for reinforced angiographic catheters. Based on this extensive in-vitro assessment, it has been concluded that laser-cut reinforced shaft catheter performed better in advancement force and flexibility than the braided catheter. In performance evaluation, the laser-cut reinforced shaft catheter has outperformed 16 and 32 wires braided catheters, exhibiting an exceptionally minimal pushability force of 6.25 N.

1 INTRODUCTION

Atherosclerosis is the buildup of plaque inside coronary arteries; as plaque continues to accumulate in artery walls, arteries tend to stiffen, causing narrowing and blockage of arteries, and not getting enough blood supply to the heart muscle can lead to chest pain (Mozaffarian D, 2016) (Roth, 2017) (Prabhakaran D, 2018) (Moran AE, 2014) (Sampasa-Kanyinga H, 2015) (Heart, 2022), (Lappegård, Kjellmo, & Hovland, 2021), (Lorkowski & Smith, 2022), (Kostromina, et al., 2022).

The major advantage of coronary angiography is precisely identifying the narrowed artery leading to the instantaneous decision of requirement of coronary angioplasty or stent implantation. Angiography has evolved into a safe and frequently used component of cardiac catheterization due to advancements in catheter design, radiographic imaging, contrast media, and the introduction of therapeutic choices for the treatment of coronary artery disease. (Baim, 1986), (Ghelfi et al., 2022).

Immediate complications during coronary angiography include problems with an angiographic catheter such as catheter advancement, pushability, kinking trackability, torqueability, vascular damage, perforation site pain, and discomfort; later complication includes vascular spasm, tissue damage caused by X-ray radiation if the procedure is prolonged, damage to the kidneys caused by the contrast dye, and heart attack. (NHS, 2021), (Liao, et al., 2022). Laser-cut tubing (LCT) uses a focused laser to ablate through a metal or polymer tube wall before removing the deteriorated material using a high-pressure coaxial gas nozzle. For more than 30 years, the method has been employed in medical device manufacture, with substantial breakthroughs following the push for miniaturization for minimally invasive treatments (Kevin Hartke, 2020). A mechanism to achieve a laser-cut catheter-reinforced shaft was theoretically introduced by Liam (Liam

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Farrissey, 2004) previously, based on the variable pitch of the proximal and distal end of the catheter's shaft as the proximal end requires more stiffness and enhanced pushability, whereas distal end requires flexibility.

This research work, laser-cut angiographic catheter, was inspired by the laser-cut hypotubes, which are being used in angioplasty catheters, as first mentioned by Liam Farrissey in 2004, who explained the requirement of variable flexibility and stiffness throughout the length of the catheter. Therefore, this research work aims to develop a novel manufacturing approach comprising disruptive manufacturing and additive manufacturing techniques to produce a laser-cut reinforced layer, also known as torque transfer layer and laser-cut reinforced angiographic catheter. This study also endeavored to manufacture a significantly thin-walled angiographic catheter.

The structural parameters of the catheter of this research are critical in achieving kink-free, pushability, and flexibility. Higher values for the 'I' slotted pattern and higher pitch between rows of slotted 'I' can provide more flexibility and, therefore, better torque response to rotating the distal end of the catheter as per the cardiologist's need. The use of lumen and jacket polymer coatings (which may extend into and interface with each other through the laser-cut lines) allows the 'I' slotted pattern to flex without plastic deformation. Thus, a closer pitch in the distal end will enhance flexibility which is desirable while moving through tortuous anatomy.

2 MATERIAL AND METHODS

2.1 Design Considerations of the Catheter shaft

The design of catheter geometry of the present laser-cut catheter reinforced shaft is built with a plurality of unit cells shown in Figure 1(b), interconnected with the help of horizontal and vertical edges to form an 'I' pattern and gaps. The design width (DW) and design length (DL) of the 'I' pattern remain the same; however, the pitch varies from proximal to the distal end. The proximal and distal shaft dimensions are 900 mm and 100mm, respectively. The tube has a 1.8mm outer diameter having a wall thickness of 0.1mm (Hafsa Inam, 2022).

To develop a hollow 'I' patterned geometry and configure it into a tubular reinforced layer form, Stainless Steel 304 was selected as a material. PEBAX® and PTFE hollow tubes were acquired to construct 'I' patterned reinforced shaft geometry into a laser-cut reinforced catheter configuration. The inner lumen of the catheter was lined with thin-walled polytetrafluoroethylene (PTFE), as it has a lower coefficient of friction to reduce the advancement resistance when going through the mock vascular system. Flouropeels heat shrink extruded tube was acquired to fuse all polymeric layers to the laser-cut reinforced shaft for the development of the catheter.

2.1.1 Development of Laser Cut Shaft for Angiographic Catheter

Laser Cutting of the Catheter's Reinforced Shaft

The thermo-mechanical cutting method by computerized numerical control (CNC) guided laser was adopted to fabricate a laser-cut reinforced catheter shaft (Silvio Genna, 2020). The laser cutting method employed in this study was further optimized, and the fabrication of the catheter reinforced shaft was conducted on a realistic size of 6 French angiographic catheters. Medical grade stainless steel 304 tube, commercially known as "18-8 stainless steel," was procured from Hechuang Hitech China based on its highly anti-corrosive and durable properties (Medical Grade & Surgical Stainless Steel, 2022); these hollow 'I' patterned geometry was manufactured specifically for medical applications. The stainless steel 304 tube was 0.1mm thick, as illustrated in Figure 1 (c), and the overall length of the reinforced tube was 1000mm, as illustrated in Figure 1 (d).

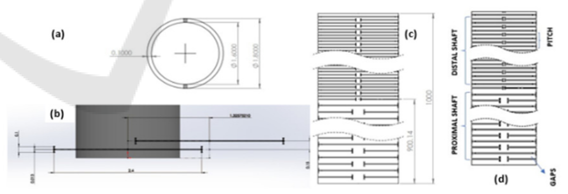

Figure 1: (a) Outer Diameter, Inner Diameter and Wall Thickness of Metallic tubing (b) The unit cell is hollow 'I' pattern (b) 'I' hollow pattern measurements (c) The geometry for the proximal and distal end of the angiographic catheter's reinforced shaft (d) Illustration of 'I' pattern drawing from proximal to the distal end of catheter reinforced tubing. To fabricate an 'I,' pattern laser-cut catheter reinforced shaft, a Star Cut CNC guided laser system was used; the in-process image is shown in fig.2 (a).

The 2D hollow 'I' geometry DXF design was fed into high precision fiber laser cutting machine's software, Preco RT1000, and the laser system emitted optical energy in an invisible infrared beam. The laser system used a laser power of around 150W to cut the workpiece material.

Process of Acid Pickling

Acid pickling solution (150 mL) for the laser-cut reinforced tube was prepared using pickling solutions consisting of hydrofluoric acid and nitric acid. The catheter tubing was immersed in 150 mL of pickling solution and ultrasonicated for 15 mins. Subsequently, the laser-cut catheter tubing was rinsed with warm water and air-dried. The whole process is shown in Figure 2(b, c, d).

Passivation Process

The passivation solution consisted of nitric acid as it is an oxidizing acid and is always used. Acid-pickled laser-cut tubing was dipped in the nitric acid solution for 5 minutes to create a passivated layer; catheter tubing was removed, washed with DI water, and dried with air, as shown in Figure 2(e, f, g).

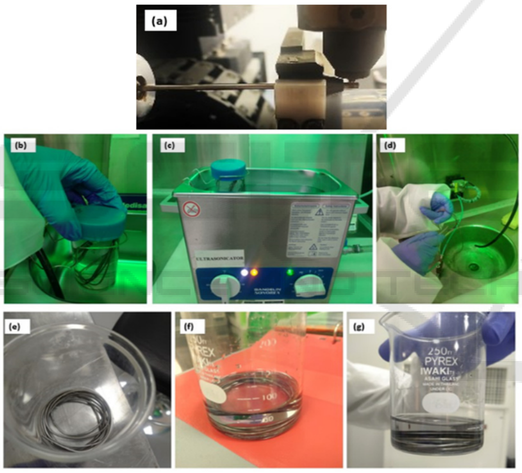

Figure 2: (a) Laser-cutting of catheter reinforced shaft (b, c, d) Acid Pickling processes & (c, d, and f) passivation processes of the laser-cut reinforced shaft.

2.1.2 Development of Laser Cut Angiographic Catheter

PEBAX® 7233 extruded jacket tubing and the PTFE inner lumen were sourced from Zeus (USA). PTFE monofilament mandrel having an outer diameter of 1.57mm was used as the inner lumen. A peelable heat-shrink tubing was used as an external layer to facilitate polymer fusion to laser-cut catheter-reinforced shaft.

Thermal Fusion of Polymeric Jacket and PTFE Extruded Tubing

In this process, PTFE, as the inner lining of the catheter-reinforced shaft, mounted on a PTFE mandrel, was inserted in passivated laser-cut catheter-reinforced shaft. An extruded PEBAX® jacketing, 7233 (72D durometer), was used to cover the reinforced shaft. A heat shrink, having an inner diameter of 2.10mm, was used as an external layer to combine the whole material. The arrangement is illustrated in Figure 3(a). The whole shaft was then exposed to 170°C for 15 minutes in a pre-heated forming oven. After completing the process, the catheter tubing was cooled down, and heat shrink was removed. The polymer-fused catheter-reinforced shaft is shown in Figure 3(b).

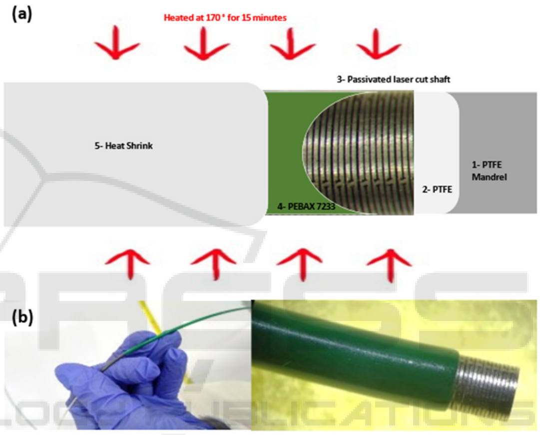

Figure 3: Illustration of the polymeric and metallic layer layering, depicting heat fusion process (b) Polymeric jacket fusion on the laser-cut reinforced shaft after removal of heat-shrink tubing.

Soft Tip and Distal Tube Shaping of Novel Angiographic Catheter Shaft Using a Thermoforming Process

The preparation of a novel angiographic catheter was conducted by welding a soft tip, PEBAX® 35D durometer (CUUMED Taiwan), and tapering. A female luer lock, polycarbonate, was attached at the proximal end using Loctite, a medical-grade glue. To shape the distal end of the catheter, the catheter shaft is assembled in Judkins right die Figure 4 (a); the whole shaft was then placed in a pre-heated longitudinal oven at 150°C for 15 minutes using assembling mandrels, Figure 4 (b, c). After completing the distal shaping process, the catheter was removed from the thermoforming machine and eventually from forming die.

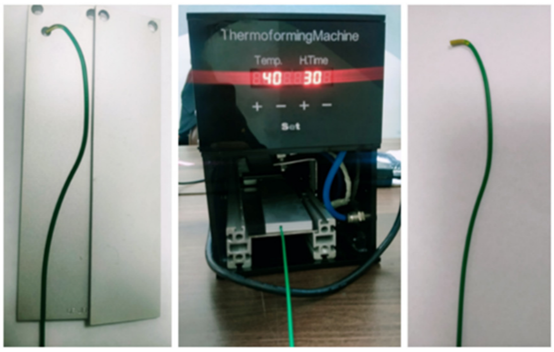

Figure 4: (a); the whole shaft was then placed in a pre-heated longitudinal oven at 150°C for 15 minutes using assembling mandrels, (b, c). After completing the distal shaping process, the catheter was removed from the thermoforming machine and eventually from die.

3 RESULTS

3.1 Characterization, in Vitro Mechanical and Performance Testing

The novel reinforced DAC was characterized, and its performance was evaluated in comparison with a commercially available catheter. In vitro mechanical testing was carried out to analyze and evaluate the mechanical performance of the laser-cut reinforced shaft and laser-cut reinforced angiographic catheter. A hemolysis test was carried out as per ASTM F756, physical tests were carried out as per ISO 10555-1:2013+A1:2017, and pushability testing was carried out on a mock arterial system developed on ASTM F2394.

3.2 Statistical Analysis

All experimental approaches were executed in triplicates. Results are represented as mean ± standard deviation, $n \geq 3$. Statistical analysis was done to analyze the differences between the experimental results, and a value of $p < 0.05$ was considered significant.

3.3 Analysis of Laser-Cut Metallic Shaft Fabrication

Formation of 'I' Geometry Pattern

The laser-cut reinforced shaft design pattern comprising a hollow 'I' pattern was cut by interpolating 304 stainless steel tubing movements in both linear and rotational directions. A thin stainless-steel tubing of 0.1mm thickness with hollow 'I' geometry is shown in FigureFigure 5(a). The reinforced shaft has wider gaps in the proximal end whereas tighter gaps in distal end making distal end of reinforced metallic shaft more flexible.

Effect of Pickling on the Laser-Cut Reinforced Shaft Design

Acid pickling is the smoothest method to remove slag and impurities from metallic surfaces. Slag was removed from the laser-cut metallic reinforced shaft during the acid pickling process as the smoother surface of the acid pickled shaft is shown in Figure 5 (b). After acid pickling, the unit cells (hollow I pattern) and laser-cut metallic reinforced shaft geometry were visible.

Achievement of Passivation

The surface peaks and valleys (i.e., surface roughness) were removed, and material reduction and surface smoothness were obtained by dipping the laser-cut metallic shaft in passivation solution consisting of nitric acid. As depicted below in Figure 5 (c), the surface definition and characteristics were significantly improved after passivation.

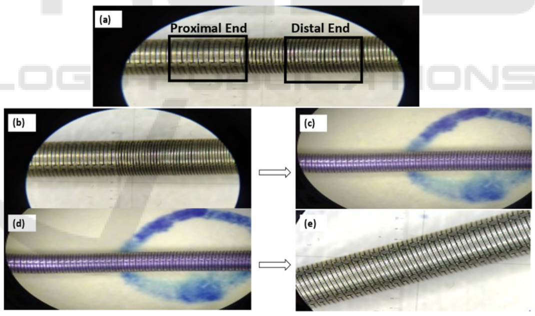

Figure 5: (a) 'I' patterned geometry of Laser Cut Metal Shaft (Proximal and Distal End of Angiographic Catheter) (b and c) Effect of pickling on the laser-cut reinforced shaft design (slags were removed) (d and e) Effect of passivation on the laser-cut reinforced shaft design (the shaft surface was passivated).

Quantitative analysis was conducted by Ultraviolet (UV) Spectrophotometry at 550nm wavelength of the supernatant as the absorbance range of hemoglobin is 520-550nm. As shown in Figure 6, the quantitative analysis results revealed that the laser-cut reinforced shaft showed 1.27%. The laser-cut reinforced catheter showed 1.48% hemolysis while negative control with 0% hemolysis. The laser-cut reinforced shaft and laser-cut reinforced catheter cause <2% hemolysis when directly encountering blood, as presented in Figure , categorizing them as non-hemolytic (ASTM F756, 2017).

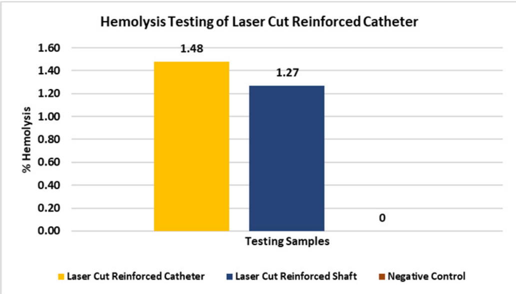

Figure 6: Hemolysis Testing of Laser Cut Reinforced Shaft & Catheter. The laser-cut reinforced shaft and laser-cut reinforced catheter cause <2% hemolysis when directly encountering blood, categorizing them as non-hemolytic.

Initially, a laser-cut metallic reinforced shaft was used to prepare the tubing from the proximal and distal end to measure the baseline tensile data of the laser-cut metallic reinforced shaft material as per ISO 10555-1. Therefore, two catheter specimens, proximal and distal end, were prepared by carefully cutting the catheter tubing, 10.0mm long, having an outer diameter of 2.00mm. A SHIMADZU AG-X plus series tensile tester was used in this study. The equipment was initially calibrated, and the laser-cut metallic reinforced shafts specimen from the proximal and distal ends were then evaluated. The same test was repeated twice, and the mean of the baseline stress-strain data for the proximal and distal end of laser-cut metallic tubing was taken. After getting the baseline data, the proximal and distal end of the catheter specimen was tested. The proximal end of catheter tubing exhibits a higher stress/strain ratio than the distal end, as shown in Figure 7.

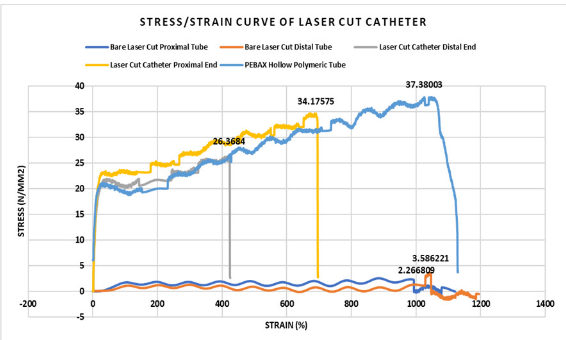

Figure 7: Stress/Strain Curve of Laser Cut Reinforced shaft, laser-cut reinforced catheter, and hollow PEBAX tubing.

Tensile strength of laser-cut reinforced catheter along with laser-cut metallic reinforced shaft was carried out, and optimal results were received, compared with Dxterity™ Medtronic (Medtronic, 2016), a fully braided catheter, having round-wire braid configuration of 2x1 (32 wires). Infiniti Cordis® and Angiodyn® BBraun consist of the non-braided distal end. Upon comparison with the fully reinforced laser-cut angiographic catheter, Infiniti® Cordis and Angiodyn® BBraun, Dxterity™ (Figure 8) exhibited a tensile strength of 16.24g, Angiodyn® experienced 33.8g, and Infiniti® experienced 22.7g. The laser-cut reinforced catheter exhibits 37.4g stress which is most significant compared to commercial catheters.

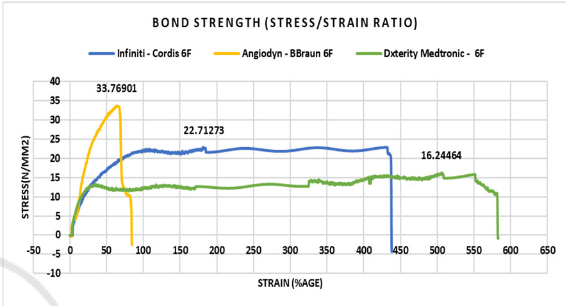

Figure 8: Stress/Strain of Commercial Catheters (Infiniti Cordis, Angiodyn BBraun, Dxterity Medtronic).

The laser-cut reinforced catheter yielded an average flow rate of 63.17mL/minute, as shown in Figure 9 as per ISO 10555-1 standard requirement.

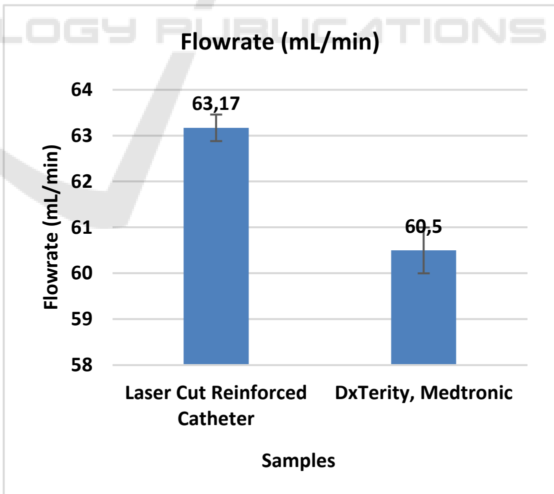

Figure 9: Laser cut Catheter - Flowrate (ml/min).

Figure 10 (a) exhibits the flexural rigidity of the proximal and distal end of the laser-cut metallic shaft, where the distal end experienced a maximum force of 5.0g when moved to 90-0°. In contrast, the proximal end experienced a maximum force of 15.0g.

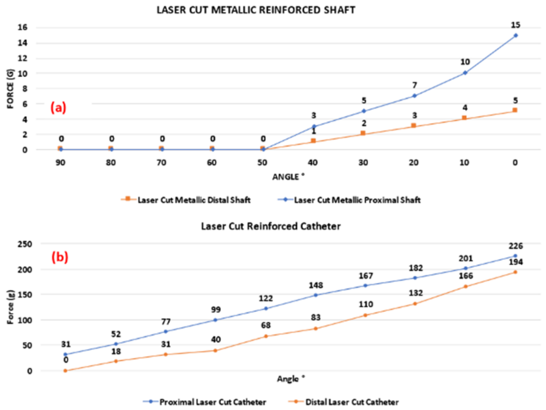

Figure 10: (a) Flexural Rigidity of Proximal and Distal end of Laser-Cut Metallic Shaft, The proximal end of the laser-cut reinforced catheter experienced a maximum force of 15.0g when moved from 90-0°, whereas the distal end of the laser-cut reinforced catheter experienced a maximum force of 5.0 g (b) Flexural Rigidity of Proximal and Distal end of Laser-Cut Reinforced Catheter, The proximal end of the laser-cut reinforced catheter experienced a maximum force of 226.0g when moved from 90-0° whereas the distal end of the laser-cut reinforced catheter experienced a maximum force of 194.0g.

Figure 10(b) illustrates the flexural rigidity of the distal and proximal end of the laser-cut reinforced catheter. The proximal end of the laser-cut reinforced catheter experienced a maximum force of 226.0g when moved from 90-0°. In contrast, the distal end of the laser-cut reinforced catheter experienced a maximum force of 194.0g, which is less than the proximal shaft. These results depict the distal end as more responsive to external forces than the proximal end of the catheter, whose characteristic is to maintain its patency when subjected to external stresses.

Kinks usually occur with counterclockwise rotation when trying to engage the left coronary artery and with clockwise rotation when engaging the right coronary artery. The best prevention is to refrain from rotating the catheter more than 180° to prevent the

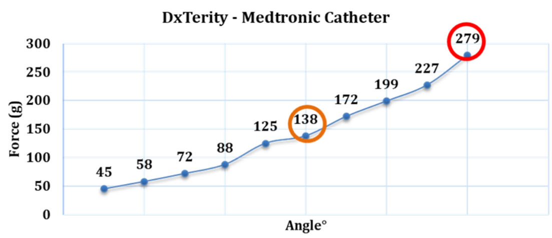

Figure 11: Dxterity™ Medtronic double braid (2x1, 32 wire) began to kink, and loss of ovality initiated at 40° (shown in green circle), and kinking, loss of braid ovality and integrity were noted at 0° (shown in red circle).

build-up of torque proximally that is not transmitted to the catheter tip (Itsik Ben-Dor, 2018).

Laser-cut reinforced catheter exhibited an average advancement force of 624.97g. Dxterity exhibited an average advancement force of 882.9g. **29.2%** lesser advancement force was used to push the catheter to the required point. **17.6%** reduced retraction force was recorded during retraction.

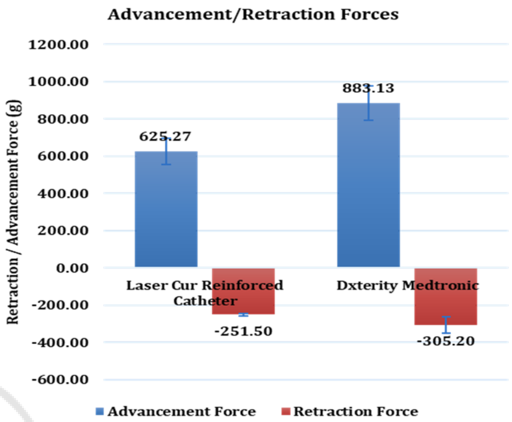

Figure 12: Laser-cut reinforced catheter exhibited an average advancement force of 624.97g. Dxterity exhibited an average advancement force of 882.9g. 29.2% lesser advancement force was used to push the catheter to the required point. 17.6% reduced retraction.

Along with a laser-cut reinforced catheter, Dxterity Medtronic was also evaluated; the distal shaft is hydrophilic coated to evaluate a fully braided catheter performance where it experienced a maximum resistive force of 922.1g and a retractive force of -402.3g. However, laser-cut reinforced catheters and Dxterity catheters lost their distal shapes after continuous usage.

4 DISCUSSION

The objective of this study was twofold: (I) designing and manufacturing a laser-cut metallic reinforced shaft in a novel way and (II) configuring this laser-cut metallic shaft as a laser-cut reinforced catheter for radiopaque media delivery.

The stiffness and flexural rigidity of various shafts may be assessed using two and three-point bend tests or other deflection-based techniques. With this knowledge, the stiffness of the adjacent shafts may be adjusted to provide a virtually perfect transition. The laser-cut metallic catheter shaft and laser-cut reinforced catheter, as shown in Figure 10, exhibit the flexural rigidity of the proximal and distal end of a laser-cut metallic shaft, where the distal end experienced the maximum force of 5.0g when moved to 90-0°, whereas proximal end experienced a maximum force of 15.0g. Figure 10 illustrates that the proximal end of the laser-cut reinforced catheter experienced a maximum force of 226.0g when moved from 90-0°, whereas the distal end of the laser-cut reinforced catheter experienced a maximum force of 194.0g, which is less than the proximal shaft. To deliver radiopaque media to coronary arteries, high pressures are required. The laser-cut reinforced catheter must maintain lumen patency and endure high pressure to avoid any vessel injuries. Laser-cut reinforced catheter can endure 1000psi static burst pressure and power injection pressure of 1200psi when evaluated on a liquid pressure tester; however, the simulation study of the design exhibited endurance till 700psi (Inam, 2022). Injecting radiopaque media multiple times during an angiographic intervention might become necessary. Therefore, not only flexible behaviours but also pressure endurance is important.

In this study, due to the limited availability of medical extruders, the direct extrusion method can be adopted to develop angiographic catheters so that cost and time can be saved.

5 CONCLUSIONS

As the medical device industry is evolving at a higher pace, there is a great need to improve the angiographic treatment of coronary heart disease patients suffering from narrowed coronary arteries. All available angiographic catheters are braided in nature; the flat and round wire braids are used as a sandwich layer between two polymeric layers. There are mainly three costs involved in the placement of an angiographic catheter to the targeted site (i) fluoroscopic guidance, (ii) angiographic catheter, and (iii) patient-specific radiopaque dye. Furthermore, due to the compromised radial strength and flexibility/ pushability tradeoff within a low-profile angiographic catheter, catheters may require a few episodes of retraction to reach the targeted site. This research was conducted with the aim of using the unique hollow 'I' pattern geometry for the development of a novel laser-cut metallic reinforced shaft and laser-cut reinforced angiographic catheter, which demonstrates to provide better pushability of 625 0g, keeping catheter profile to lower end. One of the critical questions addressed in this research is the deployment of the significantly lower profile, 2.00mm outer diameter of the catheter without compromising pushability and flexibility. The fabrication route also determines the enhancement of hydrophilicity.

The outcome of the comparative analysis, which was conducted based on the results obtained from the manufacturing and surface characterization study, clearly showed that the laser cutting method is an effective and rapid way of producing flexible, lower-profile reinforced shaft. It was also established that laser cutting of stainless-steel tubes to produce flexible lower profile reinforced shaft would avoid the problem of continuous ovality throughout. The distal tube shaping of the laser-cut angiographic catheter by complete thermal exposure was found to be more efficient and enhanced the hydrophilic properties of the catheter (71.3° angle depicts hydrophilicity of the catheter). It is envisaged that the laser-cut reinforced angiographic catheter comprising of variable geometry patterns from proximal to the distal end provides betters flexibility and flexural rigidity of an average of 210g without compromising on the advancement force; this feature of the laser-cut reinforced catheter has an advantage over the commercially available braided catheter. Building on the current findings, clinical studies on the robust use of this catheter as part of a radiopaque media delivery functionality in medical devices may be conducted.

REFERENCES

ASTM F756. (2017, april 19). Standard Practice for Assessment of Hemolytic Properties of Materials. *ASTM F756-17*. ASTM.

Baim, D. &. (1986). Coronary angiography. In M. Mauro Moscucci MD, *Cardiac Catheterization, Angiography, and Intervention.* Philadelphia, USA.

Ghelfi, J., Bacle, M., Stephanov, O., de Forges, H., Soulairol, I., Roger, P., Frandon, J. (2022). Collagenase-Induced Patellar Tendinopathy with Neovascularization: First Results towards a Piglet Model of Musculoskeletal Embolization. *Biomedicines*.

Hafsa Inam, M. N. (2022). Design Development and Modeling of the Laser-Cut Reinforced Shaft for Radiopaque Media Delivery to Coronary Artery Using Finite Element Method: Laser cut catheter reinforced shaft." . *12th International Conference on Bioscience, Biochemistry and Bioinformatics* (pp. 101-107). Tokyo Japan: ACM.

Heart, A. (2022, 13 02). *American Heart Association Coronary Artery Disease – Coronary Heart Disease.* Retrieved from heart.org: https://www.heart.org/en/health-topics/consumer-healthcare/what-is-cardiovascular-disease/coronary-artery-disease

Inam, H. N. (2022). Design Development and Modeling of the Laser-Cut Reinforced Shaft for Radiopaque Media Delivery to Coronary Artery Using Finite Element Method: Laser cut catheter reinforced shaft. . *12th International Conference on Bioscience, Biochemistry and Bioinformatics.* Tokyo, Japan: ACM.

Itsik Ben-Dor, T. R. (2018). Reduction of catheter kinks and knots via radial approach. *Catheter CardiovascInterv.*, 1141–1146.

Kevin Hartke. (2020, January). *Enhanced catheter performance made possible with laser cut tubing.* Retrieved from https://resonetics.com/wp-content/uploads/2020/03/Laser-Cut-Tubing-White-Paper-.pdf

Kostromina, M., Tukhovskaya, E., Shaykhutdinova, E., Slashcheva, G., Ismailova, A., Palikov, V., . . . Lykoshin. (2022). Screening of the Promising Direct Thrombin Inhibitors from Haematophagous Organisms. Part I: Recombinant Analogues and Their Antithrombotic Activity In Vitro. . *Biomedicines* .

Lappegård, K., Kjellmo, C., & Hovland, A. (2021). High-Density Lipoprotein Subfractions: Much Ado about Nothing or Clinically Important? . *Biomedicines*.

Liam Farrissey. (2004, December). *Metal Shafts: Designs To Meet The Required Performance.* Retrieved from Creganna: https://www.creganna.com/wp-content/uploads/metalshaft.pdf

Liao, M.-T., Lai, C.-L., Wang, T.-C., Lin, J.-W., Ho, Y.-L., & Chan, K. (2022). Red Cell Distribution Width and Mortality in Patients Undergoing Percutaneous Coronary Intervention. . *Biomedicines* .

Lorkowski, S., & Smith, J. (2022). HDL Is Not Dead Yet. . *Biomedicines* .

Medical Grade & Surgical Stainless Steel. (2022). Retrieved from Bergsen Medical: https://bergsen.com/medical-surgical-stainless-steel

Medtronic. (2016). *DxTerity™ diagnostic catheters*. Retrieved from https://www.medtronic.com/us-en/healthcare-professionals/products/cardiovascular/catheters/dxterity.html

Moran AE, F. M. (2014). Temporal trends in ischemic heart disease mortality in 21 world regions, 1980 to 2010: the Global Burden of Disease 2010 study. . *Circulation.*, 1483–1492.

Mozaffarian D, B. E. (2016). Heart disease and stroke statistics-2016 update. A report from the American Heart Association. *Circulation.* .

NHS. (2021, 12 03). *Risks, Cardiac catheterisation and coronary angiography*. Retrieved from NHS: https://www.nhs.uk/conditions/coronary-angiography/risks/

Prabhakaran D, J. P. (2018). The changing patterns of cardiovascular diseases and their risk factors in the states of India: the Global Burden of Disease Study 1990-2016. *Lancet Glob Health.*, 1339–1351.

Roth, G. A.-A. (2017). Global, regional, and national burden of cardiovascular diseases for 10 causes, 1990 to 2015. *Journal of the American college of cardiology*.

Sampasa-Kanyinga H, L. R. (2015). Frequent use of social networking sites is associated with poor psychological functioning among children and adolescents. . *Cyberpsychology Behav Soc Netw.* , 380–385.

Silvio Genna, E. M. (2020). Experimental Investigation of Industrial Laser Cutting: The Effect of the Material Selection and the Process Parameters on the Kerf Quality. *Applied Sciences , MPDI*.