Comparing natural, synthetic latex gloves

By Ryan Michel and Katrina Cornish
Ohio State University, Wooster

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 health care workers and patients.

TECHNICAL NOTEBOOK
Edited by Harold Herzlich

Hence, it is critical for medical gloves to meet a standard performance criteria. Under ASTM D 3577 and D 3578, latex 1

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 than normally are experienced by professionals in the medical field. This design was developed and later confirmed by Katrina Cornish:

Design: Effects of media outside the glove;
● Phosphate buffered saline (PBS), 70 percent 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 40 grit 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 when 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 also was used to determine human factor error among the three team members and results concluded that human factor error is negligible.

The expected deliverables were:
● 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.

The authors
Ryan Michel recently graduated from Ohio State University with a degree in food, agricultural and biological engineering.

Michel was a member of the cheer leading program throughout his college career and represented the university at every home game as well as the Orange Bowl. He received a minor in medieval and renaissance studies.

Since graduating, Michel has been finishing a two-year project under Katrina Cornish that deals with medical glove durability.

Katrina Cornish is the Ohio research scholar and endowed chair in bioemergent materials at Ohio State University, and she is director of research for the Program of Excellence in natural rubber alternatives, a private/public consortium.

She is a leading global expert on alternate rubber production, processing and products, from hypoallergenic latex to liquid biofuels, and her inventions form the foundation of the domestic rubber industry.

For six years, Cornish was the senior vice president of research and development at Yulex Corp., where she oversaw the company’s ongoing research, development, crop science, production, validation and regulatory programs for the commercialization of guayule latex applications in the manufacturing of safe medical devices and specialty consumer products, including extramural programs.

Prior to her time at Yulex, Cornish led the U.S. government’s development of domestic natural rubber sources for 15 years.

Cornish serves on the Scientific Advisory Board of the North American Renewable Fuels Alliance, on the board of directors of Edison Agro-sciences L.L.C., and of Believe in Ohio, and serves on several journal editorial boards.

She has authored more than 200 publications and patents.

In addition, she is CEO of four startup companies: EnergyEne Inc.; EnergyEne Australia Pty. Ltd; EnergyEne Africa; and DamSafe L.L.C.

Table 1. Ideal temperature range for glove materials.

<table>
<thead>
<tr>
<th>Material of Glove</th>
<th>Temperature Range (in Celsius)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latex</td>
<td>-50 to 82</td>
</tr>
<tr>
<td>Neoprene</td>
<td>-40 to 115</td>
</tr>
<tr>
<td>Nitrile</td>
<td>-55 to 82</td>
</tr>
<tr>
<td>Polyvinyl Chloride</td>
<td>54 to 80</td>
</tr>
</tbody>
</table>
In order to test the abrasion resistance of gloves, each type was put through the test described in ASTM standards D 3575 and D 3578. These standards provide guidelines for testing the durability of medical gloves. The developed tests provided enough data to rank commercially available gloves with respect to their durability after initial use. The ultimate goal is to develop these tests into a practical and reproducible application for the medical glove industry. In order for gloves to be sold and distributed, they must meet certain requirements. Standards and performance tests for new gloves are described in the American Society for Testing and Materials (ASTM) D 3575 and D 3578.

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; and
- 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 durability; and
- Ranking system compared each glove type based on time to failure.

The simulations included attaching and removing a cuffed needle to a syringe. This was followed by connecting and disconnecting a Luer-lok syringe to an intra-venous tube and manipulating a stopcock. The simulation included attaching and removing a cuffed needle to a syringe. This was followed by connecting and disconnecting a Luer-lok syringe to an intravenous tube and manipulating a stopcock.

**Technical**

![Fig. 2. Front view of system designed to test for glove durability.](image)

![Fig. 3. Top view of system designed to test for glove durability.](image)

![Fig. 4. A method was conceived to quickly and consistently fit the prosthetic hand with each glove.](image)

![Fig. 5. Immersion of glove in medium.](image)

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 glove does 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. To test the abrasion resistance of medical gloves material, researchers designed an apparatus that can exert force to lower the gloves durability. An abrader is available that can rotate in adjustable speeds that come into contact with the gloves being tested. This is the glove 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 cuffed 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 inspected visually 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.

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. 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.

This patent was developed by the Midwestern Equipment Co. 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, U.S. 3545294 A, developed by McDonald Willis V, was used to view and understand a previously patented glove testing device.

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 percent rubber particles, 55-65 percent water, and small amounts of protein, steroid 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.
Gloves

Continued from page 11

Nitrile gloves are made from 100 percent synthetic polymer, consisting of acrylonitrile, butadiene and a carbonyl acid. Nitrile material has better resistance against chemicals that 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, which means that anyone can wear them. Neoprene is produced by polymerization of chloroprene. It has good chemical resistance and heat resistance in a wide temperature range.

The tables of ideal temperature range for using of different type of material and performance of these gloves are shown in Table 1. Table 2 shows a comparison of different properties of the gloves to be tested.

As Table 2 illustrates, 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, alcohols, caustics, detergent and oxygen. When chemicals are presented, glove materials should not be penetrated easily 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 2,000 psi.

Elasticity can be used to evaluate if the glove material has high memory, allowing the glove to return to the original shape. There are some contents such as powders and chemicals in the glove material that may cause an allergic reaction. “Excellent” in this category stands for very low potential of causing allergy. Having better performance in economy means the materials have lower costs.

In order for our team to begin testing gloves (for their durability), we followed Gerard Holmzann’s 10 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 implemented easily.

Measuring the performance of the protocol as it is being executed was important as optimization. The most important rule was to make sure that the problem is well defined and that all design criteria, requirements, and constraints were reckoned.

The first thing that had to be done was to define the problem. Once the problem was defined, background research began that 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 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 Fig. 2 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 3.5 cm 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 18 cm measurement in the front view denotes how far away the edge of the thumb was positioned from the cylindrical pipe. This 18 cm 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. Initial distance 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 abrasive area in between changing sandpaper pieces to increase consistency of results.

Shown in Fig. 3, the cylinder covered in sandpaper has been divided 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 moved until the 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 one liter 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 five minutes. Upon reaching five minutes, the hand is removed and placed on the glove-application apparatus and dried off using Kim wipes.

The dryer has to pat dry rather carefully than to rub dry as this could prematurely damage the glove as well. Fig. 5 shows the hand fitted with the glove and immersed within the one liter beaker. The beaker is filled with 500 ml of a specific solution. This is done to conserve materials and to only immerse the areas of the glove that come into contact with the abrasive surface.

Glove inspection

Each glove came into contact with the abrasive surface for a set amount of time.

Table 3. Raw data for chloroprene in air.

<table>
<thead>
<tr>
<th>Gloves</th>
<th>Trial 1(s)</th>
<th>Trial 2(s)</th>
<th>Trial 3(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloroprene</td>
<td>60</td>
<td>75</td>
<td>76</td>
</tr>
<tr>
<td>Vinyl</td>
<td>17</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Latex 1</td>
<td>119</td>
<td>97</td>
<td>115</td>
</tr>
<tr>
<td>Latex 2</td>
<td>120</td>
<td>60</td>
<td>45</td>
</tr>
<tr>
<td>Nitrile</td>
<td>45</td>
<td>45</td>
<td>50</td>
</tr>
</tbody>
</table>

Table 4. Raw data for glove failure time.

<table>
<thead>
<tr>
<th>Gloves</th>
<th>Trial 1(s)</th>
<th>Trial 2(s)</th>
<th>Trial 3(s)</th>
<th>Trial 4(s)</th>
<th>Trial 5(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloroprene</td>
<td>30</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Vinyl</td>
<td>17</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Latex 1</td>
<td>119</td>
<td>97</td>
<td>115</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>Latex 2</td>
<td>120</td>
<td>60</td>
<td>45</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Nitrile</td>
<td>45</td>
<td>45</td>
<td>50</td>
<td>75</td>
<td>75</td>
</tr>
</tbody>
</table>

Table 5. ANOVA module calculations.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>2046.47</td>
<td>4</td>
<td>5104.18</td>
<td>14</td>
<td>0.0282</td>
<td>8.35E-05</td>
</tr>
<tr>
<td>Within Groups</td>
<td>5903.63</td>
<td>14</td>
<td>436.83</td>
<td>78</td>
<td>0.0015</td>
<td>3.1125</td>
</tr>
<tr>
<td>Total</td>
<td>7950.10</td>
<td>18</td>
<td>436.83</td>
<td>78</td>
<td>0.0015</td>
<td>3.1125</td>
</tr>
</tbody>
</table>
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, the glove would be operated for another 30 seconds or a visual imaging system would improve the consistency of 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 prove the data analysis and provide a more accurate depiction of medical glove durability.

Acknowledgements
This research is partly supported by the USDA-NIFA Hatch project 230887. We also thank ASTM ILS for support.

References

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

<table>
<thead>
<tr>
<th>Chloroprene</th>
<th>Vinyl</th>
<th>Latex 1</th>
<th>Latex 2</th>
<th>Nitrile</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/A</td>
<td>51</td>
<td>48</td>
<td>45</td>
<td>18</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Member</th>
<th>Trial 1(s)</th>
<th>Trial 2(s)</th>
<th>Trial 3(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>60</td>
<td>45</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>3</td>
<td>57</td>
<td>57</td>
<td>57</td>
</tr>
</tbody>
</table>

Table 8. ANOVA module calculations for human factor error.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Count</th>
<th>Sum</th>
<th>Average</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Member 1</td>
<td>3</td>
<td>125</td>
<td>41.6667</td>
<td>408.3333</td>
</tr>
<tr>
<td>Member 2</td>
<td>3</td>
<td>180</td>
<td>60</td>
<td>0</td>
</tr>
<tr>
<td>Member 3</td>
<td>3</td>
<td>174</td>
<td>58</td>
<td>12</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Member</th>
<th>Trial 1(s)</th>
<th>Trial 2(s)</th>
<th>Trial 3(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>60</td>
<td>45</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>3</td>
<td>57</td>
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</tr>
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</table>

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<th>Sum</th>
<th>Average</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Member 1</td>
<td>3</td>
<td>125</td>
<td>41.6667</td>
<td>408.3333</td>
</tr>
<tr>
<td>Member 2</td>
<td>3</td>
<td>180</td>
<td>60</td>
<td>0</td>
</tr>
<tr>
<td>Member 3</td>
<td>3</td>
<td>174</td>
<td>58</td>
<td>12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Difference between person 1 &amp; 2(s)</th>
<th>Difference between person 1 &amp; 3(s)</th>
<th>Difference between person 2 &amp; 3(s)</th>
<th>HSD(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.3</td>
<td>16.3</td>
<td>2.00</td>
<td>29.7</td>
</tr>
</tbody>
</table>

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

**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 39.2 until failure between each type of glove. ANOVA modules (Table 6) 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 groups means.

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

\[
\sum (x_i - \overline{x})^2
\]

**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:

\[
HSD = q \times \sqrt{\frac{MS_{within}}{n}}
\]

Where \( n \) is the sample mean and \( N \) is the number of trials. Below is a sample calculation for the standard deviations of chloroprene in air as shown in Table 3.

\( N = 3 \) \( x = 60+75+76 = 70.3 \)

\( \text{standard deviation was calculated as follows:} \)

\( \text{Equation 2: Calculation of variance} \)

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:

\[
HSD = q \times \sqrt{\frac{MS_{within}}{n}}
\]

As 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 five groups. Based on these values, the "q" obtained from the Studentized Range Statistics table is 4.11. MS within groups from the ANOVA module obtained alongside the obtained 
used to calculate the HSD, which yielded 39.2. The HSD value is compared to the HSD value in the obtained "q" was module alongside the obtained "q" was 39.2. The HSD value is compared to the HSD value in the obtained "q" was module alongside the obtained "q" was 39.2. The HSD value is compared to the HSD value in the obtained "q" was module alongside the obtained "q" was 39.2. The HSD value is compared to the HSD value in the obtained "q" was module alongside the obtained "q" was 39.2. The HSD value is compared to the HSD value in the obtained "q" was module alongside the obtained "q" was 39.2. The HSD value is compared to the HSD value in the obtained "q" was module alongside the obtained "q" was 39.2. The HSD value is compared to the HSD value in the obtained "q" was module alongside the obtained "q" was 39.2. The HSD value is compared to the HSD value in the obtained "q" was module alongside the obtained "q" was 39.2. The HSD value is compared to the HSD value in the obtained "q" was module alongside the obtained "q" was 39.2. The HSD value is compared to the HSD value in the obtained "q" was module alongside the obtained "q" was 39.2. The HSD value is compared to the HSD value in the obtained "q" was module alongside the obtained "q" was 39.2. The HSD value is compared to the HSD value in the obtained "q" was module alongside the obtained "q" was 39.2. The HSD value is compared to the HSD value in the obtained "q" was module alongside the obtained "q" was 39.2. The HSD value is compared to the HSD value in the obtained "q" was module alongside the obtained "q" was 39.2. The HSD value is compared to the