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3D PRINTED CANCER TRAP FOR METASTASIS OF CANCER

Nowmi Haider

3D PRINTED CANCER TRAP FOR METASTASIS OF CANCER

by

NOWMI HAIDER

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The fabrication of the cancer trap was performed in Dr. Tang's lab in the Engineering Lab Building at UT Arlington.

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ABSTRACT

3D PRINTED CANCER TRAP

FOR METASTASIS

OF CANCER

Nowmi Haider, B.S. Biomedical Engineering

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Faculty Mentor: Liping Tang

The goal of this project is to create a cancer trap that can be able to trap cancer cells by attracting them with slow-releasing cytokines that are loaded on a gel inside of the cancer trap. This will be used on patients who have metastatic cancer or when the cancer cells are starting to spread in other parts of the body. The cancer trap will be a cylindrical scaffold that is porous to let cells in. How the cancer trap will work is when it is placed in the body, there will be an inflammatory response, attracting immune cells and cytokines to the cancer trap. Also, the cancer trap can have other cytokines, like erythropoietin, included in it as well. These all can lure cancer cells, which are looking for these types of cytokines since they make a suitable environment for them. So the cancer cells will start migrating to the cancer trap and will stay inside since they will have their basic needs from the gel (which has nutrients) and because of the cytokine attracting it. The cancer trap itself is

being monitored, so it can be seen how many cells are coming into the trap. Once the cancer cells are in the trap, they can be killed by chemotherapy or radiation or be removed for diagnosis.

Multiple designs of the cancer trap will be made on SolidWorks, a 3D design software. The designs will then be printed on a 3D printer with PLA filament. They will all be tested for reproducibility on the 3D printer and for their porosity. Then the best trap will be chosen based on those criteria and will be used in future applications.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Cancer and Metastasis

Cancer is when cells in the body replicate out of control in a certain organ and start forming a mass called a tumor. This can occur from mutations, diet, heredity, and more. Cancer is a term that is well known worldwide due to its fatality, since it is currently an incurable disease. Much time, money, and effort has been put in to studying cancer in order to come up with solutions that can cure any cancer patient of their illness. However, this is not an easy task, since there are many types of cancers (lung, skin, brain, and breast cancer to name a few) and each type works in different ways. There is one thing that all of these cancers have in common though: metastasis.

Cancer goes through many stages. As many cells start to accumulate due to the rapidity of their reproduction, the cancer starts getting worse and worse. Eventually, the cancer starts trying to find new outlets in the body to go to. This is metastasis, when the cancer starts to spread to different places in the body. The cancer cells usually travel through the blood stream, but they are also able to travel through the lymph nodes. From there, they are able to reach different parts of the body, where they like to stay and reproduce. They then invade the organ and cause it to fail, leading to a higher chance of mortality for the person, or even death.

This research conducted over the study of this disease is an attempt to provide a way to fight or diagnose cancer once it has metastasized. Our method will focus on making a trap to capture the cancer cells metastasizing all over the body by 3D printing the trap.

1.2 3D Printing

There are four ways to manufacture products: etching, forming, additive and subtractive methods. 3D printing in particular is an additive method – it prints objects by adding layers and layers of material until the object is complete. There are many types of 3D printers. Some use lasers while others use melted down filament to 3D print the object. They also come in different sizes, depending on how precise you want the print to be. But in order for the 3D printer to print out an object, you must design that object first.

1.2.1 3D Printing Design Software

There are multiple types of software available to use to design a model to print. Solidworks®, Autocad®, and Tinkercad® are a few of the most popular. These programs allow the designer to create their product virtually in a computer. Each one of the software works in different ways, but the method used to design a product is very similar. There are usually three planes you can use to design your 3D product: the top, right, and bottom planes. These planes are there to start you off on your design, but you can add in as many planes as you need to make different parts of your design. A shape is then made on any one of these planes. Then it can be extruded out by another tool to make it 3D. Many other tools can also be utilized to give it certain features that are necessary for the product.

1.2.1.1 Slicing Programs

After the product is fully designed, it can be imported into a slicing program that converts the design into gcode. Some examples of this type of software are KISSlicer and

Slic3r. In these programs it is also possible to adjust the printing parameters to your liking and where it will be printed on the printbed. Support material can also be added to the product to prevent it from collapsing. Then the gcode will then be imported into the Arduino, which controls the 3D printer itself. It will tell how the printer should print the product layer by layer.

1.2.2 3D Printer Parts

There are many parts to the printer that allow it to function. One of the main parts is the printbed. This is where the product will be printed on. Another main part is the nozzle head. This is what the filament is extruded out of onto the printbed. A stepper motor powers the movement of the nozzle head by moving it along the rails and a pulley belt to move the nozzle left or right and up or down. The 3D printer has a frame (large or small depending on the printer size) that helps support it when it is printing. All of these parts work together to produce a 3D product.

Figure 1.1: 3D Printer Apparatus (Buy Best Tronxy..., n.d.).

CHAPTER 2

LITERATURE REVIEW

2.1 The Nature of Metastasis

Why metastasis occurs and how it works is a very important topic to study because 90% of cancer deaths occur from metastasis (Seyfried et. al., 2013). Hypotheses have been suggested to explain why metastasis occurs. The most common hypothesis is Paget's seed-and-soil hypothesis. It states that the cancer cells that spread throughout the body are not randomly spread, but rather because they find a particular place in the body that would make a suitable microenvironment. Metastasis occurs in 5 stages: invasion of ECM, intravasation into the lymphatic or blood vessels, survival in circulation, extravasation into distant sites, and growth at those sites. By these means, cancer cells are able to get to other organs and destroy them through their uncontrollable growth (Ko et. al., 2012).

What attracts them to these areas are certain biochemical factors, such as VEGFR1+ bone marrow-derived hematopoietic progenitor cells. Factors such as matrix proteins, chemokines, and cytokines attract cancer cells to specific areas. (Azarin et. al., 2015). Immune cells, neutrophils, chemoattractants, integrin interactions, mechanical topography and stiffness of the microenvironment are also factors that attract cancer cells to those sites. Also when ECM proteins in the organs accumulate, they can attract cancercells to that site. Once they adhere to the ECM, they can start proliferating there. Changes happen to the ECM in which there is excess fibronectin and collagen forming. These changes occur partially from immune cells, which further attract cancer cells.

(Aguado et. al., 2016). By having these certain factors in their microenvironment, they can be able to migrate, invade, proliferate, and induce angiogenesis at that site (Azarin et. al., 2015).

Since metastasis is a serious problem, it is necessary to develop ways to detect any metastatic cancer cells that are wandering in the body. One imaging modality used is inverse spectroscopic optical coherence tomography (ISOCT) to track down cancer cells without the need for labeling (Azarin et. al., 2015). In addition, radiologic imaging modalities, flow cytometry, and fluorescence imaging are also used to detect cancer cells. If the cancer is detected quickly, before metastasis has occurred, then it is possible to treat it before it starts to spread and damage other organs (Rao et. al., 2016). Since early detection is so important, enhancing the ability of imaging modalities to detect and cancer in the body would help decrease the amount of people dying from cancer.

2.2 Previous Cancer Trap Experiments

The cancer trap itself has been designed to combat metastasis. It is a small scaffold that is to be implanted into a person. It uses certain factors (like those mentioned in section 2.1) to attract the cancer cells towards it and get trapped in. It can cause them to become trapped in the body, which will provide an opportunity for diagnosis.

Many previous experiments have been done to test out how well this device is able to detect cancer cells early on and capture cancer cells. In one experiment, a cancer trap was implanted into the peritoneal fat pads in the breast. It was made using porous PLG microspheres. The cancer trap had fibronectin (a protein part of the ECM) to attract the cancer cells. In this study they tested breast cancer, which usually has cells that metastasize to the lung and liver. The results showed that the cancer trap had reduced the amount of

cancer cells found in those organs. Also, it had been found that the tumor cells could be detected early. Using ISOCT imaging, they were able to find cancer cells in the scaffolds first before there were able to find any tumor cells in the lung or liver (Azarin et. al., 2015).

A different group did an experiment that had a group of mice with the scaffold placed subcutaneously in a mouse's dorsal space in order to easily access the scaffold and for noninvasive imaging. Another group of mice did not have a scaffold in them. The scaffold was made out of a PCL microsphere. They also were testing with breast cancer cells. These cells don't metastasize to the subcutaneous space, so if they showed up in that area, it would be because of the scaffold placed there. Tumor cells were present in the scaffold and again the amount of tumor cells in the usual metastatic sites (in the liver and the brain) was reduced. The tumor cells were also detected early as well (by ISOCT imaging). Mice with the scaffold lived longer than mice without the scaffold. This means that the scaffold can increase survival and increase time for surgery as well. Different materials were tested for the scaffold as well: PCL and PLG. PLG degrades too quickly whereas PCL has greater stability. Also, the PCL scaffold had more cells than the PLG scaffold, so it was better able to decrease tumor burden in other metastatic sites and reduced immune cells that support metastasis (Rao et. al., 2016). Another study tested PLA against aluminum hydroxide and glass. The PLA were found to attract more inflammatory cells and cancer cells than the aluminum hydroxide and glass (Ko et. al., 2012).

The previous two experiments used the inflammatory response to attract cancer cells into the scaffold or cancer trap. In this experiment, they tested scaffolds with cytokines: One with SDF-1 alpha and the other with EPO. According to their results, EPO is a better cytokine to use to attract cancer cells than SDF-1 alpha because they found that

it had the highest cancer cell recruitment. This also helped to prolong survival. This could be because EPO helps to induce proliferation, chemotaxis, angiogenesis, and inhibit apoptosis. It has an essential role in immunomodulation (Ko et. al., 2012).

Another study used ECM proteins instead to attract cancer cells in a PCL scaffold. The two proteins it was coated with were fibronectin and collagen IV, both of them part of the proteins in the ECM. After testing this, the addition of these proteins to the scaffold resulted in a two-fold increase of tumor cells over bare scaffolds. Interestingly, they also tested the effect of coating the scaffold with proteins from a decellularized matrix (DCM). This is the ECM after all of the cells on it have been removed (decellularized). Proteins that were present in DCM in a diseased organ attracted the most tumor cells. MPO is an abundant protein in the diseased DCM. MPO is a protein that is involved in the progression of inflammatory-based diseases. This was determined as the reason why the DCM coating was able to attract more cancer cells relative to other treatment groups since they are attracted to inflammatory cytokines (Aguado et. al., 2016).

CHAPTER 3

METHODOLOGY

For making the cancer trap, a two-step process was implemented to produce it: designing it in SolidWorks® and printing it out on the 3D printer.

3.1 Designing in SolidWorks®

SolidWorks® is a program that enables the user to design their product or device in the software, using certain tools provided by the program to create it. This software allows anything a person can think of to be designed right in the software. Once a design is created, an .stl file can be made from the existing design file. In the program, even though structures look solid, the program actually leaves everything hollow – there is no defined internal geometry initially. Once the .stl file is made, it solidifies the design made by generating a triangular mesh of the design. This file can then be uploaded into a slicing program, which can take the .stl file and turn it into gcode. This code allows the 3D printer to know how to build the design and therefore print it out.

3.1.1 Brainstorming

In the beginning, a couple of cancer trap designs that were previously made in Dr. Tang's lab to use as examples. Based off of these designs, I made a few variations on Solidworks®. My initial design, Design #1, was a cylinder with a solid hemisphere cap at one end. On the other end of the cylinder, there was a small hole. Pores were then introduced through the sides of the cylinder. These pores are for the cancer cells to migrate into the cancer trap. The hole on one side of the cancer trap is to insert and retrieve the

hydrogel that will go inside. The cap was to prevent any cells from getting out. Design #2 is significantly different than Design #1. It has a capsular design, with two hemispherical caps on each side, making it bigger overall than the last design. A larger hole was also cut through the whole cylinder, reducing the wall thickness. There are also pores in it as well for the cancer cells to travel into the cancer trap, though the porosity is less. Designs #3-4 are similar to Designs #1 and #2, respectively, just with different sized pores. Design #5 is similar to Design #2, but is much more porous. All of these designs were made using the different planes by drawing circle sketches on those planes and cutting it all the way through the trap design.

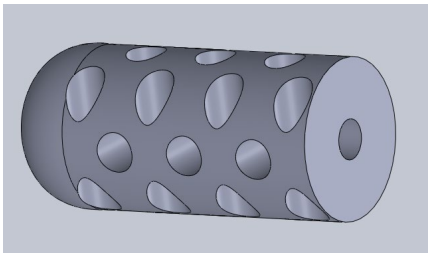


Figure 3.1: Design #1

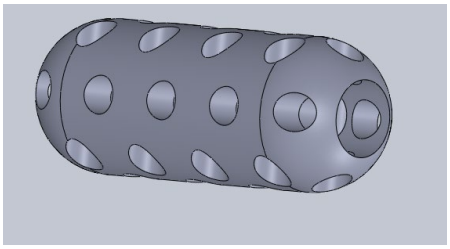


Figure 3.2: Design #2

Design #6 is also similar to Design #2, but a different method was used. For the caps, instead of cutting a hole straight through, a revolved cut was made so the cap was essentially hollowed out. This made the thickness match the cylinder's thickness. Also, the pores were not made by the previous method, but rather using a circular pattern tool that uses the circles on the planes and rotates them around the cylinder and cuts through the design. It is a faster method and is able to cut straight through the trap rather than at an angle. This method is used for the rest of the designs that were made. All design dimensions are listed in Table 1. Porosities were calculated using a porosity calculator created in Excel.

Table 3.1: Dimensions for Designs #1-6

	Design #1	Design #2	Design #3	Design #4	Design #5	Design #6
Pore size (diameter)	1 mm	1 mm	0.5 mm	0.5 mm	1 mm	1 mm
Hole diameter	1 mm	2 mm	1 mm	2 mm	2 mm	2 mm
Length	9 mm	11 mm	9 mm	11 mm	12 mm	12 mm
Inner cylinder diameter	1 mm	2 mm	1 mm	2 mm	4 mm	4.5 mm
Outer cylinder diameter	4 mm	4 mm	4 mm	4 mm	4.5 mm	4 mm
Wall thickness	1.5 mm	1 mm	1.5 mm	1 mm	0.5 mm	0.5 mm
Porosity	33%	23%	24%	43%	83%	66%

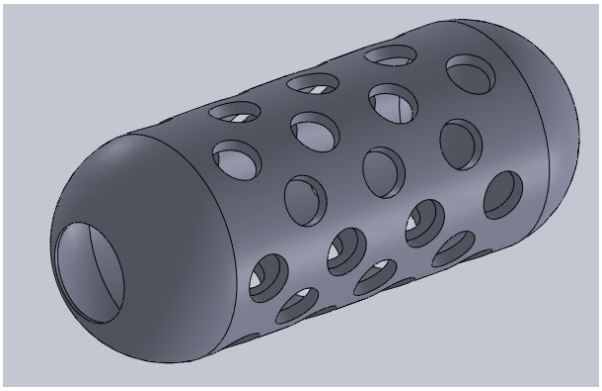


Figure 3.3: Design #6

3.1.2 Improvements

Since my mentor suggested a more capsular design with the two caps, I made all of the next designs based off of that. Doing so would allow more cancer cells to enter the cancer trap since the caps would provide more room. Designs #7-10 all had the same dimensions, but were made with different pore sizes and porosities. This was done to test out how the pore size would affect the porosity once it was printed out. Design #11 had dimensions based off of previous work done by a master student in Dr. Tang's lab. These dimensions were found to be the optimum design from what the master student has tested,

since it was the best at retrieving the gel (Cantú, 2018). The dimensions are shown in Table 2.

Table 3.2: Dimensions for Designs #7-11

	Design #7	Design #8	Design #9	Design #10	Design #11
Pore size (diameter)	1 mm	1.8 mm	0.4 mm	0.8 mm	1.44 mm
Length	12 mm	12 mm	12 mm	12 mm	11 mm
Cylinder inner diameter	4 mm	4 mm	4 mm	4 mm	3.5 mm
Cylinder outer diameter	4.5 mm	4.5 mm	4.5 mm	4.5 mm	4 mm
Hole diameter	2 mm	2 mm	2 mm	2 mm	2 mm
Wall thickness	0.25 mm	0.25 mm	0.25 mm	0.25 mm	0.25 mm
Porosity	40%	44%	37%	38%	38.68%

3.1.2.1 3D Printing

Since designs #7-11 had the capsule design with different pore sizes, these were printed out in the 3D printer. As mentioned before, the files were converted to a .stl file and then put into the gcode converter Sli3r. The file was then transferred onto a SD card that was then put into the 3D printer, which is the Gmax 1.5+. Each design was then printed. The nozzle was heated to 200 degrees Celsius with a 0.1 mm nozzle. All prints were done with 10-15% speed.

3.1.2.2 ImageJ

After they were printed, I took photos of 4 sides of each trap and the top and bottom of the each trap. Each image included a ruler in order to scale the size of the pores to the correct and actual length. The images were then imported into ImageJ in order to see and

measure the average pore size of each cancer trap. This data was then used to calculate porosity, which was done using an Excel sheet.

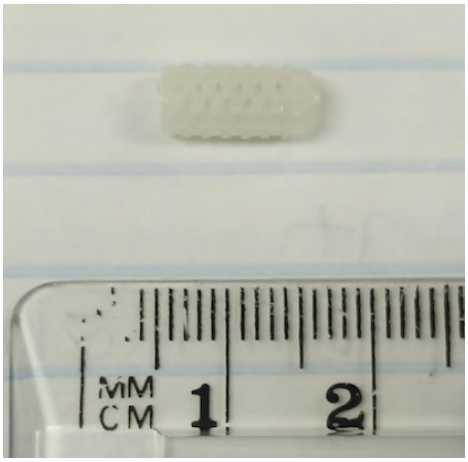


Figure 3.4: Sample Photo for ImageJ

3.1.2.3 Newer Designs

With all of the data calculated, a cancer trap with the best porosity would then be printed based off of the results that were found. Newer designs were made, #12-14, to improve the previous designs.

Table 3.3: Dimensions for Designs #12-14

	Design #12	Design #13	Design #14
Pore size (diameter)	0.8 mm	1 mm	1.44 mm
Length	12 mm	12 mm	12 mm
Cylinder inner diameter	4 mm	4 mm	4 mm
Cylinder outer diameter	4.5 mm	4.5 mm	4.5 mm
Hole diameter	2 mm	2 mm	2 mm
Wall thickness	0.25 mm	0.25 mm	0.25 mm
Porosity	48%	56%	54%

These designs imitate the previous designs in the pore sizes that did fairly well in the printed tests. The cancer trap with 1.8 mm pore size was not taken into consideration

even though it has a fairly good porosity because that pore size would be too big to capture the cells. The difference between the designs is their theoretical porosity, which has increased from the previous designs. This should enhance the porosity from the 3D printer. This is important because with higher porosity, more cancer cells can be able to migrate into the cancer trap. Reproducibility from the printer is also important because the traps that are printed out need to be as close as possible to the original design made in the software. It also includes how easy it is to print on the 3D printer without any major issues, such as when the layering of the print is off as it is being made. These designs were then printed out. Then the same process was done to analyze their porosity with ImageJ. Based on the reproducibility and porosity of the design, 1.44 mm was determined to be the best design.

To keep the hole at the top of the design from closing (which would make it difficult to insert and take out the hydrogel that will go in it), a base of 6x6x1 mm was put on the bottom of the cap on the cylinder. This was to ensure the hole was kept open and to not ruin it when taking it off the print bed. Several prints of this were made and tested.

CHAPTER 4

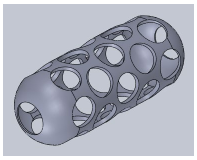
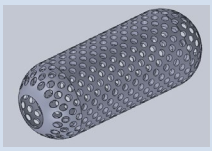
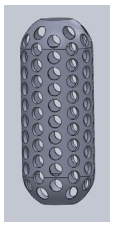
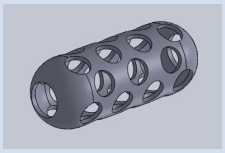
DISCUSSION

There were multiple attempts at making the perfect cancer trap, as mentioned in the methodology section. The results of these experiments will be discussed in detail in this section.

4.1 Cancer Trap Printing Results

Designs #7-11 were printed out. In Table 4.1, they are compared to their SolidWorks® design. This table displays the 3D printer's fidelity in how closely it can print out the trap compared to the original design.

Table 4.1: 3D Printer Fidelity for #7-11

Design Number	SolidWorks® File	Print out
7		
8		
9		
10		
11		

4.1.1 Porosity Calculations for Designs #7-11

Calculations of all of the cancer traps' porosities were collected in Excel after gathering their pore sizes from the ImageJ software. Then the computations were done in Excel. The tables below show the results from the Excel files.

Table 4.2: Calculations for Design #7

	Theoretical	Actual
Pore Size	1 mm	0.62 ± 0.11 mm
Total Surface Area	228.435 mm^2	228.435 mm^2
Porosity	40%	15.65%
Total Open Area	91.37 mm^2	40.02 mm^2
Total Open Pores	84	80

Table 4.3: Calculations for Design #8

	Theoretical	Actual
Pore Size	1.8 mm	1.10 ± 0.17 mm
Total Surface Area	228.435 mm^2	228.435 mm^2
Porosity	44%	23.67%
Total Open Area	100.50 mm^2	54.31 mm^2
Total Open Pores	30	30

Table 4.4: Calculations for Design #9

	Theoretical	Actual
Pore Size	0.4 mm	0.28 ± 0.058 mm
Total Surface Area	228.435 mm^2	228.435 mm^2
Porosity	36%	6.71%
Total Open Area	82.24 mm^2	24.37 mm^2
Total Open Pores	464	6

Table 4.5: Calculations for Design #10

	Theoretical	Actual
Pore Size	0.8 mm	0.63 ± 0.098 mm
Total Surface Area	228.435 mm^2	228.435 mm^2
Porosity	38%	31.18%
Total Open Area	86.80 mm^2	71.04 mm^2
Total Open Pores	126	9

Table 4.6: Calculations for Design #11

	Theoretical	Actual
Pore Size	1.44 mm	0.93 ± 0.21 mm
Total Surface Area	183.69 mm^2	183.69 mm^2
Porosity	39%	10.43%
Total Open Area	71.04 mm^2	22.85 mm^2
Total Open Pores	28	25

For all of the designs, the pores were printed smaller than the theoretical pore size in the SolidWorks® file. This resulted in the cancer traps having a very low porosity, such as in Cancer Trap #9. It is also very difficult to reproduce on the 3D printer due to the small pore size. The nozzle is unable to print small pores with precision. So bigger pore sizes are better for reproducibility and porosity. Design #10 had a very good porosity that was very close to the theoretical porosity. Design #7 also had very good reproducibility since it was very easy to print, but had poor porosity. Again, this could be due to the small pore size, since the printout was 62% of its original pore size, which can be seen in Table 4.7. Design #11 was also very reproducible, but it also had a poor porosity. This could be because the cap areas (the top and bottom of the cancer trap) were closed, so when added to the calculations, it made the porosity low. The pore size of the printed trap was 65% of the original pore size of 1.44 mm. Design #8 also has potential, in which it achieved a fairly high porosity compared to the rest, but it was deemed too big in pore size. The cancer cells could start leaking out, which would end up in a less cancer cells retrieved by the trap.

4.1.1.1 Pore Size Fidelity

The pore sizes of the cancer traps can be seen to have generally reduced in size compared to the designs in the SolidWorks® file. This is a critical factor to consider regarding porosity. If the 3D printer is able to keep the pore size the exact same way as it

dimensioned in the file, then it can be possible to print out cancer traps with good reproducibility of the pore size and porosity.

Table 4.7: Pore Size Fidelity for Designs #7-11

Designs	Theoretical Pore Size	Actual Pore Size	Pore Size Fidelity
7	1 mm	0.62 ± 0.11 mm	62%
8	1.8 mm	1.10 ± 0.17 mm	61%
9	0.4 mm	0.28 ± 0.058 mm	70%
10	0.8 mm	0.63 ± 0.098 mm	79%
11	1.44 mm	0.93 ± 0.21 mm	65%

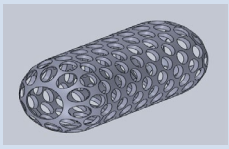
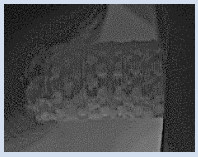
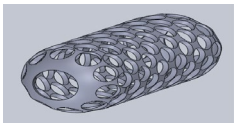
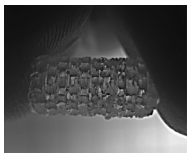
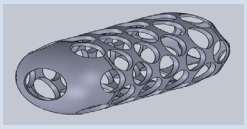
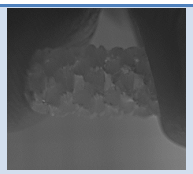
In Table 4.7, displays the pore fidelity, in which each percentage represents how much the actual pore size (from the cancer trap that was printed out from the 3D printer) is compared to the theoretical pore size (from the SolidWorks® design file)**.** For most of the cancer traps, it can be seen that for most of the designs (#7,8, and 11) the 3D printer can make a little more than half of what the theoretical pore size is for the print out. The other two (#9 and 10) have relatively high pore size fidelity. This is probably because the printer tends to shrink the pore size from the original design, but there is a certain amount it can shrink it by. The smaller the theoretical pore size is, it has less capability of shrinking it down from the theoretical pore size.

4.1.2 Porosity Calculations for Designs #12-14

The optimal trap designs were determined to be Designs #7, 10, and 11. These cancer traps were redesigned and reprinted. The only change made was the theoretical porosity – it was boosted up to about 50% porosity for all of them. The new designs were named Designs #12-14. Then they were reprinted on the 3D printer. The printed results of the cancer traps compared to their original files are shown in Table 4.8. This comparison

shows the fidelity of the 3D printer by showing the capabilities in how well it can produce the design compared to the design in software file.

Table 4.8: 3D Printer Fidelity for #12-14

Designs	SolidWorks® File	Print out
12		
13		
14		

Again, all of the calculations for the pore size, porosity, etc. were done in Excel. These results are shown below.

Table 4.9 Calculations for Design #12

	Theoretical	Actual
Pore Size	0.8 mm	0.60 ± 0.17 mm
Total Surface Area	228.435 mm^2	228.435 mm^2
Porosity	48%	9.31%
Total Open Area	109.64 mm^2	21.26 mm^2
Total Open Pores	170	13

Table 4.10: Calculations for Design #13

	Theoretical	Actual
Pore Size	1 mm	0.55 ± 0.13 mm
Total Surface Area	228.435 mm^2	228.435 mm^2
Porosity	56%	19.62%
Total Open Area	127.92 mm^2	44.82 mm^2
Total Open Pores	130	130

Table 4.11 Calculations for Design #14

	Theoretical	Actual
Pore Size	1.44 mm	1.02 ± 0.26 mm
Total Surface Area	228.435 mm^2	228.435 mm^2
Porosity	54%	22.15%
Total Open Area	123.35 mm^2	50.60 mm^2
Total Open Pores	60	60

Design #12 did not do as well as expected in terms of porosity. The porosity was much lower than design #10, which had the same pore size. Even though the theoretical porosity was increased, the porosity came out very low. This indicates that this particular design with a 0.8 mm pore size does not have good reproducibility with the 3D printer. Also, since the theoretical porosity was increased, more holes had to be created, so the 3D printer was unable to print all of those holes properly.

Design #13 also was not the best because the printed pore size (0.51 mm) was much smaller than 1 mm and smaller than the previous design #7. It has good reproducibility on the printer, however its porosity is very poor. So this design would not be a good choice to be the optimum design.

Design #14 had a good pore size that is very similar to the theoretical pore size (1.44 <1.02 mm). The pores are not too big so that cancer cells will not leak out or too small that there would not be many cancer cells captured inside the trap. Its porosity is not that high either, but it has the highest porosity out of the three designs. The reproducibility is also good as well. Therefore, it was decided this would be the best design to choose. A base was added to one end of the capsule to keep the cap end from closing up. Putting a base gave a nice platform for the 3D printer to evenly lay down the filament.

CHAPTER 5

CONCLUSION

For designing a cancer trap, it was decided early in the beginning to create a capsule shaped trap: a cylinder with two spherical caps on each side. The whole structure would be hollow. From this, multiple designs were made, with main differences in their pore size and porosity. Then they were printed on the 3D printer to test reproducibility and how well the porosity came out. The best ones were then picked to be redesigned to a better porosity and printed again. From those, it was determined that design #14 was the best out of all of them due to its good reproducibility and porosity.

The 3D printer used in this experiment, the Gmax 1.5+, has some limitations. The printer does not have good repeatability in general. Repeatability was difficult since the 3D printer was not consistent with its prints even if no changes were done on the settings. Therefore, some came out fairly well and some came out flawed and unusable. This also made it difficult to test reproducibility of designs due to this flaw. Also, sometimes the nozzle stops extruding out the filament at random times during the print, so it messes up the printing process. Hopefully in the future, more efforts will be put in to get a 3D precision printer that can print small objects with higher precision and accuracy.

For future applications, it can be tested *in vivo* in a mouse model. The cancer trap can be inserted into the mouse after the cancer cells have been injected. Then using imaging modalities, the metastasis of the cancer cells can be recorded. It can be seen if the cancer trap effectively traps cancer cells in it. Also a chemokine can be placed into the cancer trap

to attract cells and keep them inside the cancer trap to make it even a more effective method. Different chemokines can be used to test which one is the most effective in keeping the cancer cells in the trap. Dr. Tang's lab is currently working on this research now, but more mice models are needed and more testing needs to be done. Soon enough, it can hopefully be used not only for early diagnosis of cancer by seeing whether there are cancer cells spreading in the body, but also as a way to get rid of metastasized cancer cells in the body.

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BIOGRAPHICAL INFORMATION

Nowmi Haider is a student at the University of Texas at Arlington (UTA) who is currently in her senior year. She is striving to achieve a Bachelor in Biomedical Engineering in Spring 2019. Nowmi has earned her place in the Dean's list for 2016 and 2017 fall and spring as well as 2018 spring. She is a member of the BMESS, MSA, and Honors College at UTA.

She is interested in the subject of cancer research, in which she has enlisted herself in pursuing cancer research topics under qualified mentors. Currently she is working with Dr. Tang on her cancer trap project to test the device *in vivo*. Nowmi is also working with Dr. Kim for Senior Design to understand gastric cancer by seeing their epigenetic and morphological changes during metastasis.

In the future, she hopes from there that she can then move onto obtaining a Masters in Biomedical Engineering. Also Nowmi wishes to work in the Biomedical field for research or development of a biomedical device and continue researching different and new topics in biomedical engineering. She hopes to be in continual pursuit of these aspirations and hopefully make an impact that can help so many lives.