

# *Prosthesis Disinfectant and Deodorizer*

## **Final Report**

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## Abstract

The purpose of our project is to simplify the prosthetic liner cleaning process. Our client has proposed using ultraviolet radiation to sanitize and deodorize prosthetic liners. Before a prototype can be designed, testing must be conducted in order to determine if cleaning prosthetic liners by ultraviolet radiation is plausible. We have decided to perform germicidal, degradation, and odor reduction tests. The results of these tests yielded results suggesting sufficient sterilization with ultraviolet radiation with minimal signs of liner degradation.

## Background

### *Silicone Liners*

Silicone liners in prosthetics serve two primary purposes – comfort and performance. Comfort is important, especially in load-bearing prostheses, and the cushioned gel of the liner aids in the comfort of the wearer. Performance is also important, since poor-fitting liners can hinder movement and cause skin irritation. Liners require regular sanitation to prevent infection and discomfort since they are in direct contact with the body.

### *Current Problems*

The biggest problems prosthesis wearers have are infection and odor. Improper or inadequate sterilization techniques can lead to an increase in bacterial growth and possibility of infection. In some cases, the infection requires surgical intervention to prevent exacerbation. Along the same lines, bacteria typically results in substandard aromatic appeal due to the increase in odor.

### *Current Cleansing Methods*

Currently, the most common practice of disinfecting the liner is with mild soap and water – this is what most prostheses companies suggest. Alcohol swabbing is also a common technique many wearers use. Neither of these methods is completely effective, considering the persistence of infection. Irregular sanitation and missing spots when cleaning by hand contribute to a heightened risk of infection.

### *Ultraviolet Ultraviolet (UV) Radiation*

UV radiation has a shorter wavelength than visible light and is used in a number of applications. It is currently used as a purifier in air and water applications, such as drinking water and aquariums. These uses rely on the mutagenic radiation of ultraviolet light. This physical mutagenic property disrupts the thymine dimers in DNA, which therefore mutates a cell's DNA, effectively killing it. It is because of this special quality of UV radiation that our client chose to use it to sterilize the silicone liner of the prosthesis. His daughter actually uses a UV light (coined the “Kelly Light” after her) to

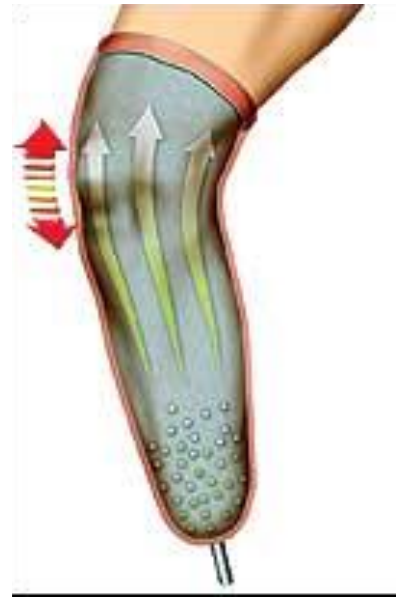
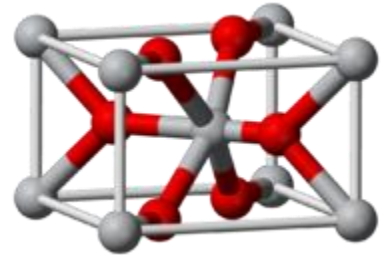


Figure 1 - Prosthetic liner diagram

sterilize her prosthetic leg; she does not use a liner. UV light is also responsible for some harmful effects to the skin and eyes, including sunburn, skin cancer, cataracts, and macular degeneration. The dangerous qualities of UV light make it imperative that we incorporate safety precautions when dealing with the light.

### ***Titanium Dioxide (TiO<sub>2</sub>)***

Titanium dioxide is a photocatalyst. When activated by UV light, titanium dioxide serves to aid in killing and decomposing bacteria. This occurs through a photoreaction, in which the free radicals generated from titanium dioxide (as a photocatalyst) oxidize organic matter to kill bacteria. Titanium dioxide also serves to catalyze the oxidation of noxious chemical odors, acting as an effective deodorizing agent. We hope to determine whether or not this added benefit is cost effective to the method.



**Figure 2** - Molecular representation of titanium dioxide

## **Project Motivation**

In this project, we are attempting to validate the effectiveness and feasibility of using ultraviolet light to sterilize and deodorize prosthetic liners. Our client intends to use the information discovered as a means to segue into a prototype or concept for consumer use. The concerns of ultraviolet use include the effects of radiation on the liner and possible silicone degradation, the sterilization efficiency of ultraviolet light, and the deodorization capacity of ultraviolet light. Titanium dioxide is also in question as a possible deodorizing and sterilizing method to be used on liners. These parameters in mind, it is then the focus of our research to investigate each as a separate variable. Once concluded, the results will be instrumental in the progress of moving towards a consumer product.

## **Testing and Objectives**

There were three main variables instigating investigation and testing, microbial sterilization effectiveness, silicone degradation and deodorization effectiveness. The scope of the tests conducted was to verify the efficacy and feasibility of using ultraviolet radiation as a sterilization and deodorization method for silicone liners. Three tests were structured and conducted to represent each of the variables. Below is shown each of the tests structured as an introduction, procedure, results and discussion, and conclusion. Below is shown the selection of test priority. The testing goal was to investigate and conclude issues raised by each variable in a manner that is reproducible, accurate and justifiable.

In order to determine priority of the aforementioned tests, a testing matrix was implemented. The test matrix evaluated the capability of each test to cover the factors shown in the table. The factors were safety, germs, degradation, odor, wattage effect, exposure effect, repeatability, cost and time. Safety was mandatory for each test as UV light can be hazardous. Germs are an important variable to be tested. Germicidal irradiation is the main step in sanitation and verifies protection from infection. Degradation is a key element in verifying the efficacy of sanitization and deodorization. Degradation is to be tested with respect to UV radiation and titanium dioxide exposure.

Odor is the capacity to produce determinate deodorant data. Wattage and Exposure effects are variables implemented to determine the impact of UV radiation at various luminosities and lengths of time. Repeatability shows the ease of which a test is accurately reproduced. Cost and time are factors we need to be aware of, as both are limited.

Test Factors	Weight	Degradation Test	Germ Test	Odor Test
Safety	Must	Yes	Yes	Yes
Germs	18	0	16	3
Degradation	18	15	1	3
Odor	12	3	6	9
Wattage effect	8	6	4	3
Exposure effect	8	7	7	5
Repeatability	18	16	14	9
Cost	6	5	3	2
Time	12	5	10	11
Total	100	57	61	45

Figure 3 - Matrix outlining the determination of test priority

## Microbial Sterilization Test

### Introduction

The testing procedure described in the following report attempts to answer the question of the sterilizing benefits of ultraviolet radiation versus the conventional methods of mild soap, water, and alcohol in prosthetic liner cleansing. A common bacterium found on human skin that causes infection is *Staphylococcus epidermidis*, abbreviated *S. epidermidis* (Wikipedia). Therefore, we chose to use *S. epidermidis* in our microbial content test. The use of ultraviolet light as a sterilizer comes from its innate ability to disrupt the DNA of bacteria, effectively rendering the bacteria harmless (or killing it). Specifically, the ultraviolet radiation disrupts the thymine nucleotide in the DNA (Campbell 330). By comparing the sterilizing effects of ultraviolet radiation with those of the two common methods currently in practice – soap/water and alcohol – we hope to achieve results that will call for further development in the field of ultraviolet sterilization.

### Procedure

The materials required for this experiment were: 10 nutrient agar plates, an inoculating loop, a Bunsen burner, distilled water, a vial of living *S. epidermidis*, 9 2 X 2 inch squares of prosthetic liner, an incubator, a refrigerator, and 9 empty Petri dishes. Once all of the materials are secured, the first step is to culture as much of the *S. epidermidis* onto one of the nutrient agar plates as possible. This is done by dipping the inoculating loop

into the vial of *S. epidermidis* and streaking the bacterium onto the agar. Prior to inoculation, the loop must be sterilized in the flame of the Bunsen burner. It should be sterilized again following the inoculation. The purpose of this step is to get a large living colony of bacteria to use as a “supply” in the following steps. The agar and the bacteria must be thawed to room temperature for this step if they were refrigerated prior to use. After streaking, the agar plate is put into the incubator at 37° Celsius.

Number	Method
C1	Control 1
2	Soap/Water
3	Alcohol
4	Soap/Alcohol
5	5-Watt UV
6	9-Watt UV
7	9-Watt UV/TiO <sub>2</sub>
8	5-Watt UV/TiO <sub>2</sub>
C9	Control 9

**Figure 4** - Numbering system for samples

After 120 hours we removed the agar plate and distributed the bacteria, along with some of the agar, onto the nine squares of liner with the inoculating loop, which one again was sterilized. Some agar came with the bacteria so that the *S. epidermidis* would have some “bacteria food” while living on the liners. Each infected liner was now placed in its own empty Petri dish and then returned to the incubator at 37° Celsius. This was to simulate actual living conditions on the prosthetic liner.

Next, after 216 more hours, the liners were removed from the incubator and sterilized. Two of the liners did not get sterilized, to serve as controls. These liners were simply gently rinsed with distilled water into their own thawed agar plate. The agar plates were then put in the incubator again at 37° Celsius. The other seven liners were sterilized seven different ways: with mild soap and water, alcohol, a combination of soap and alcohol, a minute of 9-Watt ultraviolet radiation (one with and one without titanium dioxide), and a minute of 5-Watt ultraviolet radiation (one with and one without titanium dioxide). After each sterilization method, each liner was gently rinsed with distilled water into separate thawed agar plates. The plates were numbered, in no particular order, with reference to the sterilization technique used. A key is shown at right. These plates were then put into the incubator at 37° Celsius with the controls.

Finally, after 96 hours, the agar plates were removed from the incubator and observed with the naked eye and microscope to observe bacterial growth. The resulting growths from each of the nine liners were compared with one another to determine sterilizing ability based on ranking. Theoretically, the more growth found over the 96 hours since sterilization, the less effective the sterilization. Above all, the controls would be expected to have much more growth than any of the other plates.

### ***Results and Discussion***

After the final growth period following liner sterilization, the nine agar dishes were observed for bacterial colonies. This was done with regard to the area, individual size, and density of the colonies. Preference was given to density as the tell-tale factor in bacterial growth. The resulting growths are shown in *Appendix A*; however it will suffice to relay the rankings here. Although it was difficult to discern an *exact* ranking system based on visually analyzing the growths, we were able to gather some substantial data. First, to insure an unbiased test, we made sure to not know which samples corresponded to which sterilization methods. In effect, the order we agreed upon was, from worst to

best sterilization: C9 → C1 → 4 → 7 → 5 → 2 → 3 → 8. Translated, this corresponds to: control 9 → control 1 → mild soap and alcohol mix → 9-Watt UV with TiO<sub>2</sub> → 5-Watt UV → mild soap and water → alcohol → 5-Watt with TiO<sub>2</sub>.

An important observation to make is that sample 6, the 9-Watt ultraviolet radiation without TiO<sub>2</sub> sterilization technique, is missing from the rankings. This is because the growth that appeared on the agar plate of sample 6 was very different from the growths of the other liners. A picture of the resulting sample 6 growth is shown in *Appendix B*. Specifically, it was unclear whether sample 6 should be ranked 2<sup>nd</sup> behind sample 8 or 5<sup>th</sup> behind sample 5, or anywhere between for that matter. The reasoning behind this inconsistency came as a result of the unusually large colonies present on sample 6, while there being relatively small area and low-density colonies all the same. These qualities were in sharp contrast to the other eight samples, in which the three qualities (area, density, and size) used to determine quality of sterilization were much more consistent with each other. Since the results were unclear with respect to the other samples, sample 6 was left out of the rankings. However, it should suffice to say that it was clearly better than either control, as well as the soap and alcohol combination. This strongly suggests that the 9-Watt ultraviolet radiation had some sterilizing effect.

The rankings provided were in hopes of developing some relationship between ultraviolet light and the current methods, although clearly this was not presented. However, the differences between growth colonies were so subtle, as can be seen in *Appendix A*, that it is more apt to conclude that ultraviolet radiation works just as well as the current methods in disinfecting the liners, based on the results. Although further, larger-scale testing at the microbiological level is necessary to determine more definite conclusions, it is sufficient to note that all sterilization methods (perhaps with the exception of the soap and alcohol combination) were effective in killing the *Staphylococcus epidermidis* bacterium. However, it is also interesting that none of the methods were able to completely eradicate the strains.



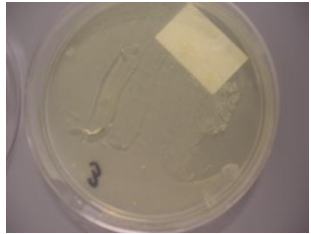

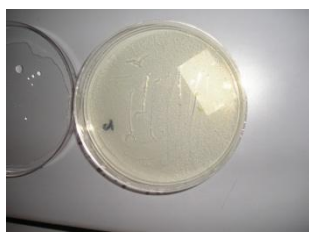

The effects of titanium dioxide, however, are not as clear. Although the clear-cut best sterilizer was the 5-Watt ultraviolet bulb with titanium dioxide, the 9-Watt bulb with titanium dioxide was at the other end of the spectrum as the second-worst sterilizer. This inconsistent and unexpected result inhibits any conclusions surrounding titanium dioxide. However, it is adequate to postulate that the effects of titanium dioxide offer little added benefit to the natural sterilizing effects of ultraviolet radiation, if any. At the same time, it is impossible to hypothesize any differences in sterilization based on ultraviolet wattage. This is because, sample 6 withholding, the sterilizing effect of the ultraviolet bulbs appeared better for the 5-Watt bulbs than the 9-Watt bulbs, which is the opposite of what one would expect, granted the difference is for the most part minimal.

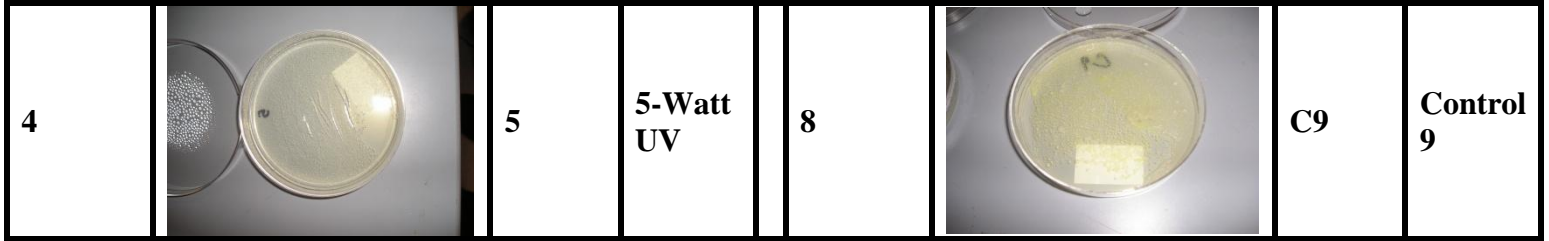
### ***Conclusion***

The primary conclusion to be drawn from the Sterilization Test is that ultraviolet radiation is about as effective in disinfecting silicone prosthetic liners as the current methods in practice. This conclusion can be drawn generally based on observing all of the bacterial growths of the sterilized liners versus the controls, where there is a clear

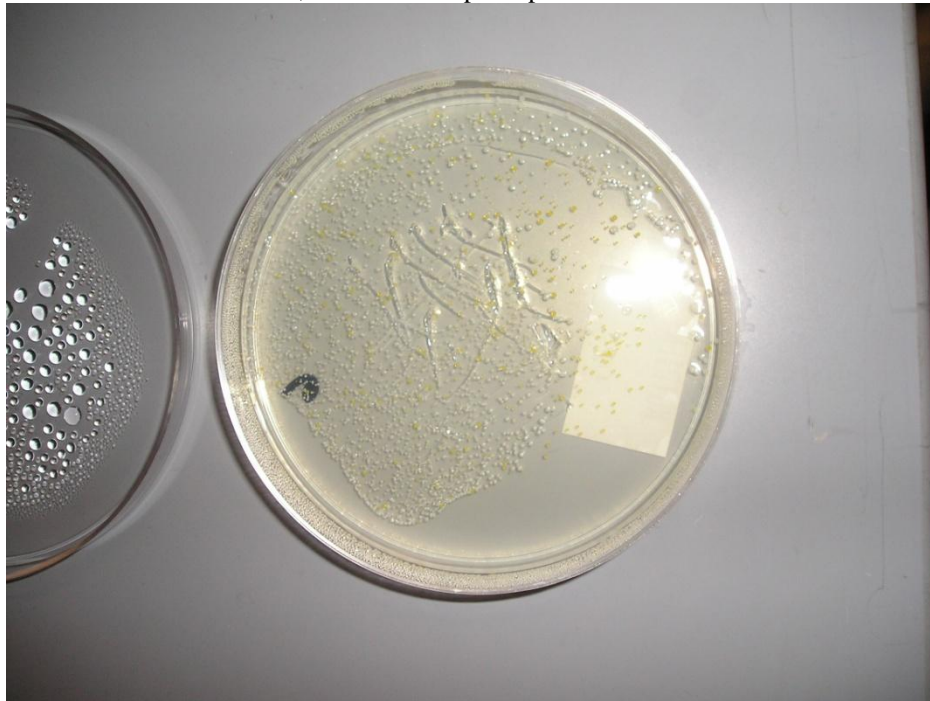
difference in bacterial accumulation. Unfortunately, we can only speculate on the effects of ultraviolet coupling with titanium dioxide and wattage. A reasonable assumption is that titanium dioxide provides little, if any, added sterilizing effects to the ultraviolet radiation based on the data collected. Wattage effect is even more obscure, and further testing is definitely needed before making any postulations.

Due to budget constraints, we were only able to use nine agar dishes, and subsequently nine liners. With only nine samples, and only the control as a duplicate, there is a high probability of error. In order to obtain more reliable results, this experiment should be repeated with many more samples. The test should repeat the seven sterilizing methods at least ten times and compare results, along with the implication of more wattages and exposure times. Consistency is an issue when seven samples, independent of one another, are used since there is no guaranteed way to insure that all liners are exposed to equal amounts of bacteria. For this reason, some sterilizing methods may have been at an unfair disadvantage in trying to disinfect larger colonies of bacteria. Another potential source of error could have occurred between the independent sterilizations and the rinsing into the agar gels. Perhaps, if there was an insufficient time elapse between the two occurrences, the bacteria would not have completely died off before escaping the hazardous conditions and entering the nutrient agar. This could explain the fact that none of the methods were able to completely kill all colonies of the *S. epidermidis*.

Ranking	Image	Sample #	Method	Ranking	Image	Sample #	Method
1		8	5-Watt UV with TiO <sub>2</sub>	5		7	9-Watt UV with TiO <sub>2</sub>
2		3	Alcohol	6		4	Mild Soap and Alcohol
3		2	Mild Soap and Water	7		C1	Control 1



**Figure 5** - Results of sterilization test, with each sample depicted



**Figure 6** - Visual growth after 9-Watt ultraviolet radiation (without TiO<sub>2</sub>)

## Silicone Degradation Test

### *Introduction*

The following protocol was utilized in a research environment to analyze the affects of ultraviolet light exposure on silicone prosthetic liners. In correlation with the study of an ultraviolet disinfecting device, Dr. John Allen, inventor and client, questioned the integrity of the silicone prosthetic liners post-ultraviolet radiation.

The average life of a prosthetic liner is approximately six months and current disinfecting methods of soap, water, and rubbing alcohol do not pose a threat on the liner's integrity. If a transition to the disinfecting ultraviolet light were made, it would need to be guaranteed that the same integrity would remain. The approximate cost of a single prosthetic liner is \$200-\$400, so more frequent replacement would not be ideal.

Past research indicates that UV-irradiation exposure can cause similar degradation effects as that of heat exposure. Over time, the material loses its material strength and elasticity. With the comfort of the patient in mind, any lose of material properties is not acceptable. This protocol explains the testing incorporated with understanding the degradation of

silicone liners to ultraviolet exposure, in hope of gaining insight on Dr. Allen's research question.

### ***Procedure***

Two new silicone prosthetic leg liners were obtained with the help of Dr. Allen from two different companies ALPS Corporation and Freedom Innovations. Upon receiving the liners, the companies were contacted and questioned about the possibility of degradation of their liners with UV light exposure. Both companies claimed the liners would maintain their integrity if exposed to UV-irradiation for extended periods of time.

The prosthetic liner from ALPS Corporation had an outer tan fabric shell connected to 1/4" of silicone material (*Figure 1*). The liner received for Freedom Innovations was a white Parydonn liner approximately 1/8" thick (*Figure 2*). In comparison, both liners were made of silicone; however, each a slightly different kind.



**Figure 7** - ALPS (tan) liner and Freedom Innovations (white/perydonn) liner

UV-irradiation is harmful to both eyes and skin. In order to reduce the risk of physical damage, a wooden testing device was constructed to allow individual testing spaces to prevent light leakage into the environment. During initial construction, three separate enclosures were included in the design, representing the three wattages of ultraviolet light bulbs Dr. Allen provided, 9-watt, 5-watt, and 3-watt. However, due to an inconsistent luminosity and irregular socket requirements, the 3-watt bulb was pulled from the degradation testing. See *Figures 8* and *9* for experimental set-up and lights used.



**Figure 8** - Experimental set-up of degradation test



**Figure 9** - 9-watt UV light (top) and 5-watt UV light (bottom) used for testing

The two liners were cut into 5”x 1” strips and exposed to ultraviolet light for extended periods of time, 12 or 24 hours respectively. The average time to disinfect the liners is approximately one minute; therefore, the times used were quite an overestimate. See *Figure 10* for a representation of the samples tested.

	<b>Liner Type</b>	<b>Total Number of Samples</b>	<b>Exposure Time (12 hrs)</b>	<b>Exposure Time (24hrs)</b>
<b><i>Control</i></b>	ALPS-Tan	2	N/A	N/A
<b>Control</b>	FI-White	2	N/A	N/A

<b>9-Watt Exposure</b>	Tan	4	2	2
<b>5-Watt Exposure</b>	Tan	4	2	2
<b>9-Watt Exposure</b>	White	4	2	2
<b>5-Watt Exposure</b>	White	4	2	2

**Figure 10** - Sample distribution of liners

Once all liners were exposed for the given amount of time, the material properties of each liner needed to be tested in order to determine a potential loss in integrity. The Instron 1000, a tensile testing machine located in the mechanics lab at the University of Wisconsin-Madison, was used to test the liners to failure in order to calculate their relative force vs. displacement relationship (See *Figure 5* for tensile test set-up). The analysis of the recorded force and displacement measurements provided quantitative data in which to compare and contrast. Because the material specimens were not all the same size and shape, dimensions were recorded and used in calculating the appropriate stress and strain. The stress-strain curves for each specimen were then graphed and compared directly. Note the equations in the text used for analysis.



**Figure 11** - Experimental set-up of tensile test; example of similar Instron Model 1000 equipment with computer to retrieve data

*Equations used for calculating relative stress-strain:*

$$\begin{aligned} \text{Stress} &= \frac{\text{Force}}{\text{Area}} \\ \text{Area} &= \frac{\pi \cdot D_1 \cdot D_2}{4} \\ \text{Strain} &= \frac{\text{Displacement}}{L_0} \end{aligned}$$

**Figure 12** - Equations used for the calculations of stress and strain

Where  $D_1$  = liner thickness,  $D_2$  = liner width across, and  $L_0$  = the length of the liner in the tensile testing machine. Force and displacement values were read from the tensile testing machine.

Due to time restrictions, the tests of the control liners and liners with the maximum exposure time and wattage (9-watt, 24 hours) were tested and compared for each liner type.

***Results and Discussion***

The following stress-strain graphs were yielded with the aforementioned analysis. *Figure 6* represents the stress-strain curve for the ALPS Corporation (tan) liner, for both the control and 9-watt, 24-hour exposed liner. As the graph shows, there is variation between the maximum failure stress (last point on each data set) and the slope of each of the data sets. The exposed liners have a smaller maximum failure stress versus the control. Relative elasticity, or slope of each line, is inconclusive from these results. During testing, the ALPS (tan) liner was able to stretch at least six times its original length and for all samples inevitably failed on the fabric portion. The variability in the stress-strain curve represents this occurrence. It is also apparent that the two liners exposed for the same amount of time are inconsistent with each other, questioning the consistency of the difference from the control.

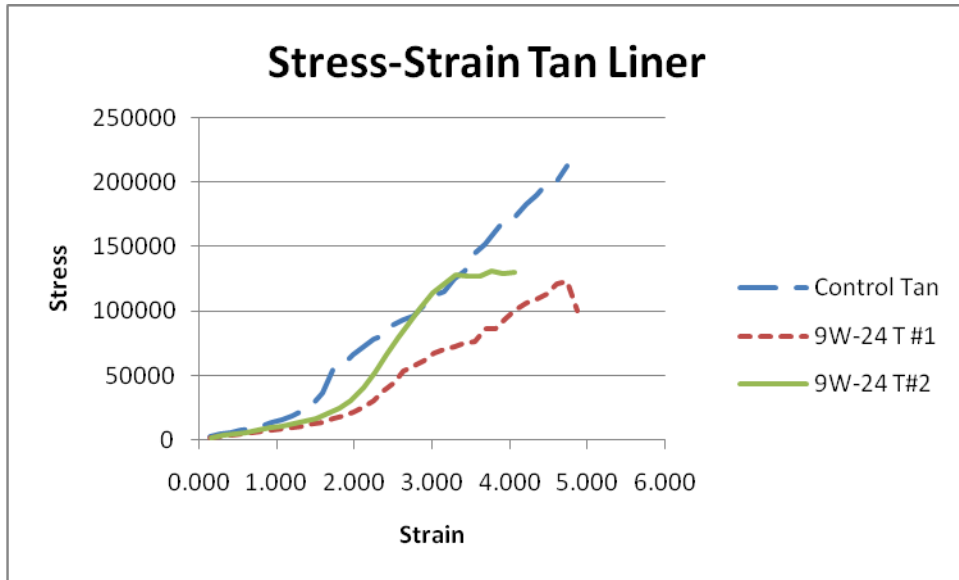


Figure 13 - Stress-strain curve for the ALPS (tan) liner; control versus 9-watt-24 hours

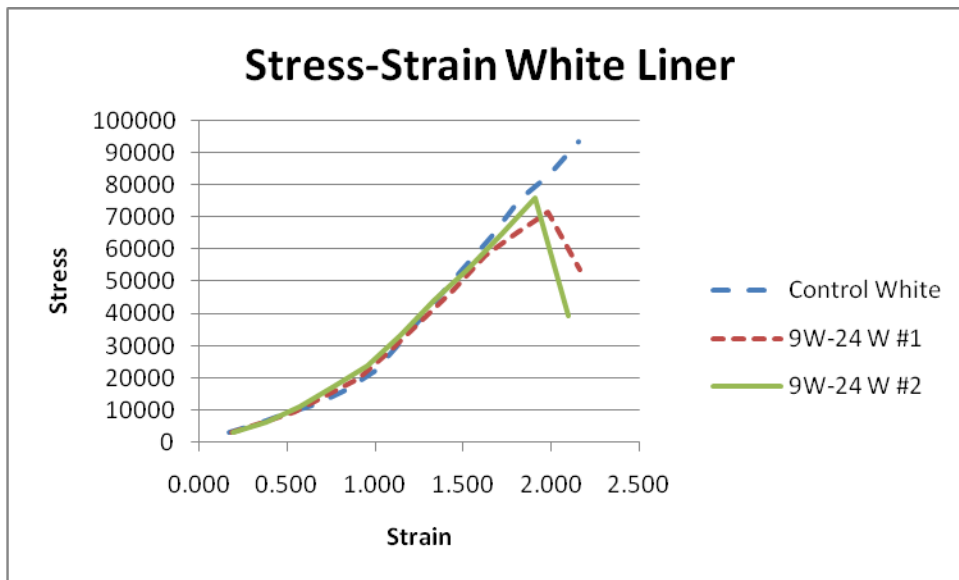


Figure 14 - Stress-strain curve for the Freedom Innovations (white) liner; control versus 9-watt-24 hours

### Conclusions

The quantitative data represented in this protocol from the tensile testing machine was just one approach to understanding the effect of ultraviolet light on silicone liners. The overall test to consider is the comfort of the person wearing the liner; they would be the best judges of whether or not the liner has lost its integrity.

However, to answer the research question by looking at the raw data, there is NOT significant evidence within these tests to prove a considerable effect to the liner's integrity for both liners tested for the following reasons:

- The testing results shown use exposure of 24 hours; however, the typical user of this prosthetic disinfectant device will only be exposing their liner for

approximately one minute each day. When summated to the 6-month life of a liner, the exposure time is approximately 3 hours total, or 1/8 of the tested time.

- The tested liners were exposed to the 24 hours of ultraviolet light within a few days. The gradual exposure of the liner will negate these affects.
- The stress-strain graph for the ALPS liner was affected by many variables, including fabric attachments and positioning of fabric seams.

Future work to understand the degradation test would be to have a clinical study with prosthetic liner wearers to more fully understand the comfort of a liner with possible integrity loss.

## **Deodorization Test**

### ***Introduction***

Our client would like us to determine the optimal bulb wattage and duration of exposure for the sanitization of prosthetic liners by ultraviolet radiation. He also wants us to determine if the deodorizing effects of titanium dioxide are worth its inclusion in the UV deodorizing process. The results of the odor test should assist us in the determination of these three factors.

### ***Procedure***

The procedure for the odor test consists of odorizing the liners, deodorizing the liners using different methods, and then administering a sniff survey to find out which deodorizing method was most effective. First a piece of prosthetic liner was cut. Its size was about 32.5 centimeters by 6.25 centimeters. To simulate the natural odors that are associated with wearing prosthetic liners, the cut piece of liner was worn within a shoe for approximately four hours while playing basketball. The odorized liner was then cut into ten equally sized pieces (about 3.25 cm by 6.25 cm). Each piece was placed into a sealed plastic bag until deodorization. Each piece was numbered one through ten, and deodorized by the methods described in *Table 1*. The distance between the UV light and the sample was approximately one inch. The titanium dioxide was applied to aluminum mesh, which was placed about half way between the UV light and the sample. The pieces were then put back into separate plastic bags, and the survey was administered. Participants were asked to rate the strength of the odor of each sample on a scale of one to ten (ten being a very strong odor and one being no odor).

<b>Sample #</b>	<b>Deodorizing Method</b>
1	No deodorizing method
2	Water, soap, rubbing alcohol
3	UV, 5 Watts, 30 seconds
4	UV, 9 W, 30 s

5	UV + TIO <sub>2</sub> , 5 W, 30 s
6	UV + TIO <sub>2</sub> , 9 W, 30 s
7	UV, 5 W, 60 s
8	UV + TIO <sub>2</sub> , 9 W, 60 s
9	UV + TIO <sub>2</sub> , 5 W, 60 s
10	UV, 9 W, 60 s

**Figure 15** - Sample assignments used for testing odor

### ***Results and Discussion***

Our results show the average odor strength of each sample and the effectiveness of each deodorizing process. The effectiveness of each deodorizing process (as shown in *Table 2*) was calculated by subtracting the average odor strength after the deodorizing method was applied from the average odor strength of the first sample, which was not cleaned at all. There were 21 people surveyed. *Table 3* ranks each deodorizing method based off of the survey's results.

Sources of error could include an uneven distribution of odor on the liner before it was cut, and odor interference from the plastic bag and liner. Accuracy in this experiment could have been improved by including more samples and cleaning methods, increasing the number of participants in the survey, and by conducting two surveys (once before all pieces of liner are deodorized and once after all pieces are deodorized). A stronger odorizing method could also be used because of the large number of low odor strength ratings that were reported. A more consistent odorizing method would be helpful so that repeatability of the experiment could be increased.

<b>Sample #</b>	<b>Average Odor Strength</b>	<b>Effectiveness</b>
1	8.38	0
2	1.52	6.86
3	2	6.38
4	1.71	6.67
5	1.76	6.62
6	1.48	6.9
7	1.71	6.67
8	1.38	7
9	1.43	6.95
10	1.38	7

**Figure 16** - Effectiveness of each deodorizing process

<b>Effectiveness Rank</b>	<b>(EFF)</b>	<b>Deodorizing Method</b>
1	(7)	UV + TIO <sub>2</sub> , 9 W, 60 s
1	(7)	UV, 9 W, 60 s
3	(6.95)	UV + TIO <sub>2</sub> , 5 W, 60 s
4	(6.9)	UV + TIO <sub>2</sub> , 9 W, 30 s
5	(6.86)	Water, soap, rubbing alcohol

6	(6.67)	UV, 9 W, 30 s
6	(6.67)	UV, 5 W, 60 s
8	(6.62)	UV + TIO <sub>2</sub> , 5 W, 30 s
9	(6.38)	UV, 5 Watts, 30 seconds
10	(0)	No deodorizing

**Figure 17 - Ranking of deodorizing methods**

### **Conclusion**

Based off of the survey's results, the most effective deodorizing method was the 9 Watt UV bulb with a duration of 60 seconds. The result for this bulb and duration was the same with and without titanium dioxide. The data shows that the use of titanium dioxide does not matter if the duration of exposure is extended and the bulb is of a higher wattage. For example the inclusion of titanium dioxide did not matter for the 9 W bulb with 60 second exposure but there was a difference in effectiveness for the 9 W bulb with 30 second exposure and the 5 W bulb with both 60 and 30 second exposures. Basically this means that titanium dioxide is not needed if higher wattages and longer exposure times are used to clean the liner. If a lower bulb wattage is used, then titanium dioxide should be included along with a longer exposure time. This is shown by the effectiveness difference between samples 9, 3, 7, and 5.

The current deodorizing and cleaning method uses water, soap, and rubbing alcohol. This method had an effectiveness rating of 6.86. This method of deodorizing is currently accepted as a satisfactory deodorizing method. This means that any other deodorizing method that has an effectiveness rating of 6.86 or above also deodorizes to at least a satisfactory level. The following methods all deodorize better than the current method of soap and alcohol: 9 W bulb for 60 seconds with titanium dioxide, 9 W bulb for 60 seconds, 5 W bulb for 60 seconds with titanium dioxide, and 9 W bulb for 30 seconds with titanium dioxide.

The deodorizing method that is the most effective and inexpensive is the 9 Watt ultraviolet bulb with a duration of 60 seconds. This is because the other three methods that are satisfactory (excluding the current soap and alcohol method) all include titanium dioxide.

### **Materials and Costs**

The materials and cost of materials are as stated below:

<b>Material</b>	<b>Cost (\$)</b>
Agar gel	38.10
Bacteria	31.60
Hardware costs	27.92
Titanium Dioxide	44.74
Sockets for lights	15.43
Poster	30.83
<b>Total</b>	<b>188.62 (&lt; budgeted \$200)</b>

## **Conclusion**

The research in this project was conducted fluidly. Liners were tested and assessed based on three parameters: sterilization, degradation and odor. After all testing had been completed as described in respective protocols, it was found that the liners were able to be effectively sterilized and deodorized by ultraviolet light and titanium dioxide. It was also found that there was not visual evidence of degrading effects from ultraviolet light on the silicone liners. However, we only tested with the naked eye and with tensile tests. A consumer comfort tests should be conducted. The testing conducted and concluded in this project reflect positively on the possibility of using ultraviolet light and titanium dioxide as an alternative to conventional cleansing methods. Additional testing should be conducted to confirm findings.

## **Recommendations**

After concluding this project, it is our recommendation to our client that ultraviolet light and titanium dioxide are qualified candidates for sterilizing and deodorizing prosthetic liners. There was clear evidence of sterilization and deodorization of liners using these cleansing methods with no visual or tensile evidence of degradation. We propose that our client pursue the construction of a prototype and the further investigation into a consumer product. However, our team also suggests our client conduct further testing during this process. The results we found were preliminary, and future work should be conducted including consumer comfort tests and temperature effect testing.

## **Future Work**

The future holds several processes to be completed. First of all, further testing should be implemented to better quantify parameters. This testing should include consumer tests to evaluate the comfort of a liner after it has been repeatedly exposed to ultraviolet light and titanium dioxide. Temperature testing should also be conducted to investigate the heat incurred by the liner when exposed to light for a given time period. This testing has been conducted by outside sources before and can be consulted by journal. After testing has been conducted, a prototype should be built. Following its construction, testing, refining and retesting should commence until the prototype is ready for development and production.

## Appendix A - References

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## Appendix B - PDS

**Function:** The liners of prosthetic devices must be sterilized and/or deodorized on a regular basis. Currently, this process is lengthy, inefficient and inconvenient. This can lead to unsterile conditions if proper maintenance is not applied and consequently infections may result. The goal of the project is to research, test and design a method that simplifies cleaning/disinfecting prosthetics. The scope of the project includes the investigation of germicidal lamps and deodorizing substances such as titanium dioxide.

### Client requirements:

- Determine optimum wattage and duration of exposure for different silicone materials through testing
- Determine effect of UV-irradiation and quantitative analysis on silicone materials
- Determine effect of titanium dioxide on prosthetic liners
- Determine effective methods of deodorizing silicone liners

### Test setup / design requirements:

#### 1. Physical and Operational Characteristics

##### *a. Test protocol and setup performance requirements:*

- Must be easy to reproduce experimental data
- Must investigate deodorization to satisfactory level
- Must investigate sterilization of prosthetic liners to safe predetermined scales
- Must not damage prosthetic materials
- Must not radiate extensive heat

##### *b. Safety:*

- UV radiation is harmful to the eyes and skin that is exposed; prototype must incorporate safety precautions during use considering the target audience
- Temperature or long duration induced auto-shutoff
- Stable bases to prevent falling over

##### *c. Accuracy and Reliability:*

- Tests must be reproducible
- Data collected must be accurate
- Testing reports must be documented in detail

- Quantified data must be justified

d. *Life in Service:*

- Determined by testing setup demand; at least 3 years

e. *Shelf Life:*

- Determined testing setup demand; at least 10 years

f. *Operating Environment:*

- Prepared for use in dusty environment
- Must function safely indoors

g. *Size:*

- Must accommodate several samples of liners
- Must be storable
- Must be mobile to test at different locations

h. *Weight:*

- Weight is under 12 lbs

i. *Materials:*

- Oil may not be used in any form
- Plastics that will not melt under UV-irradiation
- Metals
- Titanium Dioxide
- Silicone
- TUV bulbs
- Electrical wiring

j. *Aesthetics, Appearance, and Finish:*

- Just make it functional and accurate

## **2. Production Characteristics**

a. *Quantity:* one

b. *Target Product Cost:* \$200

