# Comparative Durability and Abrasion Resistance of Natural and Synthetic Latex Gloves

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# Abstract

Medical gloves assist with the prevention of the spread of germs and are required to be worn when working with blood, body tissues, mucous membrane, and broken skin. They should provide good protection between hands and bio hazardous fluids to prevent contamination and promote safety of all healthcare workers and patients. Hence, it is critical for medical gloves to meet a standard performance criterion. Under ASTM D 3577 and D 3578, medical gloves have requirements they must meet in order to be sold and distributed as new gloves. However, there are no industry standards for gloves to meet while in use. The goal of this project was to develop a standard test for glove durability after their initial use. For the tests, gloves were worn by a mechanized prosthetic hand that was put under different conditions which are normally experienced by professionals in the medical field. This design was developed and later confirmed by Dr. Katrina Cornish:

Design: Effects of media outside the glove
- Phosphate buffered saline (PBS), 70% ethanol, air

Gloves Tested:
- Chloroprene, Latex 2, Nitrile, Polyvinyl Chloride and Latex 1

To evaluate glove durability during use, the gloves were immersed in different media before being subjected to contact with an abrasive surface. From this design, ranking of commercially available gloves are developed based on the time until failure of the gloves in these tests.

Using the designed system, five types of gloves have been tested using 40grit sandpaper as the abrasive surface with a constant force from the prosthetic hand. The results show that Latex 1 has the highest ranking and Vinyl has the lowest ranking. This indicates Latex 1 is relatively more durable than Vinyl. In between those two were Latex 2, Chloroprene, and Nitrile from highest to lowest. The overall durability differences between those three gloves are not as significant if compared to the difference between Latex 1 and Vinyl. Tukey's Honest Significant Difference method was used to determine the statistical difference. This same test was also used to determine human factor error among the three team members and results concluded that human factor error is negligible.

The expected deliverables were as follows:

- Develop a standard protocol that can be used in the development of ASTM standards and procedures to test for glove durability while it is in use
- Rank commercially available glove materials with data from the standard protocol

# Introduction

Each year, millions of medical gloves are used in the surgical room, doctor's office, and other healthcare establishments. Medical gloves play a crucial role in terms of protection for healthcare workers and patients. It would be essential for healthcare workers to know the lifespan of gloves in order to change them duly to prevent pathogens carried by bodily fluids coming into contact with skin. "Glove durability generally relates to a glove's longevity - its wear-life based on worker expectations up to the point at which the worker considers the product no longer suitable for the tasks at hand or worn out" [11]. ASTM D 3577 specification covers requirements for packaged sterile rubber surgical gloves of the natural rubber latex type (Type 1) and of the synthetic rubber latex type (Type 2) [1].

Another standard which must be met by new gloves is ASTM D 3578. This states that tests for sterility, freedom from holes, physical dimensions, tensile strength, powder-free residue, powder amount, protein content, and antigenic protein content are performed to evaluate the state of each rubber glove [2]. Before being packaged, they are also visually inspected for impurities in the material which may result in a potentially weak location. These standards are only met for gloves coming into the medical field as unused gloves. Currently, there are no tests which tell users the potential lifespans of these gloves. The goal of this project was to develop a standard practice for glove durability testing.

A robotic prosthetic hand was used to simulate the hand motions gloves are subjected to in a real-life situation. The prosthetic hand was fitted with various gloves to obtain comparable results under each condition.

Types of medical gloves that were tested include:

- Latex 2
- Nitrile
- Neoprene
- Polyvinyl Chloride

The hand was exposed to substances such as phosphate buffered saline (PBS), 70% ethanol, and air while in contact with an abrasive surface. The test we designed is reproducible, easy, and safe to execute.

The parameters of this project are:

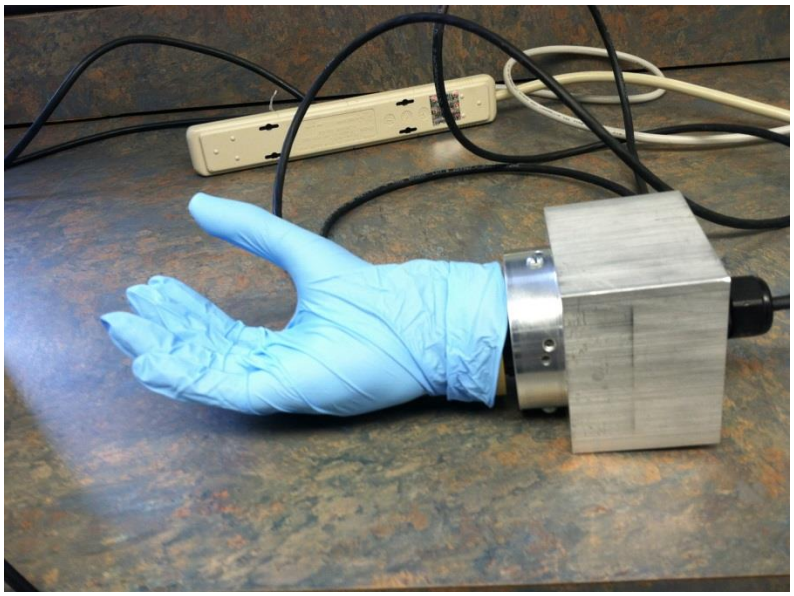
Mechanical:

- The experimental designs generated reproducible data for each type of medical glove
- The same prosthetic hand was used during each test to determine durability
- Structural integrity of the prosthetic hand was maintained

Operational:

- Prosthetic hand was operated using Simulink software
- Each glove type was put through the three selected tests to determine a durability ranking system
- Ranking system compared each glove type based on time to failure

The developed tests provided enough data to be able to rank commercially-available gloves with respect to their durability after initial use. The ultimate goal is to eventually develop these tests into a more practical application for the medical glove industry.



In order for gloves to be sold and distributed as new gloves, they must meet certain requirements. Standards and performance tests for new gloves are described in the American Society for Testing and Materials (ASTM) D 3577[1] and D 3578[2]. In these ASTM standards, characteristics of gloves and their performance requirements include their sterility, powder free residue, freedom from holes, and physical dimensions. Specific dimension standards include width and minimum thickness of gloves for different sizes. The physical requirement test includes testing gloves for elongation to break, which can be used as a ranking device if the gloves do not fail within a reasonable amount of time.

Abrasion resistance is an important quality of medical gloves to prevent exposure to unwanted pathogens. Abrasion was achieved by rubbing each glove with various grit sizes of sandpaper. The grit of sandpaper refers to the particle size of the rough material elevated above the paper to cause friction. As grit size increases, there is less space between each rough particle. This means a smoother surface correlates with a higher grit size and less friction [3]. In order to test the abrasion resistance of medical gloves material, researchers designed an apparatus which can exert force to lower the gloves durability [4]. An abrader is available which can rotate in adjustable-speeds that come into contact with the gloves being tested. This is so the gloves can be abraded in different forces. After the abrasion sequence, the barrier integrity of the material is assessed through a static leak test.

There is previous research for testing performance of medical gloves in simulated use. In this research, the durability of different types of medical examination gloves during simulated use was studied. The simulation included attaching and removing a capped needle to a syringe. This was followed by connecting and disconnecting a Luer-lok syringe to an intravenous tube and manipulating a stopcock. Gloves were visually inspected and water-tested according to the Food and Drug Administration water-testing standards. The results from this test showed that nitrile gloves had the lowest failure rate followed by latex, whereas vinyl and copolymer gloves had the highest failure rate [5]. Another durability method involved placing an assembled hand wearing gloves in a beaker. This beaker contained an abrasive material and was shaken for five minutes [6]. Another simulation performed consisted of using a sphygmomanometer and syringe. This was followed by removing and attaching a Luer-lok tip to a syringe as well as opening and closing different sized stopcocks, clamps, and hemostats. The results from both methods produced failures at similar rates. In addition, the points of failures were very similar with most of the gloves failing at the fingertips, knuckle area, and palm. The results also support that nitrile and chloroprene gloves are as durable as latex gloves.

There have been very few patents created concerning medical glove durability testing. One patent, US 3414808 A, is an electronic-electrolytic apparatus for glove testing [7]. This patent was

developed by the Midwestern Equipment Company and is an apparatus for immersing and testing a medical glove in an electrolytic solution. It may be used in order to hold various types of medical gloves in a range of solutions encountered daily by the users of these gloves. This could be used in the design of the proposed methods to hold gloves in various media. Another patent, US 2054204 A, developed by Mcdonald Willis V, was used to view and understand a previously designed glove testing device [8]. Air is pumped into each glove being tested. This glove is then submerged into water, searching for punctures within the gloves surface. If gloves in our experiments do not visually display structural damage, this device may be used to test for damage before sending gloves to Wooster for elongation and modulus measurements.

There are four types of gloves that were tested in the project. Latex is a colloidal suspension of very small polymer particles in water and can be used to make rubber. The raw material consists of 30%-40% rubber particles, 55%-65% water, and small amounts of protein, sterol glycosides, resins, ash, and sugars. The structure of latex rubber consists of a long chain made up of tens of thousands of smaller units which are called monomers. These are strung together, thus latex rubber has a polymer molecular structure and high elasticity. Natural latex is produced from the Hevea and Guayule plants. Nitrile gloves are made from 100% synthetic polymer, consisting of acrylonitrile, butadiene, and a carboxylic acid. Nitrile material has better resistance against chemicals which can provide barrier protection. Vinyl gloves are produced of polyvinyl chloride (PVC) which is a thermoplastic polymer used in many products. Since it is designed for short-term use, vinyl gloves have low costs but have lower resistance to chemicals and lower durability compared to other types of gloves. PVC does not cause allergic reactions whereas natural rubber gloves may. Neoprene is produced by polymerization of chloroprene. It has good chemical resistance and heat resistance in a wide temperature range [9] [10].The tables of ideal temperature range for using of different type of material and performance of these gloves are shown below [12].

**Table 1. Ideal Temperature Range for Glove Materials**

| **Material of Glove** | **Temperature Range (in Celsius)** |
|---|---|
| Latex | -50 to 82 |
| Neoprene | -40 to 115 |
| Nitrile | -55 to 82 |
| Polyvinyl Chloride | 54 to 80 |

Below is a table showing a comparison of different properties of the gloves to be tested [13].

**Table 2. Glove Material Comparison**

| Material | Chemical Resistance | Strength and Durability | Elasticity | Allergen content | Economy |
|---|---|---|---|---|---|
| **Latex** | Good | Excellent | Excellent | Varies | Very Good |
| **Nitrile** | Excellent | Excellent | Very Good | Very good | Good |
| **Neoprene** | Very Good | Very Good | Excellent | Excellent | Good |
| **Polyvinyl Chloride** | Poor | Poor | Fair to Poor | Good | Very Good |

As the table shown above, four types of gloves tested in the projects are compared in the performances in Chemical Resistance, Strength and Durability, Elasticity, Allergen, and Economy. The chemicals that the glove should have resistance to include: acids, alcohol, caustics, detergent, and oxygen. When chemicals are presented, glove materials should not be easily permeated by the chemical and should have inertness to most of chemicals. Material with good performance in strength and durability has high tear and abrasion resistance and will not break or puncture easily when the tensile strength is less than 2000 psi. Elasticity can be used to evaluate if the glove material has high memory allowing the glove to always return to the original shape. There are some contents such as powders and chemicals in the glove material which may cause an allergic reaction in people. “Excellent” in this category stands for very low potential of causing allergy. Having better performance in Economy means the materials have lower costs [13].

In order for our team to begin testing gloves (for their durability), we followed Gerard Holzmann’s ten rules of design to develop a testing method that would be reliable and repeatable. According to Gerard, one of the major things to take into consideration is keeping the test simple so it can be easily implemented. Measuring the performance of the protocol as it is being executed was important so as to optimize it if necessary. The most important rule was to make sure that the problem is well defined and that all design criteria, requirements, and constraints were reckoned [14]. The first thing that had to be done was to define the problem. Once the problem was defined, background research began which involved looking into methods already in use to test a glove's durability. Group members researched individually and came together later to discuss the best solution. From there the group met regularly to decide the exact methods to be used to test durability. A prototype was built that encompassed the requirements needed. These requirements included that the glove tested be in contact with an abrasive material as well as the durability of that glove quantified in time. Once tests began many problems arose in which

the group had to brainstorm and redesign this process. Based on the results and data of the tests, design changes were made and a new apparatus for testing was designed.

# System Design

The two cylindrical tubes shown in figure 1 have different roles in the system. The tube with the U shape engraved in it is for fitting the glove on to the hand. The other tube is wrapped with the abrasive surface. The wooden block used is 3.5cm thick and serves as the locking mechanism for the hand using two wing nuts. The ring stand serves as the base for the clamps to lock the cylindrical tube in the same position. The two bases are kept in a constant position by using a c-clamp. As it can be seen from the images below, the indicated dimensions are the most vital aspect to the design of the system. The 18cm measurement in the front view denotes how far away the edge of the hand should be positioned from the cylindrical pipe. This 18cm was found to be the optimal distance through trial and error. Varying this distance greatly affects which part of the hand is in contact with the abrasive material. Initially, this distance was shorter and caused the cylindrical pipe to be stuck right in the middle of the thumb and forefinger. This prevented the tips of the fingers from coming into direct contact with the abrasive material and failure was shown primarily in that region.

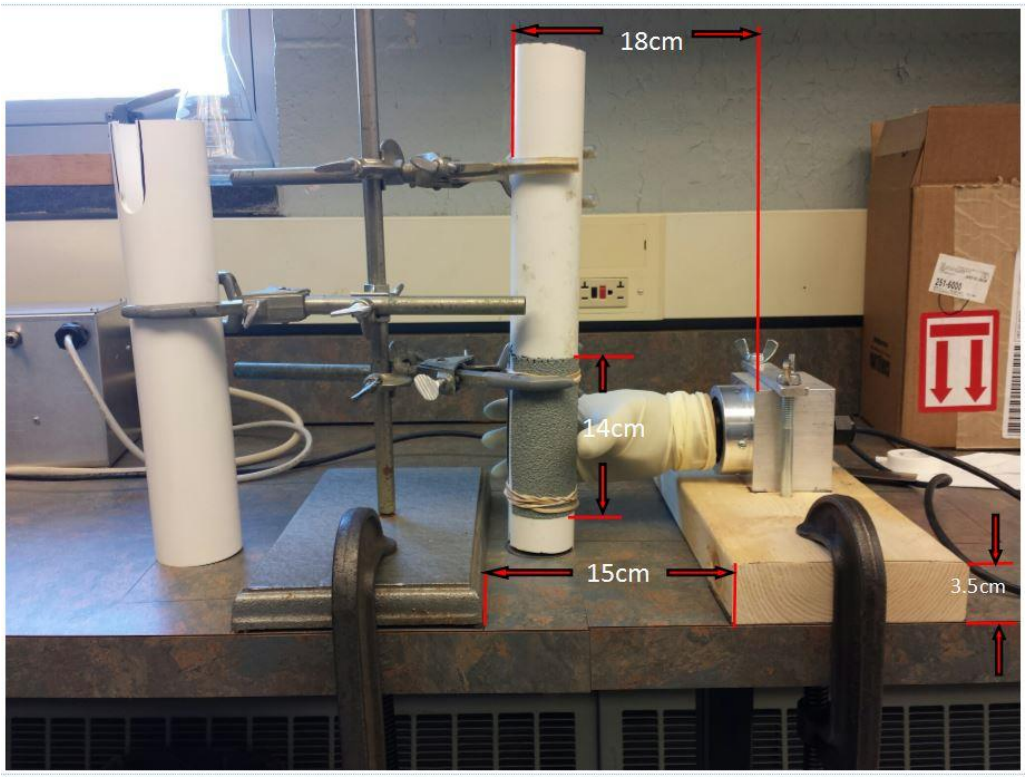



**Figure 1: Front view of system designed to test for glove durability**

Equally important, the position of the hand on the wooden block was standardized to acquire repeatable results. The block is 4.5cm away from the edge of the width and 14cm from the edge of the height. In the front view, the thickness of the wooden block determines how high the sandpaper needs to be in order to provide the most surface area for contact with the glove. The height dimension of the abrasive material should be 14cm as this will provide sufficient contact area. The controllable parameters of the hand used were pulse width and period both in number of samples. The pulse width determines how wide the thumb of the hand opens from the remaining four fingers and the period is the amount of time to complete a cycle of the hand closing and opening. The period value used throughout the tests was set to 1000 and the pulse width was set at either 200 or 300, depending on the test being done. To perform immersion of gloves into a medium, the glove fitting tube was switched out with a 1L beaker. The clamp attached to the ring stand is used to secure the hand while it is upside down and operating within a solvent.

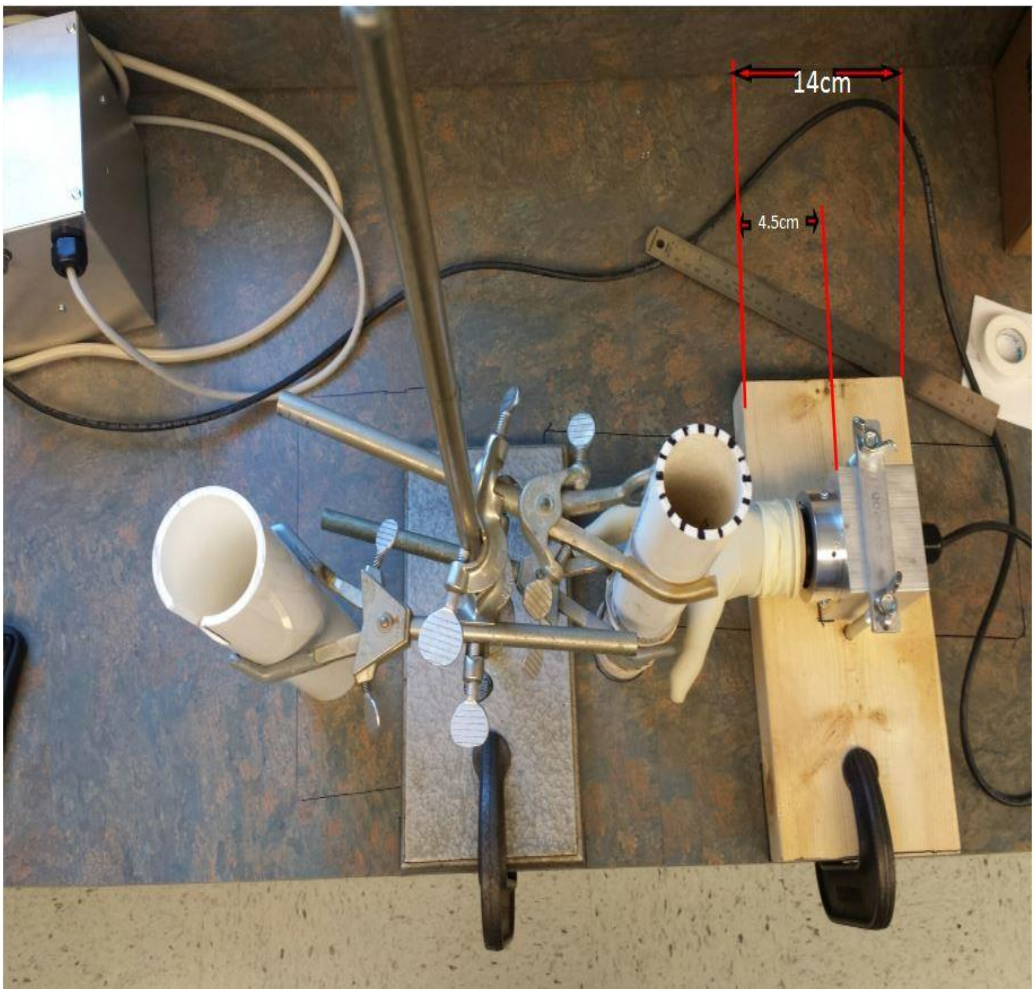
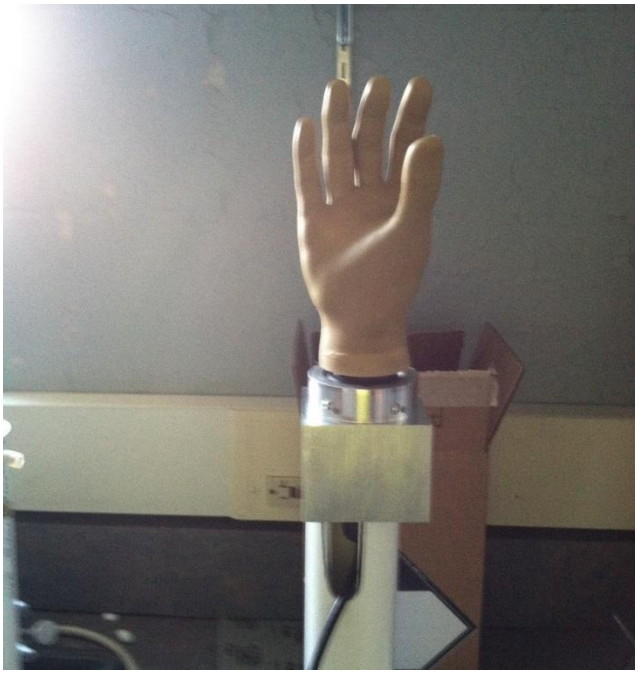



**Figure 2: Top view of system designed to test for glove durability**

# Standardized Procedures

*Glove to Hand Application*

Fitting the glove onto the prosthetic hand was one of the major problems the team faced in standardizing procedures. There is a risk of prematurely damaging the glove when fitting it on to the prosthetic hand due to the fact the prosthetic hand is not as agile as a human's. Hence, an apparatus was designed to apply the glove on to the hand with minimal amount of damage.



As it can be seen in figure 3, a method was conceived to quickly and consistently fit the hand with each glove. The prosthetic hand is set on top of the pipe and held in place with clamps to prevent moving while glove is administered. To apply the glove, one first fits glove fingers on to prosthetic fingers without the thumb being filled. The administrator then places their natural thumb into the thumb portion of glove and uses minimal force to replace their natural thumb with the thumbs of the prosthetic hands as the glove slides onto the fingers. This reduces the strain placed on the glove as it is stretched across the fingers and on to the thumb.

*Sandpaper Rotation*

The abrasive surface was found to wear down with continued testing and become less abrasive which resulted in much longer failure times for each glove. To increase consistency, the sandpaper was changed after each set of tests had been performed on each glove type. This was anywhere from three to five trials. Another method was designed to introduce the hand to a new surface area in between changing sandpaper pieces to increase consistency of results.

Shown in figure 2, the cylinder covered in sandpaper has been marked into eight distinct sections. Each section represents one potential surface area for each trial. A straight-edge ruler is placed on top of the cylinder lining up with two opposite section marks. This is then turned until ruler intersects the line created by the ring stand. Upon completion of each trial, the ruler is placed on the next two collinear line segments going clockwise. The cylinder covered in sandpaper is then rotated until the ruler is stopped by intersecting the ring stand again. This provides a new abrasive surface for the prosthetic hand to come into contact with for each trial.

*Hand Immersed within Solvent*

To perform the medium immersion of the gloves consistently, some procedures were put in place. A 1L beaker was chosen as the appropriate container size to allow for the areas of the glove that touch the abrasive surface to be completely immersed within the solvent. The pulse width of the hand was adjusted to allow for the opening and closing of the hand within the beaker. The hand is then left operating in the solution for 5 minutes. Upon reaching 5 minutes, the hand is removed and placed on the glove-application apparatus and dried off using Kim wipes. The dryer has to carefully "pat" dry rather than to rub dry as this could prematurely damage the glove as well. Figure 4 shows the hand fitted with the glove and immersed within the 1L beaker. The beaker is filled with 500mL of a specific solution. This is done to conserve materials and to only immerse areas of the glove that come into contact with the abrasive surface.

**Figure 4: Immersion of glove in medium**

*Glove Inspection*

Each glove came into contact with the abrasive surface for a set amount of time. At the beginning of each trial, 30 seconds is allotted for the hand to be in contact with the abrasive surface. After this time period, gloves are observed for holes and tears. If structural integrity was still intact, glove would be operated for another 30 seconds and observed for holes afterwards. If visual failure was detected after the first 30 second run, the glove was retested choosing a smaller time interval until inspection occurred. This is done to find a more specific time of failure. Glove inspection was updated to include the removal of the prosthetic hand from the lock position and lifted into better lit areas for closer and more thorough visual inspections.

# Results

Medical gloves have been tested in three conditions: Air, PBS and Ethanol. Within each glove type, three to five trials were completed and the average failure time for each glove type was calculated. The column graph below shows the comparison of each medical glove type in terms of time until failure.

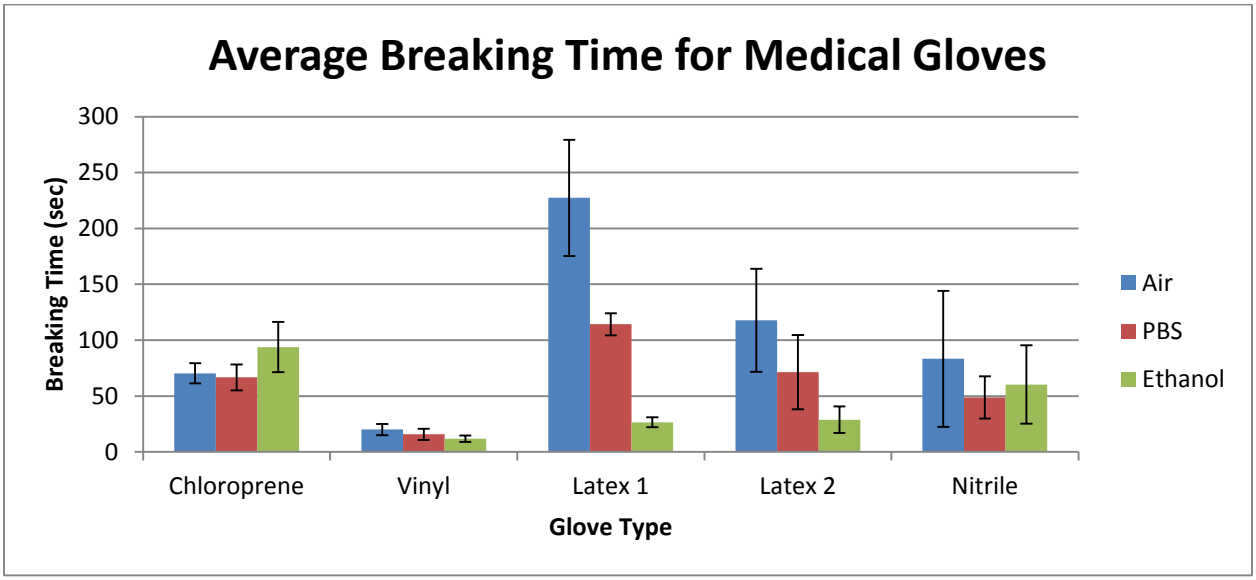



**Figure 5: Graph of average breaking time of gloves in the three media tested**

Based on the data shown above, ranks can be developed for each glove type in the conditions of air, PBS and ethanol. The error bar, or standard deviation, for each column can be used to indicate the variability of data compared to the average failure time in each glove. This means that while the average failure time may be short, the difference between the longest trial time and

the shortest trial time in each glove could be much larger due to outliers. The standard deviation was calculated as follows:

$$s = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \overline{x})^2}$$

**Equation 1: Calculation of standard deviation**

Where $x_i$ is an individual trial, x bar is the sample mean and N is the number of trials. Below is a sample calculation for the standard deviation of Chloroprene in Air:

**Table 3. Raw data for Chloroprene in Air**

| Gloves | Trial 1(s) | Trial 2(s) | Trial 3(s) | Standard deviation |
|---|---|---|---|---|
| Chloroprene | 60 | 75 | 76 | 8.96 |

**N=3**
**x bar = (60+75+76)/3 = 70.3 therefore**

**$(60-70.3)^2+(75-70.3)^2+(76-70.3)^2 = 160.7$**

**160.7*(1/(3-1)) = 80.3**

**s = sqrt(80.3) = 8.96**

Based on this analysis, the following ranking was developed.

Air:
1. Latex 1
2. Latex 2
3. Nitrile
4. Chloroprene
5. Vinyl

PBS:
1. Latex 1
2. Latex 2
3. Chloroprene
4. Nitrile
5. Vinyl

Ethanol:
1. Chloroprene
2. Nitrile
3. Latex 2
4. Latex 1
5. Vinyl

# Discussion

Tukey's HSD Post Hoc Test can be applied for data analysis in order to determine whether there is a significant difference in the average of time until failure between each type of glove. ANOVA modules (table 5) were developed by a data analysis program in Excel from raw data (Table 4). ANOVA is a collection of statistical models used to analyze the difference among group means.

**Table 4. Raw data for glove failure time**

| Gloves | Trial 1(s) | Trial 2(s) | Trial 3(s) | Trial 4(s) | Trial 5(s) |
|---|---|---|---|---|---|
| **Chloroprene** | 80 | 60 | 60 | | |
| **Vinyl** | 17 | 10 | 20 | | |
| **Latex 1** | 119 | 97 | 115 | 120 | 120 |
| **Latex 2** | 120 | 60 | 60 | 45 | |
| **Nitrile** | 45 | 45 | 30 | 75 | |

**Table 5. ANOVA module calculations**

| Groups | Count | Sum | Average | Variance |
|---|---|---|---|---|
| Chloroprene | 3 | 200 | 67 | 133 |
| Vinyl | 3 | 47 | 16 | 26 |
| Latex 1 | 5 | 571 | 114 | 97 |
| Latex 2 | 4 | 285 | 71 | 1106 |
| Nitrile | 4 | 195 | 48 | 356 |

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---|---|---|---|---|---|---|
| Between Groups | 20416.47 | 4 | 5104.118 | 14.02882 | 8.35E-05 | 3.11225 |
| Within Groups | 5093.633 | 14 | 363.831 | | | |
| | | | | | | |
| Total | 25510.11 | 18 | | | | |

From table 5, the count is the number of trials, the sum is the addition of all trials and the average is the sum divided by the number of trials. The variance is calculated by the following equation similarly to the sample calculation listed under table 3.

$$\frac{\sum(x-\bar{x})^2}{(n-1)}$$

**Equation 2: Calculation of Variance**

Based on these values, the ANOVA module in Excel calculates the sum of squares (SS), degree of freedom (df) and mean square (MS) which is the sum of squares divided by the degree of freedom.

Honest Significant Difference (HSD) value is used as a parameter when checking whether two groups of data are significantly different. HSD value can be calculated by the equation shown below:

$$HSD = q\sqrt{\frac{MS_{Within}}{n}}$$

As it can be seen from the above equation, only df and MS from table 5 is needed to calculate the HSD. "q" is a constant value which can be located in the Studentized Range Statistics table. By using the degree of freedom and number of variables one can look up the value of "q". As can be seen from table 5, the degree of freedom is 14 and the number of variables was represented by the 5 groups. Based on these values, the "q" obtained from the Studentized Range Statistics table was 4.41. MS within groups from the ANOVA module alongside the obtained "q" was used to calculate the HSD which yielded 39.2. The HSD value is compared with the trial difference in order to determine if the difference is significant.

**Table 6. Comparison of HSD value (39.2) with difference of average of time until failure between each type of glove**

| | **Chloroprene** | **Vinyl** | **Latex 1** | **Latex 2** | **Nitrile** |
|---|---|---|---|---|---|
| **Chloroprene** | N/A | 51 | 48 | 5 | 18 |
| **Polyvinyl Chloride** | 51 | N/A | 99 | 56 | 33 |
| **Latex 1** | 48 | 99 | N/A | 43 | 65 |
| **Latex 2** | 5 | 56 | 43 | N/A | 23 |
| **Nitrile** | 18 | 33 | 65 | 23 | N/A |

The values in table 6 are then compared with the calculated HSD value. According to the principle of Tukey's HSD Post Test, if the difference between the averages is greater than the HSD Value, the two groups of data are considered to be significantly different from each other. If the difference between the averages is less than the calculated HSD value, the two groups of data are not considered to be significantly different in the 95% confidence interval.

In table 6, the highlighted values are less than the HSD value and thus can be concluded that they are not significantly different from each other based on their time of failure. Conclusions that can be drawn from this statistical analysis are:

1. Latex 2 and Chloroprene are not significantly different in terms of time until failure
2. Nitrile and Chloroprene are not significantly different in terms of time until failure
3. Nitrile and Vinyl are not significantly different in terms of time until failure
4. Nitrile and Latex 2 are not significantly different in terms of time until failure
5. The numbers in black from table 6 are all greater than the HSD value and in turn considered to be significantly different

Knowing if two types of gloves are significantly different can help people have a better idea when choosing the appropriate medical glove. For example, if the two types of medical gloves are not significantly different, the ranking is not the most important factor and another factor such as cost may be considered more important. Other factors that may be taken into consideration when choosing a glove may be comfort and chemical resistance.

## *Human Factor Error Analysis*

Human factor error is also analyzed by Tukey HSD test which has been introduced in previous part. There were three members on the team that recorded data. Each member completed the same test individually using the developed protocols. Latex 1 medical gloves were tested in the condition of air by each member. The analysis of the results is shown below.

**Table 7. Raw data for glove failure time recorded by each member**

| Member | Trial 1(s) | Trial 2(s) | Trial 3(s) |
|---|---|---|---|
| **1** | 20 | 60 | 45 |
| **2** | 60 | 60 | 60 |
| **3** | 54 | 60 | 60 |

**Table 8. ANOVA module calculations for Human Factor Error**

| Groups | Count | Sum | Average | Variance |
|---|---|---|---|---|
| Member 1 | 3 | 125 | 41.66667 | 408.3333 |
| Member 2 | 3 | 180 | 60 | 0 |
| Member 3 | 3 | 174 | 58 | 12 |

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---|---|---|---|---|---|---|
| Between Groups | 606.8889 | 2 | 303.4444 | 2.165741 | 0.195869 | 5.143253 |
| Within Groups | 840.6667 | 6 | 140.1111 | | | |
| Total | 1447.556 | 8 | | | | |

Based on Tukey's HSD test and the calculated differences from table 9, it can be clearly seen that all the differences are less than the calculated HSD value. This concludes that the human error factor which occurred during the developed test is insignificant.

**Table 9. Comparison of HSD value with difference among the results from members**

| Difference between person 1 & 2(s) | Difference between person 1 & 3(s) | Difference between person 2 & 3(s) | HSD(s) |
|---|---|---|---|
| 18.3 | 16.3 | 2.00 | 29.7 |

# Conclusions and Recommendations

The team has developed a working standardized system which can be used to test for medical glove durability while it is in use. Alongside the system, standard procedures have been proposed by the team to be used in order to ensure repeatability and consistency. These protocols have been tested and the results gained were successful in distinguishing between the durability of four major currently available medical glove materials.

Looking forward into the future, the team has a few recommendations to improve the system. Firstly, an improved homogenous abrasive surface should be introduced to achieve a more uniform surface since it is difficult to regulate the exact sharpness of sandpaper. This would improve the consistency of results, decreasing the chance that a specific area of sandpaper is naturally more abrasive than others. Additionally, adding zoom in frame shots or a visual imaging system would improve the accuracy in determining the exact time of glove failure although this would incur additional cost. Lastly, the team also recommends acquiring more data in the form of trials in order to improve the data analysis and provide a more accurate depiction of medical glove durability.

# Acknowledgements

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