Interstitial Optical Fiber Probe

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Abstract

As radiation therapy becomes more essential in the treatment and diagnosis of cancer and other diseases, the ability to track the effectiveness of this new treatment methodology is increasingly important. Fractionation of radiation therapy sessions, or applying lower doses at greater frequencies, gives physicians the ability to more accurately coordinate non-uniform dose adjustment plans based on the biological response following each session. Specifically, hypoxia and reoxygenation are biological indicators tracked by absorption imaging techniques. Our probe allows our client and future physicians to measure rodent tumor growth as a function of oxygenation throughout a tumor in real-time and translates this information to apply more specific and impactful treatments. By proving the effectiveness of this probe in rodent-tumor studies, the future of this design will be applied to a bed-side device for fractionated radiation treatment plans to apply more biologically meaningful doses.

Background

Radiation Therapy and Cancer

Radiation therapy (RT) has long been an efficient and powerful treatment for cancer in the medical fields [1]. Currently, RT boasts the ability to precisely destroy tissue regardless of its location within the body while remaining non-invasive and causing minimal damage to surrounding areas [2]. Radiation therapy is administered to nearly two-thirds of all cancer patients and can be considered one of the most diverse and capable drugs of modern medicine [3]. The inception of radiation therapy, however, was neither graceful nor accurate. Discovered empirically by Wilhelm Rontgen in 1895, radiation application as a medical treatment began

almost immediately thereafter. Before long, the unsightly and dangerous side-effects were quickly realized. Developments like medical linear accelerators in the 1940s, computed tomography (CT) in 1971, and most recently tomotherapy at UW-Madison, are all advancements that quickly turned a raw dose into a precisely manufactured treatment plan [4].

Headed by advancements in Intensity Modulated Radiotherapy (IMRT) in the 1980s, today's treatments focus on applying more controlled and uniform dose treatment plans. Despite these advances, the goal of perfecting uniform dose application is not necessarily the most effective. Behind this methodology are extremely precise machines, such as the CyberKnife, combined with increasingly rigid calibration standards. Additionally, radiation treatments have become more and more fractionated, splitting large scale doses into multiple sessions. These methods all result in radiotherapy treatments today being accurate to less than 1% error [5].

Hypoxia as a Dominant Factor

As standards and instruments become more powerful, the question of what makes the most biologically meaningful dose application has re-emerged. In the new understanding of tumor growth and development, the "ideal model" of using uniform dose treatment plans has become outdated [6].

The answer to the question posed above seems to be in the oxygen dynamics of cancerous tissue and tumors. Because a large majority of the tissue damage that occurs from radiation is as a result of secondary free radicals, the presence of oxygen has been demonstrated to largely dictate the effectiveness of dose treatment plans. This results in implementation of treatment that takes advantage of oxygen levels to create more biologically meaningful applications of dose.

Hypoxia, or the deprivation of oxygen and oxygen supply, is now understood to be to the dominant factor in how cancer reacts to radiation treatment [7]. This important factor was first hypothesized by one of the fathers of radiobiology, Louis Gray who said, "The concentration of oxygen dissolved in tissues at the time of irradiation is a factor in radiotherapy" [8]. Despite this early warning, researchers and doctors are only now realizing that the mechanism of free radical therapy can be used to dictate the effectiveness of radiation therapy.

The Current State of Radiotherapy: Non-Uniform Doses

Though not largely implemented yet, the current methods of improving radiotherapy seem to be adapting dose platforms to match (or resemble) the dynamics of oxygen distribution within the tumor itself. This statement is reinforced by the increasingly strong argument for treatment hypofractionation to avoid potentially dangerous dosing to healthy tissue. As treatment plans become more fractionated, they too must become more specific to the observed tumor growth [9].

An easy and time-efficient way to track and respond to tumor reoxygenation will yield the answer for how to adjust treatment throughout its course. A simple way to provide insight as to the reoxygenation of a tumor is by taking advantage of well-defined diffuse optical techniques. Other methods, such as PET scanning have the ability to track tumor growth, but lack the precision and rapid time scale that optical techniques could bring. Measuring optical diffusion properties could result in less damage to healthy tissue in addition to facilitating faster lesioning of cancerous tissue.

Design Motivation

Economic and Social Motivation

Each year, over one million patients are treated with radiation therapy, with over 60% of all cancer patients relying on radiation therapy for treatment. With prices of therapy sessions ranging from $1,700 to $4,000 per session, radiation therapy is economically stressful both on the patients and the US Healthcare System [10]. While the economic motivation is not the most influential factor, more efficient treatment plans could save the United States population billions of dollars per year because patients will have to return less for treatment.

While treatment plans have benefited largely from recent advancements such as CT and tomotherapy, the next advancement in providing more successful dose treatment could save even more lives. Radiation therapy is a treatment method built with the intent to cure the tumor over 75% of the time. Unlike other methods, radiation therapy is employed not to relieve symptoms or control growth, but to save the life of a person who can still lead a successful life.

Client Motivation

Dr. Michael Kissick is an assistant professor of Medical Physics at the University of Wisconsin-Madison and is currently developing a novel approach towards analyzing oxygen saturation in cancerous tissues. The ability to measure oxygen saturation levels in tumors can potentially lead to more detailed classifications of cancerous tumors and more accurate treatment plans. The overall goal of Dr. Kissick's research is to create a bedside device to measure oxygen saturation dynamics of cancerous tumors in humans. Currently, he is conducting trials of his device on tumors of mice xenografts. The device used in this research consists of two probes that connect to a full spectrum light emitter. The two probes are identical and consist of optical fiber that is thread through 28 gauge (0.362mm outer diameter) needles. One probe emits light and the second probe collects the light that has diffused throughout the tissue. To take measurements on

the mice, the probes are set at a *3mm* distance, side-to-side, and puncture the skin as they are placed inside the tumor. Dr. Kissick currently uses a Styrofoam block and tape to hold the probes at the *3mm* distance. Styrofoam is a weak material and the needles may move when they enter the tumor, therefore, Dr. Kissick has requested the design of an easy-to-use device that holds the needles steady at a fixed distance and aids in the penetration of the skin. The device should be reusable and easily built.

As Dr. Kissick's research progresses, he would like to create a bedside device that holds the optical probes at a set distance to be entered into a human tumor. The design of this device would seek to minimize invasiveness without sacrificing the efficacy of the probes. We will be considering how our design can evolve into a medical device for human use because that is the overall goal of Dr. Kissick's research.

Problem Statement

Oxygen saturation in cancerous tissue can be analyzed to indicate possible transformations and adaptations to the development of future cancer tissue. By observing optical diffusion under the epidermis, doctors can very closely track possible changes or instigations in tumor development. Currently, clinical trials are being run solely on mice and with a probe that, as a result of a poor-quality design structure, may give potentially inconsistent results. Our goal is to rebuild the probe in a fashion that provides both consistent results and applicability for human use. Additionally, long term goals include making the probe convenient and reusable for the doctor and patient.

Existing Devices

Dr. Kissick's design is novel and addresses drawbacks of current probes that are used to measure oxygen saturation invasively. There are currently two devices that are similar in

Figure 1: Oxylite probe needle and connector

function and theory: the Eppendorf probe the Oxylite probe. Both of these devices use interactions between light and tissue to analyze oxygen saturation. The aspect of Dr. Kissick's design that differentiates it from these two probes is the functional scale of operation. The large area sensor Oxylite probe (Figure 1) is advertised to have a sampling area/volume of $8mm^2$, which is much smaller than Dr. Kissick's probe. The problem with having a small sampling area is that the probe may hit deoxygenated pools of blood where the oxygen saturation reading is nonexistent.

Design Alternatives

Clip Mechanism

Our device differs from those above, operating as a two-needle clip that both emits and receives full spectrum light. The primary component of this design was to determine the optimal layout of the optical needle clip to support the needles at a secure *3mm* separation, receive minimal reception error, and minimize the discomfort of the test subject/patient.

Specifications

All possible clip designs must be capable of fixing two optical probe needles at a distance of *3mm* apart from tip-to-tip, allow for a *>2mm* penetration of the epidermis, and maintain rotational/translational rigidity. Additionally, to make the clip designs as useful as possible for our client's research applications, each clip must be inexpensive to manufacture as well as reusable.

Modified Parallel Clip

The modified parallel clip (Fig. 2) is the closest design to Dr. Kissick's existing foam needle clip. This design would consist of two primary components: a channeled component and a silicone padded attachable plate. The channeled component of this design allows for researchers to thread the aspiration needles with the optical fibers in the process of loading it into the clip. By placing the aspiration needles in one side of the clip and the optical fibers in the other, you can set the two needles at a fixed *3mm* separation while reducing the risk of threading injury to the user. Once the optical fibers are loaded, the padded plate can be attached to the channeled component in order to provide the clamping force required to avoid the possible shifting of the needles during insertion or removal from a subject. The design could be made from inexpensive materials such as polycarbonate or aluminum; however, the presence of the finely sized spacing channels eliminates the clips ability to be 3D printed. The benefit of this design is its simplicity and size, which would reduce cost of manufacturing and increase its relative durability.

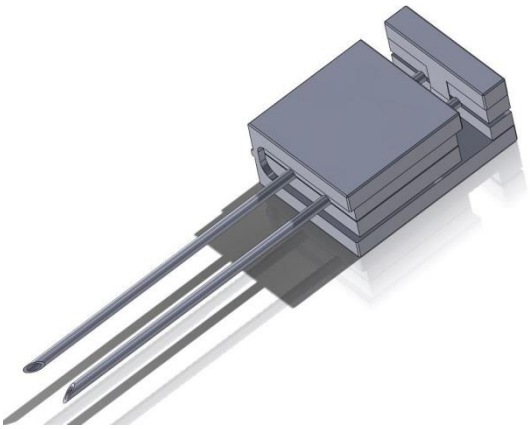

Figure 2: A SolidWorks model of our Modified Clip Design

The parallel arrangement of the needles in the clip would present a less than ideal insertion scenario. Since the needles are separated by *3mm*, the accuracy of the needle insertion ultimately relies on the skill of the user applying it. Its wide span also means that possible tugging or pulling on the clip would cause painful torsion of the needles within the patient.

Staggered Clip

The staggered clip design (Fig. 3) is based on one of the fundamental concepts of diffuse light transport theory, which states that in a diffuse medium, a directional light source radiates in all directions and can be considered a point source at any distance greater or equal to *3mm* from the light within the medium. In other words, even if a light source is directional, if it is placed in a diffuse medium the light will be refracted in a way in which the directional light source appears multidirectional. Rather than needing to position the needles parallel and facing each other, the needles may be staggered and facing any direction, as long as the distance between needle points is sufficient. This design would consist of a rubber coated clip to hold the needles, but at a much smaller separation (*>1.5mm*). The clip would also have a static rubber pad at the rear to organize the wires, and also act as a measurement bumper to set the fiber optic needles at their appropriate depths. This design shares the strengths of the modified parallel clip; however, its strength comes from its ability to be inserted into tumors that happen to be narrower than *3mm*. Having the needles located close together also means that orientating and inserting the needles would be both safer and more accurate. The disadvantages of this design are in its complexity and cost.

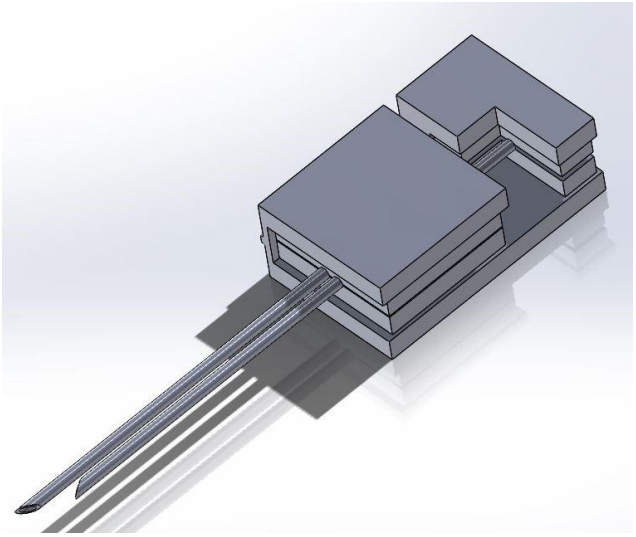

Figure 3: A SolidWorks drawing of our Staggered Clip Design

Two Unit Clasp

The third and final design alternative is the two unit needle clasp (Fig. 4). This design is composed of two primary identical components. When combined form they needle clasp which holds two optical needles parallel again at a separation of *3mm*. By expanding the design into two components, the moving clasp component of the previous designs can be removed. This eliminates the need for more durable materials, due to the lack of repeatedly bending components. This design also allows for a greater degree of versatility accommodating a wide range of needle sizes and shapes.

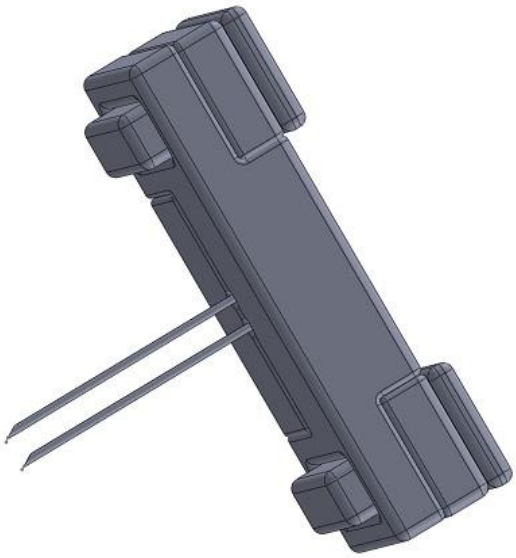

Figure 4: A SolidWorks drawing of our Two-Unit Clasp Design

The breakdown of the needled clamp into multiple components also brings a variety of disadvantages. A greater amount of material would be needed to execute this design, increasing the cost of fabrication as well as the relative size of the design. Its larger size and *3mm* parallel needle arrangement would cause the device to be both cumbersome and difficult to use, resulting in a lower degree of precision and safety.

Probe Design Matrix

Our design matrix (Fig. 5) has six different categories with which we scored each design. These categories were developed after reviewing our client's requirements and recommendations. Once all of our categories were selected, we weighted them based on what Dr. Kissick felt was essential and what we felt we could sacrifice in order to make a better design.

Interstitial Optical Probe Design Matrix Criteria (weight)	Design 1 Modified Clip		Design 2 Staggered		Design 3 Two Unit Clasp	
Ease of use (30)	4	24	5	30	3	18
Precision (25)	5	25	4	20	3	15
Longevity (25)	4	20	3	15	5	25
Size (10)	5	10	4	8	2	4
Safety (5)	4	4	5	5	4	4
Cost (5)	5	5	4	4	3	3
Total (100)	88		82		69	

Table 1: The final design matrix for our two-needle probe.

With the design matrix made, we began to score each one of our devices. The first category we scored, the ease of use of the product, was the highest weighted category at 30% of the total score. This received the highest weight because our client is performing his tests on mice that do not belong to his lab. Since he is borrowing someone else's lab time to test his device, it is paramount that our device can be handled easily and allow for quick data collection.

With a weight of 25% each, precision and longevity are the next highest weighted categories. This device will be used for data collection, so to ensure that the data collected when using this device is valid and as accurate as possible, it must be able to hold the needles in exactly the same way every time. Similarly, our client does not want to replace this device often. This means the more durable it is; the better it will be suited for our client's use.

Size is the fourth ranked category at 10% of the total score. There was no real size requirement from Dr. Kissick; however, a device that is too large or too small might affect how easy it is to use. Along these same lines, if the device is too small it will be easier to lose pieces, which would decrease the longevity to the product.

Finally, cost and safety are the lowest ranked categories at 5% of the score each. This device will be 3D-printed and will therefore have a relatively low cost. Dr. Kissick also has a contact with access to a 3D-printer, which means cost is not a real factor to be worried about. Finally, safety was tied with cost for the least weighted category. This is due to the fact that the current needle holder is a block of Styrofoam. The devices that have been designed will hold the needles much more securely than they currently are being held. This means that the safety aspect of the device was of less importance than the other categories.

Design One: The Modified Clip

Design one took first in three of the categories including precision, size, and cost. We felt that this would be the most precise device due to the fact that it will replicate Dr. Kissick's set up perfectly. This will allow for seamless integration of the device. It took first in size for the exact same reason. It will be very similar in size to the foam

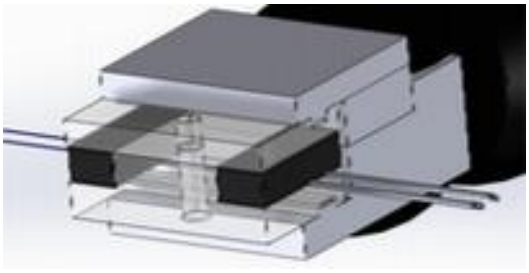

Figure 5: A SolidWorks design of our final modified clip

block currently being used. Finally it received first in cost due to its low number of parts and the ease of manufacturing it would present. Even though it did not win in every category, the first design took second in all of the categories that it did not take first in. The modified parallel clip design also possessed the highest score of 88, making it the design we ultimately used for our experimental optical diffusion probe design. The final design that we reached in creating the parallel clip design is shown in Figure 5.

Design Two: The Staggered Needle Design

When referring to the design matrix, Table 1, one can see that design two took first in ease of use as well as safety. This is due to the fact that the needles act as one needle and it will therefore be easier, quicker, and safer to insert the needles into the tumor. Design two had an overall score of 82 which is very respectable. This design, however, is lacking in longevity. We felt that with the needles this close together would lead to a device with some very small parts. We think that these small parts are more likely to break. In the future, however, this design may be the more applicable option in human applications if the previously mentioned weaknesses could be remedied.

Design Three: The Two Unit Clasp

The only category that design three took first in was longevity. This is due to the fact that it has no moving parts and can pinned together. With no moving parts, the wear on this device will be minimal. Even though these devices took first in longevity, it was severely lacking in ease of use as well as precision, and had an overall score of only 69. We felt that this device would be a little harder to put together and therefore would affect how easy it is to use. Also with it being harder to put together, there is a greater chance that the needles are not aligned properly, and this would affect the precision.

Stand

An additional component necessary to the proper utilization of the optical needle probe is a stable supporting stand which can hold the clip in place while it is inserted into a subject. Unsupported, there is a chance for undue torsion and shifting of the needles within the test subject, not only causing internal damage to the mouse, but possibly causing infidelities in testing data.

Specifications

Any stand that supports the optical needle clip must be capable of being easily mounted and adjusted to any given angle that can best handle the clips orientation. This means that the stand must be able to mount to a range of surfaces, and be reliable enough to not be compromised due to typical environmental conditions, such as a damp countertop. In addition to reliability and flexibility, the stand must be easy enough to pose into various positions that it is not a hindrance to the researcher. To clarify, both designs to be described will be weighed based on their stability as a stand. Both alternatives would require customization of the distal end to incorporate a clamp which may attach to the optical diffusion clip.

Stand 1: Altered Gooseneck Clamp

The first optical probe stabilizing stand design considered would utilize a purchasable gooseneck clamp which would be capable of being customized to support the optical probe. Using an ordered probe would be beneficial in saving time and possibly money in finding a final stand solution; however, compromises may have to be made to integrate such a stand. Typical gooseneck clamps use a spiraled, interlocking steel tubular mesh to create a poseable clamp neck. This makes for an extremely sturdy and rigid support arm. However, due to this strength, the adjustability of the stand is limited as it takes considerable force to mold the stand to a given

geometry. Additionally, such necks a habit of developing spring-back forces when posed, meaning that after adjustment most steal-mesh necks will recoil to the previous alignment slightly. In this design, the gooseneck clamp selected by our client was the BESTEK Gooseneck Seat Desk Bolt Clamp, shown in Figure 6. It utilizes a silicone-padded C-clamp as its base to attach to nearby ledges and devices. This product was competitively priced at $31.99.

Figure 6: BESTEK Gooseneck Seat Desk Bolt Clamp

Stand 2: Loc-Line Constructed Clamp

The second optical probe stabilizing stand design considered would consist of Loc-Line connectable segments acting as the stand neck. Loc-Line is a brand of air-hose connectors which combine to form long, highly adjustable links of hollow segments which may direct air pressure in any direction desired. An image of the product can be seen in Figure 7. In this application, the Loc-Line segments would serve as the stabilizing stands adjustable neck. This would give the stabilizing stand many more degrees of poseability than typical steel-mesh gooseneck clamps would, but at the cost of rigidness and strength. Additionally, using this product could mean that significantly more time would be needed to customize the segments for the desired application. To purchase roughly a foot and half of Loc-Line ½'' segments costs $23.18 from most retail locations.

Figure 7: Loc-Line adjoinable segments

Stand Design Matrix

Our comparative stand design matrix, which can be seen in Table 2, has four different categories upon which each stand alternative was weighed. These categories were selected based on the situational requirements of the design and what a stabilizing stand would require in order to help the optical diffusion probe meet the client's design criteria.

Stabilizing Stand Design Matrix Criteria (weight)	Stand 1 Altered Gooseneck		Stand 2 Loc-Line Constructed	
Stability (40)	5	40	4	32
Ease of Use (30)	2	12	5	30
Longevity (15)	4	12	4	12
Cost (15)	4	12	5	15
Total (100)	76		89	

Table 2: A breakdown of the Stand Design Matrix components

The first category we compared our stands on was their relative stability, with a category weight of 40%. Ultimately, the stability and rigidity of the stabilizing arm is paramount to the accuracy and humaneness with which the optical probe operates. Additionally, unexpected shifting of the optical probe due to supporting stand weakness could result in data discrepancies.

Next, the ease of use category was weighted as the second most important stand condition, with a category weight of 30%. Aside from the rigidness of the stabilizing stand, it is essential that the tool is simple and easy for the researchers to use. If the stand created is perfectly rigid, but is difficult to manipulate and pose, then it is likely that the stand would be ignored entirely by testing staff. Creating an intuitive stand is essential to its utilization.

Finally, both longevity and cost of the stabilizing stands were weighted equally, with a weight of 15%. The cost of each stand and how long they will both last go hand-in-hand as the relative cost of each stand is dependent on how long each stand may last. These areas are not weighted more heavily however, because of the low cost associated with both stand alternatives discussed. Whichever stand is deemed more appropriate will not create large financial turmoil for our client.

Stand 1: Altered Gooseneck Clamp

The first stand alternative scored higher than the Loc-Line Constructed Clamp in only the stability category. Due to its steel-mesh neck, a typical gooseneck clamp such as the BESTEK Gooseneck Seat Desk Bolt Clamp is extremely rigid, making it difficult for it to accidentally shift at any point once it's in place. However, this high degree of rigidity makes for an incredibly physically straining stand to use. For this reason, the altered gooseneck clamp alternative scored poorly in the ease of use category. In the remaining categories it was determined that the two alternatives possess similar application costs and longevities, with the second alternative scoring slightly higher in the cost category due only to the slightly less expensive price of Loc-Line segments over the BESTEK Gooseneck clamp.

Stand 2: Loc-Line Constructed Clamp

The second stand alternative scored higher than the altered gooseneck clamp in a majority of the categories addressed. The only category in which this alternative is lacking is within stability. Due to high degree of flexibility this alternative would exhibit, it would be less capable of standing up to possible bumps and shoves that would threaten the optical probes locational integrity. However, with the exception of stability, the Loc-Line constructed stand would be significantly easier to use and would be slightly cheaper for us to apply than the

commercial gooseneck clamp. Additionally, the Loc-Line stand is significantly easier to use, due to the lack of any positional spring-back and the ease with which the segments may be posed. Ultimately, it was the Loc-Line constructed stand that our team decided to produce and apply in our interstitial diffuse optical probe, and the clip and stand are shown together in Figure 8.

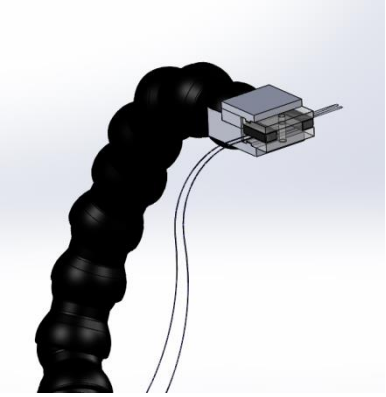

Figure 8: The Loc-Line stand connected to our optical needle clamp.

Testing

Single Needle Removal Force

Purpose: The purpose of this test was to quantitatively assess the clamping force applied to a single needle by determining the axial force required to cause a single needle to move along its axis. Determining the force at which the needle slips under the force of the clamp represents the maximum external force that a single needle in the probe can experience *in vivo*.

Methods: A single, 28 gauge needle was situated in one of the needle slots of the clip so that the blunt end was 4mm from the point of slot diameter change. The top piece of the clamp was then tightened onto the needle using the screw. The screw was turned an extra quarter turn after the point of first noticeable resistance when tightening to ensure consistency in the clamping force. The clip was then placed on its side and the needle was aligned to touch the force sensor on an electronic force gauge. To begin the test, the electronic force gauge was held steady while a gradual, normal force was applied to the back of the clip, pushing it towards the force gauge sensor. The sensor was calibrated to record the peak force, which corresponds to the force required to cause the needle slip. Five trials were conducted using the same needle and needle slot.

Double Needle Removal Force

Purpose: The purpose of this test was to quantitatively assess the clamping force applied to two needles by determining the axial force required to cause two needles to move along their axes. Determining the force at which the needles slip under the force of the clamp represents the maximum external force that the probe as a whole can experience *in vivo*.

Methods: Two 28 gauge needles were situated in one of the two slots of the clip so that the blunt ends were both 4mm from the points of slot diameter change. The top piece of the clamp was then tightened onto the needles using the screw. The screw was turned an extra quarter turn after the point of first noticeable resistance when tightening to ensure consistency in the clamping force. The clip was then placed on its side and the needles were aligned so that they both touched the force sensor on an electronic force gauge. To begin the test, the electronic force gauge was held steady while a gradual, normal force was applied to the back of the clip, pushing it towards the force gauge sensor. The sensor was calibrated to record the peak force, which corresponds to the force required to cause slip. Five trials were conducted using the same needles. See Figure 9 for the testing setup for the single and double needle removal force tests.

Figure 9: Testing setup for the single and double needle removal tests. The electronic force gauge was held steady while the clip was pushed slowly toward the force sensor.

Chicken Breast Insertion Force

Purpose: The purpose of this test is to quantitatively assess the shear forces experienced by a single needle in an organic material. The organic material used was a thawed, raw chicken breast.

Methods: The blunt end of a single needle was taped to the force sensor on an electronic force gauge so that it was aligned perpendicular to the force sensor surface. The needle was then inserted into a section of raw chicken breast, *2cm* thick, so that 0.5cm of the sharp end of the needle was fully exposed on the other side of the chicken breast. At this point, the electronic force gauge was turned on and the chicken breast was pushed toward the force gauge. The maximum shear force experienced by the 2cm section of the needle in the direction perpendicular to the force sensor was recorded. Five trials were conducted using the same needle and different sections of *2cm* thick chicken breast. See Figure 10 for the testing setup of the chicken breast insertion force.

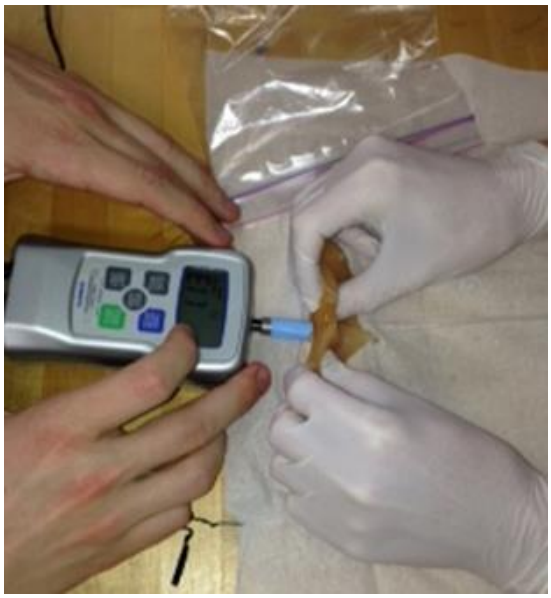

Figure 10: Chicken breast insertion force testing setup. The electronic force gauge was held steady as the 2cm thick chicken breast was pushed toward the gauge, with the needle completely penetrating the chicken breast.

Results

We performed five runs of the single needle removal force test so that we had ample data for both the average and the standard deviation. We found that our device could support a 2.05N removal force with a standard deviation of 0.032N. With a standard deviation this low in our proof of concept test, we felt that our prototype was performing consistently and decided to proceed to test a more realistic scenario.

In a similar manner, we then performed five runs and measured the peak force. For these tests, we had an average removal force of 3.34N with a standard deviation of 0.385N. It is curious that that average removal force for two needles is not closer to double the average of the

removal force of a single needle, but we believe this happened because the two needles were very hard to properly align when we weren't using the alignment system we designed into the clip. Since the needles weren't exactly aligned, one needle would touch the force gauge first and then begin to slip. Therefore we believe the results we got were a combination of static and sliding friction forces. However, we felt this would be acceptable since we were able to reasonably estimate what a true double needle remove force would be from the single needle test.

With the completion of the testing on our device, we needed to test the shear stress exhibited on the needles. We found that the average peak force was 0.198N with a standard deviation of 0.015N. Complete testing results can be seen in Table 3 on the next page.

Trial	Single Needle Removal Force (N)	Double Needle Removal Force (N)	Chicken Testing (N)
1	2.09	3.17	0.19
2	2.01	3.56	0.2
3	2.05	3.09	0.18
4	2.02	3.91	0.2
5	2.06	2.98	0.22
Average (Standard Deviation)	2.046 (0.032)	3.34(0.385)	0.198 (0.015)

Table: 3: Complete results of each of the tests perform on the final prototype. Each test category contains trials posted with the force needed to remove the needle from the clip and the chicken. The average force and standard deviation of each test scenario can be found at the bottom of the table.

The average force that our device was able to maintain on the needles seemed a little low to us at first, but with the completion of the testing, we are more than confident our device will be suitable for Dr. Kissick's use. Our double needle removal force tests showed that our device was able to hold the needles with an order of magnitude more force than was needed to remove the needles from the chicken breasts. As mentioned before, this will be sufficient for Dr. Kissick's research.

Future Work

With the design selected and constructed, we have several goals for this project going forward. First and foremost, we would like to stay in close contact with our client to continue improving our device if it falls short in any area while being used in the lab. We will be available to make any updates that need to happen to ensure that Dr. Kissick is satisfied with our product.

Now that a prototype device to use with the mice has been made, we will begin looking into making a device that is more suited towards human use. We hope to be able to make something that will allow for long term study of the tumor as well as data collection during treatment. To do this, we will need to design a device that is capable of staying on the body while remaining comfortable and usable. We believe this will involve making the device smaller and more ergonomic. It will also likely mean moving to the staggered needle design to prevent as much pain to the patient as possible.

Similarly we will want to look into ways to leave the device implanted while minimizing infection. One way that we have already brainstormed is making a device that can implant the optical fibers and then have the needles be removed. The main struggle with this design is determining a way to ensure the ends of the fibers remain three mm away from each other. Dr. Kissick has approached us about possibly working on the human project next semester. He is currently working to find a doctor that would be willing to help him get a patient to test his device on. Dr. Kissick believes with one human test, he will be able to publish some results of his system. Hopefully this could lead to some research funding and the possibility of the construction of a human device.

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