3D Printing of Conducting Polymer Devices for Electroceutical Management of Bacterial Biofilms

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ABSTRACT

Today, antibiotic-resistant bacteria represent a global health challenge, especially for the control of catheter-associated urinary tract infections (CAUTI). Conventional antibacterial treatments for CAUTI require a high dose of antibiotics that could cause side effects in the patients. For this reason, it is necessary to develop effective antibacterial therapies that require less amount of antibiotics.

Recent studies indicate that some electro-therapies are promising alternatives to avoid the growth of bacterial films in some metallic implants. However, to apply this concept to address CAUTI, it is necessary to develop biocompatible materials and urinary catheters with the required mechanical and electrical properties.

Therefore, the present work aims to explore the viability of integrating 3D printed conductive polymer catheters in an electrotherapy to fight against CAUTI. For this purpose, catheters (small tubes) were 3D printed using a commercial (Protopasta®) and different lab-made conductive filaments. These thin threadlike materials were fabricated via extrusion using a solvent-free method and activated carbon as the filler.

After growing E.coli biofilms on the surface of the 3D printed structures, these were integrated into an electro-therapy system to study their performance. Mechanical and electrical properties of the fabricated materials were also evaluated via tensile test and impedance spectroscopy.

Preliminary qualitative results indicate that the proposed electro-therapy has the potential to eliminate biofilms of E.coli bacteria growth onto the 3D printed conductive catheter models.

The materials characterization experiments suggest that all the fabricated materials exhibit lower elastic module and tensile strength than Protopasta®.

Regarding the electrical properties, some of the fabricated filaments exhibit higher electrical conductivities than the commercial material. This result is promising, since one of the drawbacks of Protopasta® is its limited electrical conductivity.

INTRODUCTION

Urinary catheters are commonly used in patients with urinary retention or urinary incontinence. About 15 – 25% of hospitalized patients need urinary catheters.[1] The use of these medical devices comes with risk of complications to the patients. One of the most common issues is the development of nosocomial urinary tract infections known as catheter associated urinary tract infections (CAUTI).[2] It accounts for approximately one-third of all device-related infections and 40% of the hospital-wide infections.[3] The high incidence of CAUTI has a severe impact on human health and health care costs.

Among the bacteria that causes CAUTI is Escherichia coli (E. coli), which migrates along the exterior or internal lumen of the catheter. Over the last decades, this kind of bacteria has become more resistant to antibiotics, creating biofilms inside the catheters.[1] Biofilms are complex differentiated communities comprising multiple associations of cells and extracellular polymeric substances (EPS). The bacterial wall formed inside the catheters, acts not only as a barrier for the flow of fluid but also as a barrier for the antibiotics provided to the patients.

Due to bacteria becoming more antibiotic resistant, it is necessary to explore new ways to combat CAUTI in the health-care industry. Recently, electro-therapy has gained attention as one of the most promising alternatives to overcome this global health challenge. Current literature suggests that when electric current is applied to some bacteria biofilms, the bacteria's membranes become more permeable, which facilitates the work of the antibiotics.

This promising electro-therapy requires the design and fabrication of novel urinary catheters that are biocompatible, electroconductive, and chemically and mechanically resistant to the urine environment.

Additive manufacturing (AM), also known as 3D printing, is a new technology that can be integrated in all types of industries. This new process is very beneficial for the medical device industry, since it has the potential to act as a form of personalized medicine by creating devices customized to the patient's anatomy and needs.

The present work aims to explore the viability of integrating 3D printed conductive polymer catheters in an electro-therapy to fight against CAUTI. For this purpose, catheters (small tubes) were 3D printed using a commercial (Protopasta®) and different lab-made conductive filaments. After growing E.coli biofilms on the surface of these 3D printed structures, these were integrated into an electro-therapy system to study their performance.

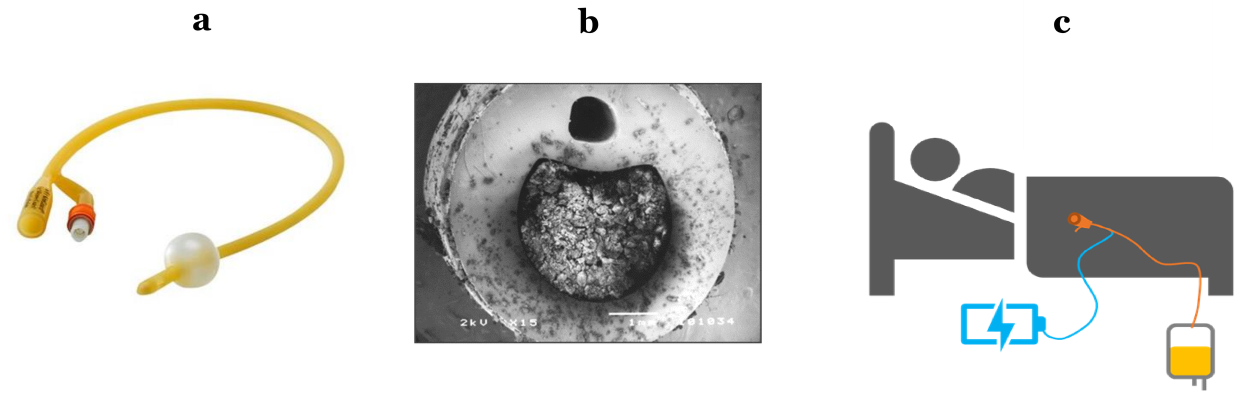


Figure 1: (a) Two-way catheter -30 cc balloon capacity, (b) Cross-sectional image of a catheter removed from a patient after blockage with biofilms, (c) Futuristic electro-therapy to prevent CAUTI.

OBJECTIVES

This research project has three main objectives:

(1) Determine the feasibility of integrating 3D printed conductive polymer catheters into an electro-therapy to help combat antibiotic resistant bacteria causing CAUTI.

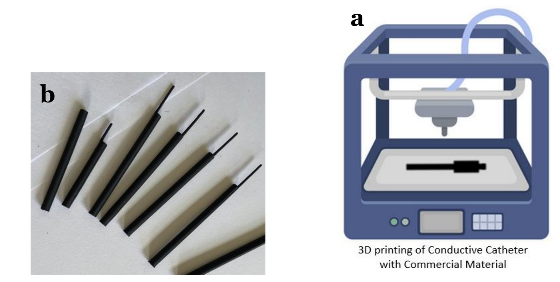
(2) Fabricate conductive polymer filaments with enhanced electrical and mechanical properties as compared to the conductive commercial material.

(3) Determine the performance of the fabricated catheters in the proposed electro-therapy.

METHODOLOGY

3D Printing of Catheters Using a Commercial Filament

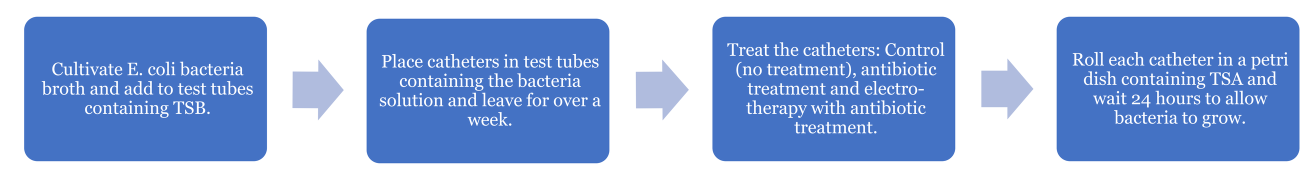
Figure 2: (a) The 3D printer machine and (b) 3D printed catheter models.



3D Printing Conditions:

1. Ender 3 Pro printer from Creality®
2. 0.2 mm nozzles heated at 200 °C
3. Glass bed heated at 60 °C
4. Printing speed set at 30 mm/s with line patterns

E.coli Biofilm-Coated Catheters



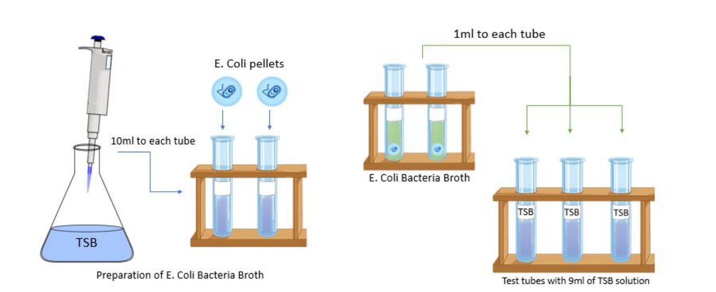


Figure 3: Preparation of E. coli broth and cultivation medium.

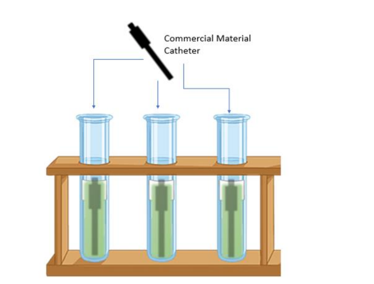


Figure 4: 3D printed catheters placed in the bacterial solution.

Electro-Therapy Experimental Set-Up

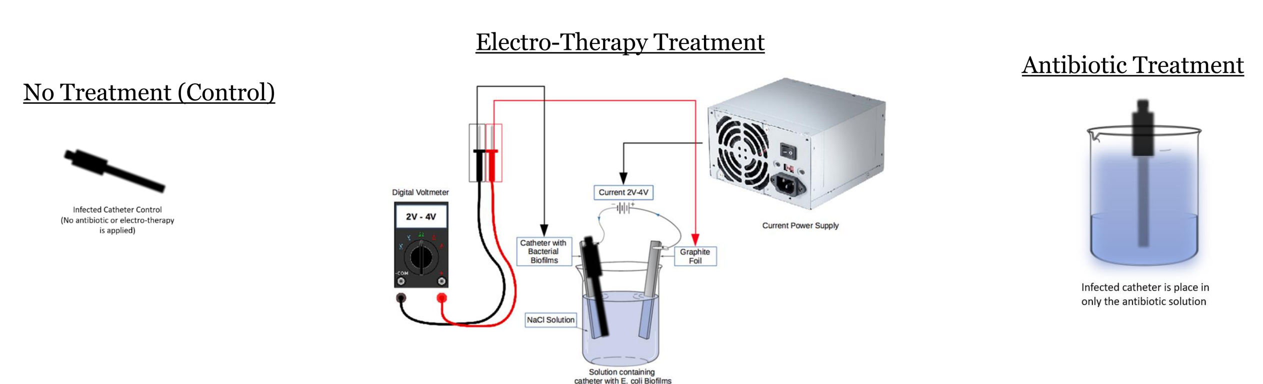
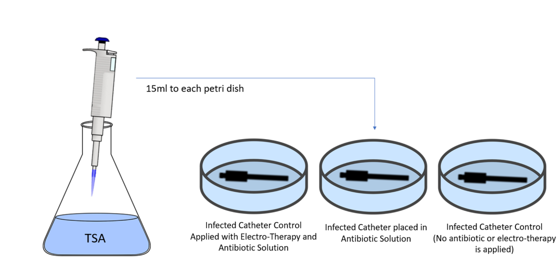


Figure 5: Different treatments applied on the E. coli biofilm-coated catheters.

Treatment Assessment

Figure 6: Catheters rolled on Petri dishes.



Filament Fabrication Process

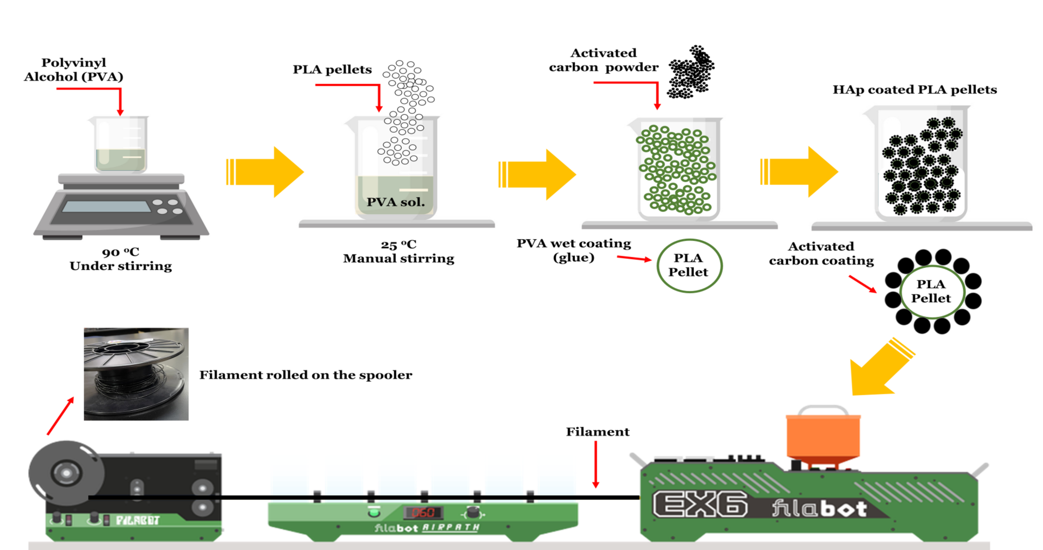


Figure 7: Filament fabrication process.

Temperatures of the extruder chamber in the Filabot EX6 were adjusted depending on the wt% of activated carbon content. For the recycling of the filaments, these were cut in small pieces and were added to the extruder hopper.

Nozzles of 0.2-mm and 1.0-mm were set at 200 °C, while the glass bed plate temperature was set at 60 °C. The printing speed was set at 30 mm/s with a line pattern.

To determine the electrical properties of the AC/PLA specimens, a Keysight 16451B dielectric attachment containing the sample was connected to a high-resolution E4990A impedance analyzer (IA). The conductivity values were determined at 30,000 Hz. To determine the mechanical properties of the specimens, tensile tests were carried out using a ADMET tensile test machine following a modified ASTM D638-14 standard.

PRELIMINARY RESULTS

Fabricated Materials and Specimens

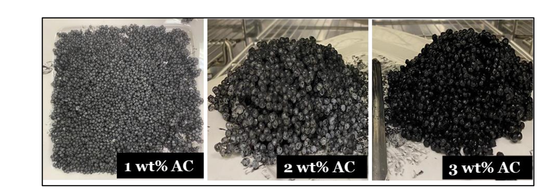


Figure 8: Coated PLA/AC pellets.

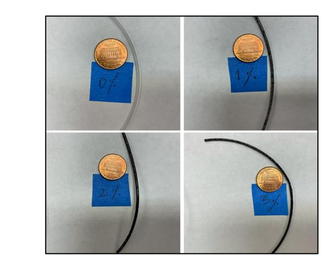


Figure 9: PLA/AC fabricated filaments.

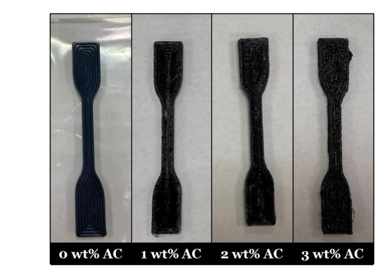


Figure 10: PLA/AC Dog-bone specimens.

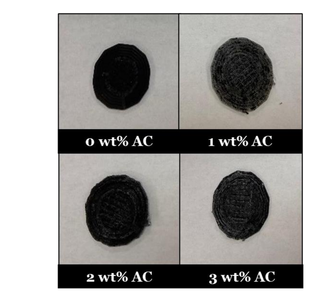


Figure 11: PLA/AC coin specimens.

Important: All the specimens were fabricated using nozzles with a diameter of 1 mm, since at smaller diameters (0.2mm), the fabricated filaments clog the nozzle aperture avoiding the flow of material.

Treatment Assessment

Figure 12: Petri dishes containing E. coli bacteria.

Electrical Characterization of Specimens

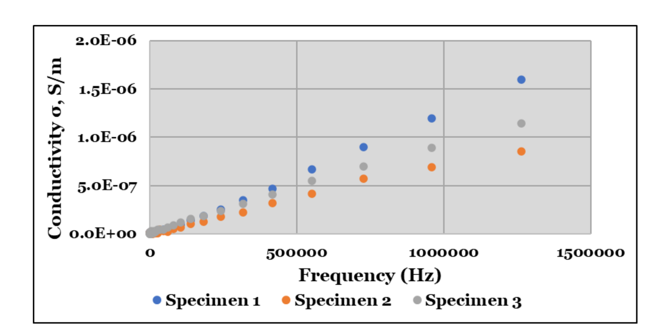


Figure16: Conductivity-frequency of PLA with 3 wt% of AC.

Table 1. Specimen conductivity at different AC wt%.

AC wt%	Conductivity (S/m)
Protopasta®	0.00031 ± 2.60E-08
1%	0.00037 ± 2.79E-08
2%	0.00031 ± 7.35E09
3%	0.00037 ± 1.86E-08

Mechanical Properties of Specimens

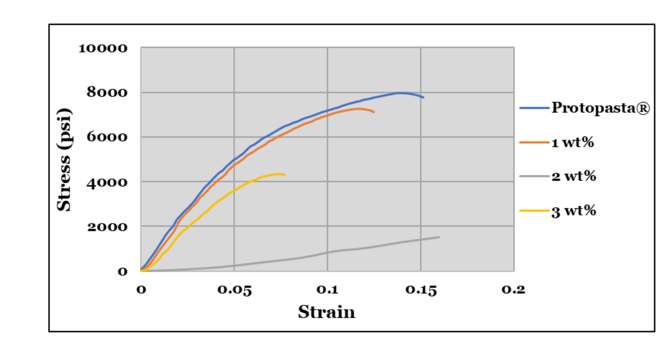


Figure 13: Stress-strain curves of different specimens (1, 2, and 3 wt% of AC and Protopasta®).

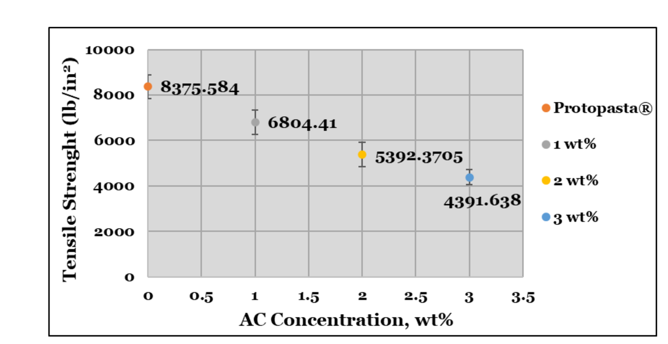


Figure 14: Tensile strength of different specimens (1, 2, and 3 wt% of AC and Protopasta®).

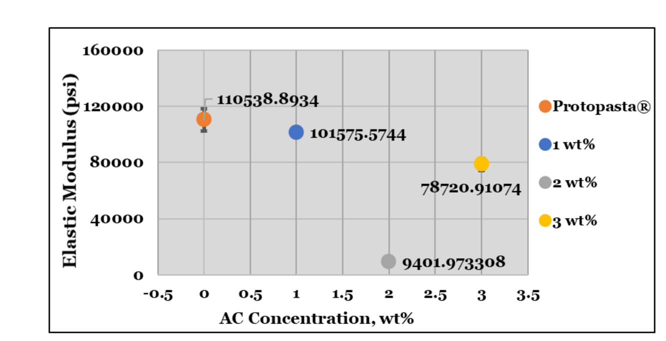


Figure 15: Elastic modulus of different specimens (1, 2, and 3 wt% of AC and Protopasta®).

CONCLUSIONS

- Preliminary results indicate that the proposed electro-therapy concept could be used as an alternative against antibiotic resistance of CAUTI causing bacteria. It is necessary to perform further experimental research.
- PLA/AC filaments having a composition of AC ≤ 3 wt% were fabricated via extrusion using a solvent-free coating method. At AC wt % > 3, the filament was to brittle to place in spooler. Selection of inappropriate temperatures of extrusion caused problems during the fabrication of filaments such as clogging of the nozzle and/or bubbles in filament.
- Tensile test analysis suggests that the commercial material (Protopasta®) exhibits better mechanical properties than the fabricated filaments. Both the elastic modulus and tensile strength decrease with the AC content in the specimens. These results suggest a poor interaction between the PLA and the filler. Sample with 2% AC are out of the trend.
- Impendence analysis suggests that the filaments fabricated with a concentration of AC of 1wt% and 3wt%, has a slightly higher electrical conductivity than Protopasta®. Samples with 2% AC are out of this trend.

FUTURE WORK & RECOMMENDATIONS

- Complete installation and training of new equipment: Test-Equity 101H-B Benchtop Temperature/Humidify Chamber and the Fluorescent Microscope to proceed with the electro-therapy concept and bacterial characterization.
- Perform electro-therapy experiments using the fabricated filaments to evaluate their performance.
- Obtain images of the microstructure of the fabricated filaments/specimens via Scanning Electron Microscopy (SEM) to understand their mechanical, electrical, and antibacterial performance.
- It is recommended to (1) implement a wet-based procedure to enhance the dispersion of the fillers in the polymer matrix (PLA), and (2) the use fillers of nanometric size to avoid nozzle clogging.

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