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Original Article

Development of an experimental technique to determine the barrier performance of medical gloves when stretched

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Abstract

Protective clothing standards, such as test methods published by ASTM International, play an integral role in ensuring the performance of personal protective equipment. The standard tests are not without limitations and are periodically reviewed and often updated. Some tests may not be reflective of in-use conditions. A new test cell was designed using sanitary fixtures to evaluate the effect of glove stretch on barrier performance using fluorescein solution as the challenge agent for enhanced visualization and fluorometer detection. Domed-shaped and flat screens were developed to permit and limit glove stretch within the test cell. The barrier performance of glove swatches was evaluated for both stretched and unstretched states. Latex, nitrile, and vinyl glove models of various thicknesses were evaluated. The tests were conducted following pressure and time parameters specified in ASTM F903, ASTM F1670, and ASTM F1671. Fluorescein solution movement, which may occur through penetration, was measured using a fluorometer. Glove stretch caused a reduction in glove thickness ranging from 16% to 40%. Overall, 21 sample failures were found (16.7%; $n = 126$) regardless of test condition. Nitrile gloves provided better barrier efficacy with the lowest failure rates (2.38%; 1 failure out of 42) compared to latex (19.4%; 7 failures out of 36) and vinyl gloves (27.1%; 13 failures out of 48). Differences in failure rates between stretched and unstretched gloves were insignificant; however, the latex material showed a 2.5 times increase in failures when stretched compared to unstretched. The new test apparatus was able to differentiate between the barrier performance of different glove materials. The use of a domed screen allowed the gloves to stretch, a condition that better represents the state of gloves when in use. Analysis of samples collected from the glove surface opposite to the exposure may provide a way to assess chemical permeation in addition to penetration.

Key words: disposable medical gloves; glove penetration; glove stretch; glove thickness; glove barrier; PPE.

What's Important About This Paper?

This study demonstrates a new experimental technique to determine the barrier performance of medical gloves when stretched. The incorporation of a domed-shaped screen into ASTM 1670/71 may be more predictive of the barrier performance of glove material when in use, when hand movements stretch glove material. The new test apparatus was able to differentiate between the barrier performance of different glove materials.

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Introduction

Medical gloves, such as surgical gloves and examination gloves, provide a protective barrier between the wearer and pathogens, body fluids, and certain chemicals. There are also specialty examination gloves that claim protection against chemotherapeutic agents. Medical gloves are evaluated for a variety of characteristics, such as size and thickness, tensile strength, and barrier properties. Barrier properties of medical gloves are measured using tests such as the Food and Drug Administration (FDA) 1000 mL Water Leak Test (21 CFR 800.20) or ASTM D5151 to assess barrier integrity (Code of Federal Regulations 2017; ASTM International 2019; Phalen and Hamidi 2023). The water leak method does not challenge gloves with viruses, body fluids, or chemicals, thus does not assess protection against these types of agents. Kotilainen et al. (1990) incorporated virus into a water leak test and found that some gloves demonstrated virus penetration without visible water leakage, which suggest that the assessment of the barrier performance of gloves against specific agents of concern may need to be evaluated using other consensus standards.

ASTM International publishes standards for protective clothing, including gloves to measure the barrier performance against synthetic blood (ASTM 1670), bacteriophages (ASTM 1671), chemical penetration (ASTM 903) (ASTM International 2017, 2018, 2022), chemotherapy drug permeation (ASTM D6978-19) ASTM International., (2019d) and liquid and gas permeation (ASTM F739) ASTM International., (2020b).

ASTM F903, ASTM F1670, and ASTM F1671 use the same test cell design to evaluate the penetration barrier performance of glove swatches and not whole gloves. The swatches are placed into a test cell in and against a flat screen to limit stretch. Similarly, the test cell described in ASTM F739 and used in ASTM D6978 to measure chemical permeation through glove swatches without consideration of glove stretch. Table 1 describes the various test methods that can be used to assess the barrier performance of gloves.

Properly fitted gloves can stretch, and the degree of elongation is influenced by glove size, hand size, and hand movement. Glove stretch has been shown to negatively impact penetration barrier performance (Kisielewski et al. 2000; Phalen and Wong 2011; Fisher et al. 2024). Kisielewski et al. (2000) showed that virus penetration through holes and tears was detected more frequently when the glove swatches were allowed to stretch by incorporating a domed-shaped screen within

Table 1. Various test methods that can be used to assess the barrier performance of gloves.

Test method	Sample type	Sample condition	Challenge agent	Detection method	Penetration or permeation detection
ASTM D5151, Standard Test Method for Detection of Holes in Medical Gloves, to assess barrier integrity	Whole glove	Stretched	Water Pressure from the weight	Visual inspection	Penetration
ASTM F1671 Standard Test Method for Resistance of Materials Used in Protective Clothing to Penetration by Blood-Borne Pathogens Using Phi-X174 Bacteriophage Penetration as a Test System	Swatch	Unstretched	Bacteriophage Phi-X174, includes interval of pressurization of challenge reservoir	Virus enumeration by plaque assay	Penetration
ASTM F1670 Standard Test Method for Resistance of Materials Used in Protective Clothing to Penetration by Synthetic Blood	Swatch	Unstretched	Synthetic blood, includes interval of pressurization of challenge reservoir	Visual inspection	Penetration
ASTM F903 Standard Test Method for Resistance of Materials Used in Protective Clothing to Penetration by Liquids	Swatch	Unstretched	Chemical (liquids) includes interval of pressurization of challenge reservoir	Visual inspection	Penetration
ASTM D6978-19 Standard Practice for Assessment of Resistance of Medical Gloves to Permeation by Chemotherapy Drugs	Swatch	Unstretched	Chemotherapy Drugs	Commonly chromatographic	Permeation
ASTM F739 – 20 Standard Test Method for Permeation of Liquids and Gases Through Protective Clothing Materials Under Conditions of Continuous Contact	Swatch	Unstretched	Chemicals (liquids and gases)	Commonly chromatographic techniques	Permeation

the test cell specified for ASTM 1671. Fisher et al. stretched gloves samples before placement into the test cell described in F739 and noted that stretched gloves were less effective for limiting fentanyl permeation.

Others have developed novel methods that do not employ the test cells or parameters described within consensus standards and demonstrated the effect of glove stretch and flexion on glove barrier performance (Wallemacq et al. 2006; Phalen et al. 2014), achieved simulated whole glove movement using inflation and deflation driven by a pneumatic controller.

The aim of this study is to develop an experimental technique to assess the effect of glove stretch on the barrier performance of a variety of examination glove materials and models using a novel test cell and the parameters described in ASTM F930, which also apply to ASTM 1670 and 1671. A fluorescent test agent (fluorescein) and sensitive detection device (fluorometer) were incorporated to increase the likelihood of permeation detection, which occurs at the molecular level and cannot be visualized. Additionally, this study (i) describes a proposed domed screen that promotes uniform biaxial stretch of a defined value, (ii) characterizes the change in glove thickness due to stretching, and (iii) evaluates the use of sanitary fixtures and clamps as a test cell for gloves.

Methods

Patient examination gloves

Eight commercially available glove models were selected from a variety of medical examination glove types, differing in material composition and thickness. The tested gloves of the same type were drawn from the same manufacturing lot. The tested gloves included 3 latex (models A, B, and C), 3 vinyl (models D, E, and F), and 2 nitrile glove models (models G and H).

Test apparatus

All experiments were conducted using a modified liquid penetration test apparatus (Model CSI-122, Custom Scientific Instruments Inc., Easton, PA). Major modifications to the commercial liquid penetration apparatus, which is in accordance with ASTM F903, include the addition of a critical orifice, test cells constructed of sanitary clamps and fixtures (Fig. 1), and domed and flat screens as described below (Fig. 1).

Critical orifice and bonnet needle valve

The test apparatus included a 0.25-mm diameter critical orifice for improved pressure control of multiple cells and a 0.25-inch bonnet needle valve (Part # SS-1KS4, Swagelok Company, Solon, OH) between the pressure

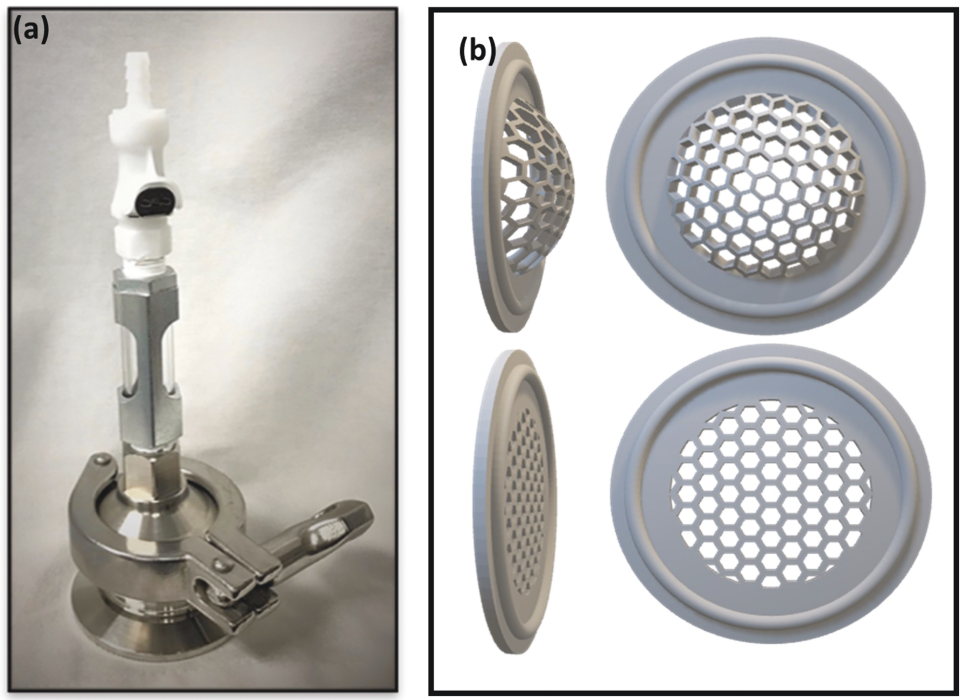

Fig. 1. A test cell constructed of sanitary clamp and fixtures (a) and a domed and flat screen assembly as described below (b). A custom domed screen was made through 3D printing with acrylonitrile butadiene styrene (ABS), based on a catenary curve and was designed to produce a 20% elongation of gloves to simulate a stretched glove.

regulator and 3-way directional valve to ensure a slow rise in the pressure to 13.8 kPa gauge [2 psig] at a rate no faster than 3.5 kPa/s [0.5 psig/s] as specified in ASTM F1671-22 (ASTM International 2022). The pressure at the test cell was evaluated using a digital pressure gauge with a range of 0 to 15 psi and an accuracy of ±0.25% (Mfr. Model 302132SD15LXBKBLCYC4LM15# Ashcroft, Stratford, CT).

Sanitary fixtures and clamps

Test cells were constructed of 1.5-inch stainless steel sanitary clamps and fixtures (Glacier Tanks, Portland, OR) including a cone with 1.5-inch Tri Clamp and with a 0.25-inch female national pipe thread (22MP-G150-025-CONE), end cap reducer (B3155MP-G200-150), and a single hinge sanitary clamp (13MHM-G150). The benefits of the sanitary clamp design include that parts are readily available, the parts are low-cost, a reduced volume is needed for the challenge liquid, and an easy single-bolt clamp is used that applies equal pressure around the cell. An upper sight glass was added to the sanitary fixtures to provide a visual indication of the fluid level, similar to that previously described (Li et al. 2019).

Test screens

Flat screens and domed screens, designed to seat into the sanitary clamp and fixtures, were printed in acrylonitrile butadiene styrene (ABS) using a 3D printer. The domed screen was designed to allow the glove swatch to stretch an additional 20% of its unstretched area. The 20% stretch was selected with consideration to glove sizing specifications described in ASTM D3578, Standard Specification for Rubber Examination Gloves, and anthropometric hand measurements based on dynamic positions (ASTM International 2019a; Griffin et al. 2018). An ideal design would allow the glove material to simultaneously touch all points of the screen. The screen shape was based on a catenary curve with considerations to several factors such as the radius of the opening, the angle of clamping at the boundaries, and the percentage of stretch, as well as physical properties such as elasticity (Griffin et al. 2018). A catenary curve is the shape that a hanging cable makes under its own gravitational weight and is similar to a parabola. Those properties provided a basis for the calculation of the shape of the dome upon the catenary equation:

$$Y(x) = a \cosh\left(\frac{x}{a}\right)$$

and

$$L = 2a \sinh\left(\frac{h}{2a}\right)$$

where:

a = intensity of dip
h = distance between poles
L = length of chain

Given the opening of the test cell (h) being 1.25 inches, a 20% stretch would extend the length (L) to 1.5 inches to provide a dip intensity (a) of 0.587. To approximate the dome shape that allows a natural stretch, the 2-dimensional catenary curve was fitted to a binomial, quadratic equation ($y = 0.8189x^2 - 0.167x$) in MS Excel, plotted in CAD software and revolved 360 degrees about the x-axis.

Barrier efficacy tests

The barrier performance of glove swatches was evaluated using a fluorescent liquid challenge following pressure and time parameters described in ASTM F1670 and ASTM 1671. Prior to performing the barrier test, gloves were preconditioned for at least 24 h at 21 ± 5°C and 30% to 80% relative humidity (RH) as specified in ASTM F1671-3. Swatches of the gloves were cut from the palm area. Glove swatches were loaded into test cells, which were then filled with 7 mL of nutrient broth (Difco Nutrient broth, Lot# 7102744, Becton, Dickinson and Company, Franklin Lakes, NJ) amended with fluorescein disodium salt (Acros Organics, Lot# 173240025, Thermo Fisher Scientific, Waltham, MA) for a final fluorescein concentration of 75.2 µg/ml. All glove swatches were challenged with the fluorescent fluid at 0 kPa pressure for the first 5 min, under 13.8 kPa pressure for 1 min, followed by 0 kPa for the remaining 54 min. Following the 1-h exposure period, the glove swatches in the test cell were observed under UV light to visualize fluorescein penetration. Following visualization, 5 mL of nutrient broth was used as a recovery buffer to wash the unexposed surface of the gloves to collect the fluorescent fluid that possibly penetrated through the glove.

The fluorescent liquid challenge and recovery buffer of each sample were analyzed using an internal automated spectrofluorometer (Dual-FL, Serial# 0120U-3115-DFL-800, Horiba Scientific, Piscataway, NJ). Specifically, an excitation-emission data matrix (EEM) of the fluorescent liquid challenge was measured at excitation wavelengths between 481 and 497 nm (3-nm increments), an emission wavelengths range between 250 and 820 nm (0.58-nm increments) at a medium detector gain setting, and an integration time of 0.1 s.

Fluorescein detection sensitivity and limit of detection

The fluorometer was able to detect fluorescein with a concentration of 7.52 ng/ml and failed to detect fluorescein with a concentration of 0.752 ng/ml. The limit of quantification of the test method was determined to be roughly 3 ng/ml which considers the dilution that occurs when recovering the sample from the test cell using 5 ml of recovery buffer.

Glove thickness measurement

The change in glove thickness created by the stretched screen was estimated by measuring glove swatches in a relaxed condition and when biaxially stretched 20% using measurement specifications per ASTM D3767-03 (reapproved in 2020), Standard Practice for Rubber—Measurement of Dimensions (ASTM International., 2020a). A digital material thickness Gauge (Model MTG-DX, Checkline Inc.)was used to measure the thickness of 8 models of gloves, including 3 latex (models A, B, and C), 3 vinyl (models D, E, and F), and 2 nitrile glove models (models G and H) when unstretched and stretched biaxially 20% to simulate the stretch that occurs within the test cell. Six paralleled glove samples were collected for each glove model.

Data analysis

For each test condition, 2 screen types per each glove model were selected and 6 replicates of each condition were performed. The total number of trials were 126: 96 swatches for the initial screening of glove performance at phase I (8 glove models × 2 screens/model × 6 replicates/screen = 96) and 30 swatches for the validation screening of glove performance at phase II (2 glove models × 2 screens/model × 6 replicates/screen and 1 glove model × 1 screen/model × 6 replicates/screen = 30). Note that the tests were conducted with and without a gasket to assess its necessity to generate a tight seal around the permitter of the test cell, given the elastic properties of the examination gloves.

Criteria for the failure of a glove swatches were determined by (i) the visible penetration of the fluorescent liquid challenge observed in the collection reservoir (normally the outside surface of the test cell sample) similar to ASTM F1671M-22 and (ii) the excitation emission matrices (EEMs) of fluorescein as determined through fluorometer analysis (Supplementary Fig. S1a) and compared to Milli-Q water sample (Supplementary Fig. S1b). It should be noted that if visual penetration (or the sample suspect) was observed during the penetration test, the test was terminated, but the fluorometer assessment procedure was still performed, and the swatch failed. The Wald Chi-squared test was used to compare the differences between the test parameters such as with or without glove stretch (significantly different, $P < 0.05$). All thickness change data were analyzed with JMP statistical software version 13.2 (SAS Institute, Cary, NC, USA), and the Mann–Whitney *U* test was used to analyze the differences in the thickness changes with and without stretched gloves (significantly different, $P < 0.05$).

Results

Test cell performance

The test cell was shown to maintain an accurate pressure of 13.8 kPa pressure for 1 min as measured with the digital pressure gauge as required in the previously mentioned ASTM standards. Visual inspection of the glove sample during pressure initiation showed that the glove conformed to the shape of the domed screen indicating that stretch of the glove occurred. The open face of the collection chamber allowed for the visual determination of challenge liquid penetration. Seven millimeters of challenge fluid was sufficient to fill the void of the challenge chamber permitting exposure across the entire surface of the glove swatch.

Glove barrier efficacy

Table 2 shows the percentage of fluorometer-determined failures of the barrier performance of glove swatches under different test conditions. The percentage of failures in glove swatches between the screen type was not statistically different; however, latex gloves had a 23.1% increase in failures when a domed screen was used compared to a flat screen. The change in the percentages of binary results between the glove type, gasket status, and glove model displayed noticeable differences. The effect of glove type was statistically significant (*P*-value <0.05). Overall, 21 failures were found (16.7%, $n = 126$) regardless of test condition. The nitrile glove provided better barrier efficacy with the lowest failure rates (2.38%; 1 failure out of 42), whereas the latex (19.4%; 7 failures out of 36) and vinyl gloves (27.1%; 13 failures out of 48) were less effective. Fluorescein penetration varied widely by gasket status and glove model. Table 2 also provides detailed information on fluorometer-determined failures of the barrier performance under various glove models. Nitrile A showed no failure (0 out of 30), followed by Latex A and Nitrile B (in both cases, 8.33%; 1 failure out of 12), while other glove models showed 25.0% (3 failures out of 12 sample swatches) to 29.2% (7 failures out of 24) failure rates of the selected glove swatches. Results showed noticeable differences in the failure results of each barrier penetration test over the type of screen and the glove type, indicating strong interaction among the above test parameters, which also can be seen in Fig. 2. Figure 3 shows that the difference in thickness between unstretched and stretched gloves ranged from 16% to 44%.

Discussion

The method including the newly designed test cell was able to discern the difference in performance of the various glove materials in both stretched and unstretched conditions. A comparison among the tested glove materials found nitrile to have the best resistance against the fluorescein liquid challenge. Although other research that compares the performance of stretched examination gloves against fluorescein, synthetic blood, or viruses is scarce, similar results that demonstrate the

Table 2. Failure of glove swatches based on glove type, screen type, and use of gasket.

Variable	Condition	*N*	Fluorometer	
			Failures	Failures (%)
Glove type	Nitrile	42	1	0.79
	Latex	36	7	5.56
	Vinyl	48	13	10.32
Screen type	Domed	66	11	8.73
	Flat	60	10	7.94
Gasket	With gasket	66	8	6.35
	Without gasket	60	13	10.32
Total		126	21	16.67

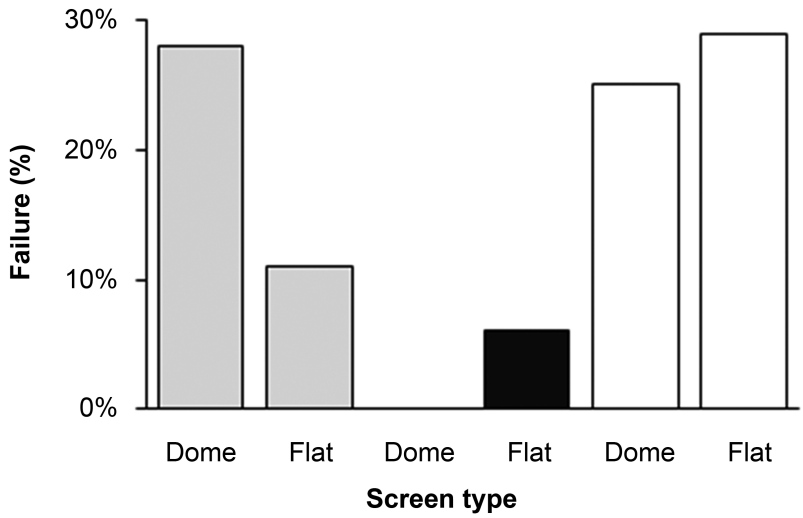

Fig. 2. The failure of the barrier performance test of latex (gray bars), nitrile (black bars), and vinyl (white bars) glove swatches against fluorescein in stretched (domed screen) and unstretched (flat screen) states. Nitrile swatches with a domed screen had 0% failure.

superior performance of nitrile gloves can be found in chemical resistance studies (Wallemacq et al. 2006; Oriyama et al. 2017; Greenawald et al. 2020). Other barrier integrity data of latex, vinyl, and nitrile gloves using the 1,000 mL water leak test also concluded that nitrile gloves are a suitable alternative to latex, while vinyl and other polymer gloves provided less effective barrier protection (Rego and Roley 1999; Korniewicz et al. 2002).

Effect of stretch

The effect of stretch on the barrier efficacy of disposable patient examination gloves has been an issue observed in several studies because the stretching of gloves reduces thickness, which may negatively impact barrier performance (Colligan and Horstman 1990; Dillon and Schroeder 1997; Perkins and Rainey 1997; Schwerin et al. 2002; Phalen et al. 2014). The results show that latex gloves tested with the domed screen showed a decrease in barrier performance against the fluorescein challenge when stretched. Similarly, Katz et al. (1989) showed that there was fluorescein penetration detected due to glove stretch. Colligan and Horstman (1990) reported increased permeation of cancer chemotherapeutic drugs through latex gloves in flexed conditions with no permeation for unstretched gloves.

In our study, nitrile and vinyl gloves did not show a difference in performance when the domed screen was used compared to the flat screen. The lack of visualization of the fluorescein fluid penetration and the lack of detection of fluorescein by the fluorometer may be considered as a passing result similar to that described in ASTM 1670, which uses synthetic blood

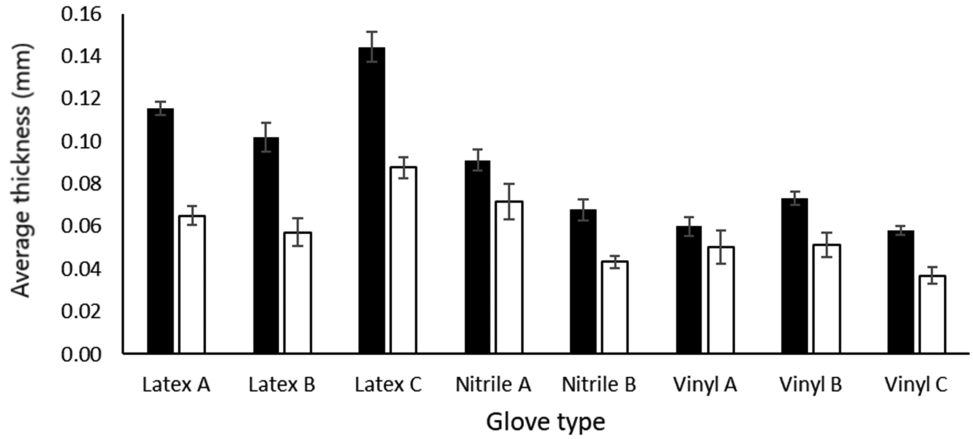

Fig. 3. The average thickness of 8 models of gloves when unstretched and stretched biaxially 20%, to simulate the stretch that occurs within the test cell. The difference in thickness between unstretched (black bars) and stretch gloves (white bars) ranged from 16% to 44%. Note that 6 paralleled glove samples were collected for each glove model (n = 6).

as the challenge. Test materials passing test method ASTM 1670 should then be tested against bacteriophage penetration using ASTM 1671. Other studies have shown that it is possible to have virus penetration without visual detection of fluid (Kotilainen et al. 1990; Li et al. 2019); therefore, the virus barrier efficacy of the stretched nitrile and vinyl gloves tested in our study should be evaluated.

The thickness of gloves is an important factor in the degree of protection provided, and recommendations regarding the specific use of gloves are based on their construction material and thickness. In our study, the glove materials stretched biaxially by 20%, to simulate the stretch occurring during the disposable glove use, showed significantly reduced thickness. Moreover, disposable patient examination gloves are constructed of semi-porous materials with uneven thicknesses, and glove stretch would increase the size and decrease the thickness of the microporous structures of gloves (Richards et al. 1993). Additionally, the 20% stretch used in this investigation may not represent the stretch experienced with glove use in the field but was loosely based on the potential size variation of gloves based on ASTM glove width tolerance (ASTM 2019c). Many factors contribute to the fit of gloves including, but not limited to, user glove-fit preference, dimension tolerances of the standard methods for sizing, the dimensions of the hand-formers used to create the gloves, the material type, and hand movement. A bench study of simulated dynamic testing reported that the thickness of the glove and 3 other physicochemical parameters (i.e. molecular weight, topological polar surface area, and hydrogen bond donor) are the potential parameters affecting the chemical permeation, while surgical and examination gloves are used to against chemotherapy drugs (Nalin et al. 2021). Chemicals with low molecular weight and high lipophilia seems to be easier to permeate through the medical gloves (Oriyama et al. 2017; Wallemacq et al. 2006). Incorporating glove stretch into barrier tests would better characterize the performance of glove materials to better inform sizing and use recommendations.

Fluorescence detection

Fluorescein analysis using a fluorometer provided increased detection sensitivity compared to visual inspection but may not provide a comparable sensitivity as the use of virus. The limit of fluorescein detection of the fluorometer used in our study is roughly 3 ng/ml, which is equivalent to 10 nL of the starting solution. In comparison, ASTM 1671 has a challenge titer of 2 (±1) × 10^8 viruses in 60 ml, and the detection of one virus is considered a failure. One virus is equivalent to 0.1 nL of liquid. Assuming a uniform penetration of all the constituents in the challenge medium (fluorescein in growth medium or virus in growth medium) through the glove material, the virus challenge test provides increased sensitivity by 2 orders of magnitude compared to the fluorescein challenge used in the current study. It may be possible to increase the concentration of the challenge fluorescein solution, which was optimized for visual detection (Li et al. 2019) and not fluorometer analysis to enhance the limit of quantification. This should be further examined.

Implications for standard test method improvements

A permeation test with a pressurized challenge

The use of the newly designed test cell that permits easy access to wash the glove swatch surface opposite to the

exposed surface opens the prospect of converting the ASTM F903 penetration tests for liquids into a permeation test for liquids. Sample analysis with detection with equipment with increased detection sensitivity such as a fluorometer as used in this study or gas and liquid chromatographers as used in other permeation methods provides the level of sensitivity required to measure permeation of liquids that occur at the molecular level through glove material. A method that incorporates a pressurized challenge described in the parameters of ASTM F903 for liquid penetration may provide a more challenging test compared to permeation tests such as ASTM F739 and ASTM D6978-19, which lack pressurization of the liquid challenge.

The use of sanitary fixtures and clamps provided an economical, accessible means to build multiple test cells. Sanitary fixtures and clamps are widely used in the food and beverage industry and are readily available on the market. Domed and flat screens to fit the sanitary clamps can be easily printed with a 3D printer. Sanitary clamps and fixtures require roughly 1/10 of the test fluid specified for ASTM F903, ASTM 1670, and ASTM 1671. A test method that is readily available and economical to perform may be valuable when PPE supply is a concern (Patel et al. 2017). The use of 1.5-inch sanitary fixtures and clamps would permit the testing of materials excised from the finger area of gloves in addition to the palm area, and sanitary clamps with smaller diameters are available to accommodate smaller regions of gloves as needed for smaller gloves and areas between fingers. The virus challenge in the future study will be conducted, and the new test cell will be run in parallel with the original test cell specified by ASTM F903 to assess the feasibility of barrier efficacy of the selected glove.

Conclusion

In this study, we proposed a method that incorporates domed screens into the current ASTM 1670 and ASTM 1671 method to enhance the detection of failure for glove integrity and that may be more predictive of barrier performance of glove material when in use. This test method was able to discern differences in barrier performance among glove materials. Future experiments will be conducted to determine the penetration of Phi-X174 bacteriophage through gloves when using the domed screen compared to a flat screen as specified by ASTM F1671M-22.

Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. Mention of any company or product does not constitute endorsement by the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

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Conflict of interest

The authors report this study has no conflicting interests to declare.

Data availability

The data will be available on the NIOSH Data and Statistics Gateway once cleared by NIOSH.

Supplementary material

Supplementary material is available at *Annals of Work Exposures and Health* online.

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