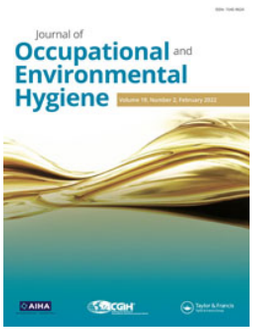

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Evaluation of the effects of repeated disinfection on medical exam gloves: Part 2. Changes in mechanical properties

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ABSTRACT

Many healthcare professionals have been forced, under acute shortages, to extend medical exam gloves beyond their intended single use. Despite limited available literature, the CDC proposed a set of guidelines for repeated exam gloves use, indicating a maximum number of treatments for three widely available disinfectants. This study examines how these treatments affect the mechanical properties of latex and nitrile gloves. Furthermore, an acceptability threshold is proposed for changes in tensile property, specifically elastic modulus, as an indication of degradation. This proposed criterion was also applied to similar studies available in the literature to determine applicability and aid in recommendation development. Three different latex glove brands and three nitrile brands were exposed to repeated treatments of an alcohol-based hand rub, diluted bleach, or soap and water. Tensile tests of samples cut from untreated and treated gloves were performed to assess the change in elastic modulus induced by each treatment. The findings suggest that latex gloves performed well within the CDC recommended guidelines of six repeated treatments for an ethanol-based hand rub and 10 repeated treatments of either dilute bleach or soap and water. Nitrile exam gloves, on the other hand, showed significant changes in elastic modulus, with more inconclusive results among brands. This was especially true for treatment with dilute bleach and soap and water. Further research is needed to investigate the effects of disinfection products on the mechanical integrity of nitrile exam gloves. The results support the use of five repeated treatments of ethanol-based hand rub for nitrile exam gloves, a lower threshold than currently recommended by the CDC. This research also supports that the CDC recommendation of 10 repeated treatment with soap and water is appropriate for latex exam gloves, but not for nitrile exam gloves. Occupational safety and health professionals involved in the selection of disposable exam gloves for infection control should consider the compatibility of the glove polymer type with available disinfectants, especially if extended use with repeated disinfection becomes necessary.

KEYWORDS

COVID-19; disinfectant; elastomeric; extended use; PPE; tensile

Introduction

As described in the companion paper (Part 1), in 2020 the U.S. Centers for Disease Control and Prevention (CDC) issued crisis capacity strategies for institutions and settings facing shortages of personal protective equipment (PPE) during the COVID-19 pandemic (CDC 2020). These recommendations included extending the use of disposable medical exam gloves by sanitizing them between patients. Per the guidelines, gloves can be sanitized with up to six rounds of treatment with alcohol-based hand rub (ABHR) or up to 10 rounds of treatment with dilute bleach or soap and water (CDC 2020). Extended use of PPE is not a recommended practice in typical situations, but it became necessary for many healthcare providers facing acute PPE shortages caused by the

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COVID-19 pandemic. Shortages are also common in low-income countries where supplies are chronically low. One critical gap is that few studies have investigated the impact of common sanitizing agents on the mechanical integrity of medical exam gloves.

For mechanical integrity, the CDC cited one available study on ABHR in support of their extended use recommendations (CDC 2020). Gao et al. (2016) evaluated five latex and eight nitrile glove brands against repeated disinfection with both an ethanol-based and isopropanol-based ABHR. The authors reported variable results among different glove brands of the same polymer type. The authors also reported that changes in tensile strength and elongation were generally less with the ethanol-based ABHR and also less prominent with the latex gloves. They concluded that the latex and nitrile gloves could be treated up to six times without any significant change in tensile strength or elongation, as per a National Fire Protection Association (NFPA) standard NFPA 1999. This standard stipulates that the ultimate tensile strength and elongation at break should be at least 14 MPa and 500%, respectively (NFPA 2018). However, it must be noted that two of the thinner brands of nitrile gloves included in their study did not meet these criteria. Furthermore, statistically significant changes in tensile strength, in excess of 50%, were observed with several nitrile brands after six ABHR treatments (Gao et al. 2016). The changes in tensile strength and elongation also increased with the increasing number of treatments, which indicates that establishing limits on the number of treatments is an important consideration.

Furthermore, the CDC cited little evidence to support their recommendations of up to 10 repeated treatments with a dilute bleach solution or soap and water. This was likely due to a lack of available studies in the literature. The justification for bleach treatments was based solely on a manufacturer's chemical permeation data (CDC 2020). Permeation is a process of molecular diffusion and different from chemical degradation, which is more likely to affect mechanical integrity of polymers than diffusion (Forsberg et al. 2014). For example, water absorption has long been shown to affect the polymer microstructure, significantly modifying physical and thermomechanical properties such as strength, ductility, elastic modulus, storage modulus, impact strength, and glass transition temperature (Cassidy et al. 1983; Jabarin and Lofgren 1986; Pai et al. 1989; Agarwal and Farris 1999; Nogueira et al. 2001; Butler et al. 2003; Saha and Hamaguchi 2006; Startsev et al. 2018). The same is evident with chemical absorption and degradation of protective clothing (Henry and Stull 2003). Therefore, applying different sanitization treatments to exam gloves is expected to affect their physical and thermomechanical properties, and a safe threshold number of applications needs to be determined for each sanitization scheme.

Two studies, published after the CDC issued its recommendations, provided additional evidence on the effects of disinfection on the mechanical properties of medical exam gloves. Garrido-Molina et al. (2021) evaluated the effects of several hospital disinfectants on the mechanical properties of a single brand of nitrile exam gloves. However, the disinfectants were applied directly to one face of the cut glove specimens and not to the whole glove as with normal use, and only one treatment was performed. After treatments with the alcohol-based disinfectants, the authors reported reductions in tensile strength ranging from 27 to 39%. They also reported about a 17% drop in tensile strength after treating the cut specimens with a 1:10 dilution of bleach.

Another recent study also evaluated the effects of repeated disinfection, including bleach and ethanol, on the mechanical properties of one nitrile and one vinyl medical exam glove (Esmizadeh et al. 2021). After 20 cycles of treatment with 75% alcohol spray or 2% bleach solution, no significant changes were observed in the tensile properties of the nitrile glove. However, the error bars on the graphs showed a substantial amount of variation, which may have contributed to the determination of no significant effect.

It must also be noted that even the control samples in recent studies (Esmizadeh et al. 2021; Garrido-Molina et al. 2021) did not meet the criteria used by Gao et al. (2016), namely a tensile strength of at least 14 MPa and/or an elongation at break of at least 500%. It is likely the NFPA 1999 criteria, which are not designed for degradation testing, are not well suited for evaluating chemical degradation, especially for thinner gloves. Furthermore, NFPA 1999 does not address extended use and repeated disinfection of medical exam gloves, which are more specific to crisis conditions faced under the COVID-19 pandemic.

The three key takeaways from the aforementioned studies are that (1) the effects of sanitizing agents on mechanical integrity are variable among different glove brands of the same polymer type, (2) the method of treatment varies among these studies and may play a role in the observed variability, and (3) no clearly established criteria exist for determining whether or not a significant change in mechanical integrity has occurred. On the third point, it may be

Table 1. Glove code based on polymer type, brand, and powder status.

Glove Code	Polymer Type	Glove Brand	Powder Status	Country of purchase	Country of manufacture	Palm thickness [mm]
L-B3-P	Latex	SurgiGloves	Powdered	India	Malaysia	0.076 ± 0.011
L-B3-F	Latex	SurgiGloves	Powder-free	India	Malaysia	0.095 ± 0.014
L-B4-F	Latex	Polymed	Powder-free	US	Thailand	0.103 ± 0.011
N-B1-F	Nitrile	GlovePak Europa	Powder-free	US	Malaysia	0.055 ± 0.003
N-B2-F	Nitrile	SemperSure	Powder-free	US	Malaysia	0.062 ± 0.004
N-B3-F	Nitrile	SurgiGloves	Powder-free	India	Malaysia	0.059 ± 0.005

prudent to apply a set criterion for changes in tensile properties, specifically one that will indicate whether significant molecular-level changes have occurred within the polymer that could compromise its performance, which would aid in the selection of a suitable combinations of glove type and disinfection treatment. Unfortunately, no clear guidelines exist.

The purpose of this study was to evaluate the effect of repeated applications of an ethanol-based ABHR, dilute bleach, and soap and water on the mechanical integrity of latex and nitrile medical exam gloves. This study also establishes a practical acceptability criterion for degradation of medical exam gloves. The results of this study support a companion study (Part 1) that evaluated the physical integrity, measured using a water leak test, of these same gloves against the same disinfectants.

Methods

Gloves

Details on the single-use medical exam latex and nitrile gloves evaluated in this study are provided in Table 1. This includes information on the brand, country of purchase (U.S. or India), country of manufacture (Malaysia or Thailand), and measured palm thickness. Four different brands of gloves were tested, including three types of latex and three types of nitrile gloves. One of the latex gloves sourced from India was powdered, while all others were powder-free. Glove codes were assigned to each based on the polymer type, brand, and powder status (Table 1).

Controls

Twelve pre-conditioned (50 ± 5% relative humidity) and 12 unconditioned gloves were prepared and tensile tested to evaluate for intra-product variation and to assess whether or not pre-conditioning was required prior to treatment. Pre-conditioning was performed in a Boekel environmental chamber (Fisher Scientific, Houston, TX, USA) with saturated calcium chloride (ACROS Organics, 96% purity, Fischer Scientific, Houston, TX USA) solution to control humidity. No significant differences existed between the gloves that were and were not pre-conditioned, indicating that pre-conditioning was not necessary. For each glove type, 24 control samples were used, with six samples cut from each of the four individual gloves. Tensile properties of the treated samples were compared to those of the 24 control samples for each respective product. For each glove type, six additional control samples from a single glove were used for the six repeated treatments of ABHR, as the gloves for these tests were received at a later date, and are likely to come from a different batch.

Treatments

Treatments with ABHR, dilute bleach solution, and soap and water were performed in accordance with the companion study that evaluated glove integrity (Part 1), and outlined in Table 2. These treatments were based on CDC and WHO guidelines for hand hygiene (WHO 2009; CDC 2020). Ten repetitions of the three treatments were performed for each glove, prior to tensile testing. In addition, six repeated treatments with ABHR were conducted for all gloves, as described in the companion study (Part 1) and in accordance with previous recommendations (Gao et al. 2016; CDC 2020).

The ABHR was Purell Advanced Gel Hand Sanitizer (70% ethyl alcohol, GOJO Industries Inc, Akron, OH, USA). After delivery of one pump (approximately 1.5 mL) of ABHR, the gloved hands were rubbed together, palm-to-palm, working the ABHR evenly over the entire surface of both hands until the alcohol evaporated, which took approximately 20 sec. An additional 20 sec evaporation time was included prior to each repeated treatment.

The diluted bleach solution was prepared using one-part Clorox Disinfecting Bleach (The Clorox Company, Oakland, CA, USA), containing 6.0% sodium hypochlorite, to 16 parts tap water (Harris County, TX, USA) with no water softening treatment. Gloves were donned, with a protective glove underneath, submerged into the bleach solution for 1 min, and then pulled out and drip-dried in the open air for 5 sec, which constituted a single treatment. At the end

Table 2. Sanitization protocols and application methods.

Sanitizing agent	Current crisis capacity strategy recommendations (U.S. CDC, updated December 2020)	Selected application method
Soap and water (WHO 2006; 2009; CDC 2020)	Up to 10 applications (CDC) No evidence cited	1. Turn on faucet and wet gloved hands with lukewarm water. 2. Apply one pump of soap to palm of gloved hand. 3. Rub hands palm-to-palm, spreading the soap and water. 4. Rub each palm over the back of its opposite hand with interlaced fingers. 5. Interlock fingers, palm to palm, rubbing them together. 6. Ball each hand into a fist, twisting its knuckles into the opposite palm. 7. Wrap and twist each thumb inside the opposite hand's fingers. 8. Rub the fingertips of each hand on the opposite hand's palm. 9. Rinse gloved hands with lukewarm water. 10. Dry hands thoroughly with single-use towel. 11. Turn off the tap and/or faucet with a towel. Duration: 40-60 sec.
ABHR (WHO 2006; 2009; Gao et al. 2016; CDC 2020)	Up to six applications (CDC) six applications of ABHR on latex and nitrile gloves resulted in minimal change in glove tensile properties	1. Apply a palmful of ABHR to one hand. 2. Rub hands together, palm-to-palm, ensuring even spread of the product on each palm. 3. Place one palm over the top of the opposite hand, interlocking and moving fingers; repeat by reversing the position of each hand. 4. Interlock and then fingers, with palms touching one another. 5. Ball one hand partway into a fist, rubbing knuckles into the opposite hand's palm in a twisting motion; repeat for each hand. 6. Sanitize the thumbs, wrapping each thumb inside the opposite hand's fingers; rotate fingers around the thumb until completion. 7. Rub the fingertips—including the thumb—of each cusped hand on the opposite hand's palm in a twisting pattern. 8. Once hands are dry, the process is complete. Duration: 20-30 sec.
0.35% sodium hypochlorite solution (Kimtech Brand 2009; CDC 2020)	Up to 10 applications (CDC) Manufacturer's testing of Kimberly Clark nitrile gloves found no detectable permeation of 10-13% sodium hypochlorite solution using ASTM standard test methods for permeation after 480 minutes of continuous contact	1. While gloves are donned, dip hands into a dilute bleach solution for 1 min to ensure complete coverage. Solution should not touch the skin. 2. Allow the dilute bleach solution to remain on the donned gloves for 5 sec (starting after removing gloved hands from the solution) to ensure adequate decontamination. Leave hands in a downward position to reduce the risk of the bleach solution dripping onto arms. 3. Rinse dilute bleach solution off gloved hands using water. 4. Wipe gloves dry with a clean, absorbent material. 5. Check gloves again for signs of damage (e.g., holes, rips, tearing), or degradation (e.g., brittle, stiff, discoloration, tackiness). If damage or degradation is observed, discontinue use and discard the gloves.

of treatment, the bleach was rinsed from the gloves and the gloves patted dry with a paper towel. The treatment concentration and submersion time were different that those in the companion study (Part 1). The bleach concentration was higher and the submersion time was greater. The overall treatment time was the same.

The soap and water treatments were performed using Dial Basics Hypoallergenic liquid hand soap (Henkel Consumer Goods Inc, Stamford, CT, USA). One pump, approximately 2 mL, of the liquid soap was dispensed into the palm, while the other gloved hand was wetted with tap water. The gloved hands were rubbed against each other for 40 sec to spread and foam the soap, moving from the palms to the backs of the hands, fingers, knuckles, base of the thumb, and lastly the fingertips. At the end of treatment, the soap was rinsed from the gloves and the gloves patted dry with a paper towel.

Tensile testing

Samples were prepared in accordance with ASTM Method D6287 (ASTM International 2017), using a 1 cm by 6 cm die cutter (W.R. Sharples, North Attleboro, MA, USA). The die allowed collection of up to six longitudinal samples from a single glove, which was necessary to ensure an adequate sample size with the limited number of available gloves for testing.

It is worth mentioning that all samples were cut from the palm region of each glove to ensure consistent

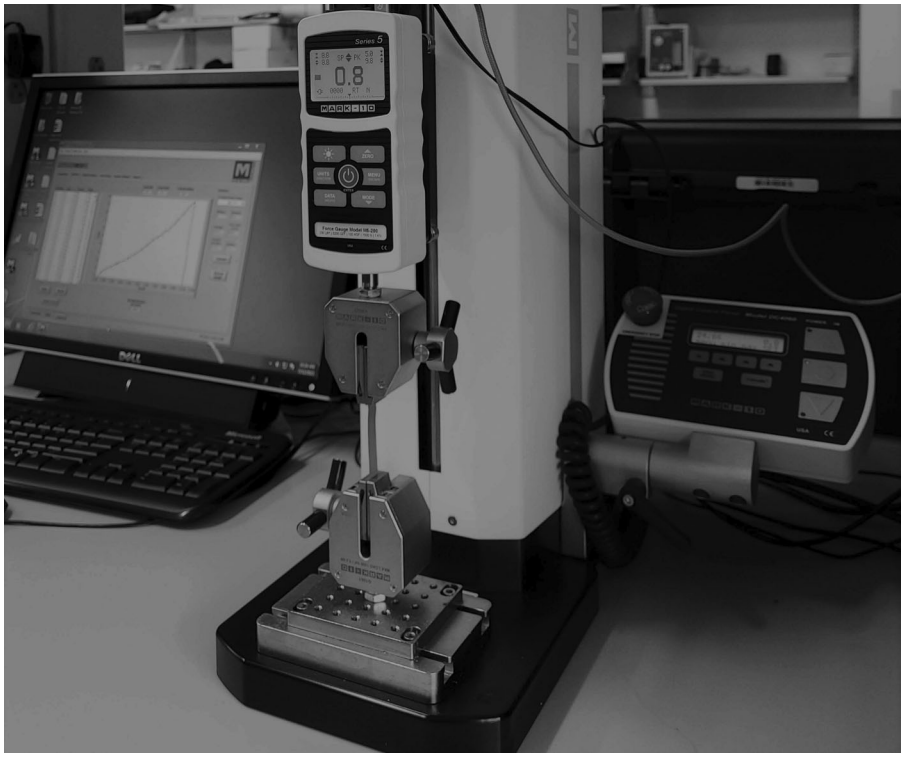

Figure 1. Tensile testing apparatus.

thicknesses. Thickness, used to establish the cross-sectional area for each sample, was measured in accordance with ASTM Method D6988 (ASTM International 2013), using a Marathon Digital Micrometer with 0.001 mm resolution (Fisher Scientific, Houston, TX, USA).

Tensile testing was performed in accordance with ASTM Method D882 (ASTM International 2018), using a Mark-10 ESM303 tensiometer test stand with Series 5 force gauge (Copiague, NY, USA). The set distance between clamps was 2 cm and the speed of travel during tensile testing was 200 mm/min. Figure 1 depicts the tensile testing apparatus, with a cut sample under tension, along with the measured force and displacement displayed on the monitor.

Elastic modulus was used as a primary measure, as prior studies indicated that variability of elastic modulus was lower than both ultimate tensile strength and percent elongation at break, and that it may be a better indicator of polymer performance with regards to chemical permeation and integrity (Phalen and Wong 2012, 2015). Elastic modulus was determined at an optimized region from 175 to 225% strain, based on preliminary stress-strain curves for glove controls and treatments.

For treated samples, all tensile tests were performed no later than 1 hr after treatment to ensure consistency and limit the effect of desorption on mechanical property measurements. This was also more relevant to real-world conditions, in which gloves are used shortly after disinfection.

Selection of degradation criterion

Both ASTM D471 and EN 374-4 standards can be used to evaluate the chemical resistance of gloves to degradation. However, neither standard provides criteria for pass/fail nor a rating system (ISO 2019; ASTM International 2021). Other researchers have recommended rating systems for chemical degradation based on changes in weight or tensile properties (Henry and Stull 2003, 188–189). A review of the available rating scales provided by the aforementioned authors shows higher performance levels (e.g., excellent/good) with weight changes less than 20% and tensile strength changes less than 40%.

Additional considerations for degradation testing include: (1) use of a sensitive and predictive measure of the molecular changes occurring in the polymer; and (2) use of a measure that has lower associated variability. In an evaluation of 37 nitrile exam gloves, Phalen and Wong (2015) found lower overall variability with elastic modulus, compared to tensile strength. The elastic modulus, also referred to as stiffness or Young's modulus, is a measure of a material's resistance to elastic deformation. The authors also reported improved correlations between elastic modulus and

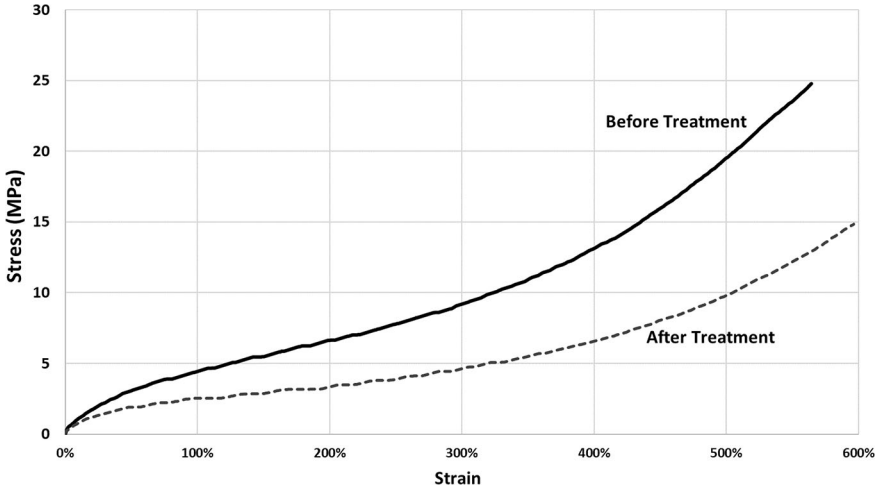

Figure 2. Sample stress-strain curve of nitrile gloves (N-B1-F) before and after treatment with dilute bleach.

measures of chemical resistance, as compared to tensile strength and elongation at break. Variability also appears related to glove material. Similarly, Garrido-Molina et al. (2021) observed lower variation with the elastic modulus (~3%) of a nitrile exam glove, compared to tensile strength (~6%). Additionally, the results of Gao et al. (2016) exhibited lower overall variation in tensile strength with five different latex glove products (maximum of ~12%), as compared to eight different nitrile glove products (maximum of ~38%). Nevertheless, the authors did not report elastic modulus. Based on these results, it is presumed that latex gloves show less variability in tensile test results than nitrile gloves.

Thus, for the purpose of this study, and to establish a threshold for selection of an appropriate glove type and disinfectant combination, any change in elastic modulus greater than 40% was selected as a criterion for significant chemical degradation. The 40% acceptability threshold is consistent with the upper-performance levels of a proposed rating scale associated with ANSI/ISEA 105 puncture resistance testing (Henry and Stull 2003, 189). The current ANSI/ISEA 105-2016 maintains a similar rating scale for chemical degradation and puncture resistance (ANSI 2016). It is also supported by power analysis for a standard sample size of five used with tensile testing (ASTM International 2016, 2018, 2021), alpha of 0.05, and beta of 0.8, which indicates 40% as a limit for statistical significance given an observed variation in elastic modulus of ~20%. This threshold is proposed as a more pragmatic acceptability criterion after potential degradation, which can aid in selecting a suitable combination of glove polymer type and disinfection treatment protocol.

Statistical analyses

The sample size was selected in accordance with ASTM Method D882 (ASTM International 2017) plus one specimen to increase power. The sample size for each glove and treatment combination was six specimens cut from each glove. These were compared to 24 control samples (or six controls for the six repeated ABHR treatments) for each respective glove type using a two-tailed heteroscedastic *Student t* test (Microsoft Excel, Version 2016, Houston, TX, USA). Results were deemed statistically significant at an alpha of 0.05. Changes in elastic modulus were reported as a percent difference. As previously discussed, the criterion for poor performance was any change in elastic modulus greater than 40%, based on a power analysis of standard sample testing sizes and available performance rating scales. This interval of acceptability excludes both increases and decreases in elastic modulus that exceed 40%, as both would cause the material to become either too brittle (increase higher than 40%) or too ductile (decrease of 40% or more).

Results

Glove treatment with any disinfectant is observed to affect their mechanical behavior, yielding changes in elastic modulus, tensile strength, and percent elongation at break. Figure 2 shows an example of stress-strain curves for one of the nitrile glove types (N-B1-F) before and after treatment with dilute bleach. The change in mechanical performance of the investigated gloves after treatment with each disinfectant are presented separately below.

Table 3. Effect of ABHR treatment on the elastic modulus (mean ± standard deviation) of latex and nitrile exam gloves.

	Elastic modulus (MPa)			Elastic modulus (MPa)		
Glove code	Control	Six treatments	Percent Change	Control	Ten treatments	Percent change
L-B3-P	1.21 ± 0.28	1.00 ± 0.28	NS	1.06 ± 0.27	0.99 ± 0.19	NS
L-B3-F	0.89 ± 0.13	0.74 ± 0.19	NS	0.86 ± 0.14	1.24 ± 0.34	+44.2%[a]
L-B4-F	0.77 ± 0.11	0.54 ± 0.10	−29.9%	0.80 ± 0.16	0.68 ± 0.11	−15.0%
N-B1-F	1.80 ± 0.09	1.55 ± 0.37	NS	2.36 ± 0.30	1.89 ± 0.20	−19.9%
N-B2-F	1.17 ± 0.07	1.13 ± 0.14	NS	1.79 ± 0.18	1.38 ± 0.24	−22.9%
N-B3-F	1.60 ± 0.21	1.11 ± 0.35	−30.6%	2.02 ± 0.40	1.84 ± 0.44	NS

[a]Outside the established acceptability criterion of a ± 40% change in elastic modulus
NS = not significant; $p > 0.05$.

Alcohol-based hand rub

The elastic modulus data for all six glove types and ABHR treatments are summarized in Table 2. It must be noted that no significant differences were observed between the ABHR treated and control glove samples for the latex gloves. However, this was not the case for the nitrile gloves. Significant reductions in elastic modulus, in the range of 21 to 35% ($p \leq 0.05$) were observed with the later analyses of nitrile exam gloves, specifically performed for six treatments (Table 2). This was likely a result of batch-to-batch variability within the same glove brand, and/or aging and storage conditions during the approximate six months between the 10 and six repeated treatment cycles. As previously discussed, all treatments were compared to their respective controls.

The latex control gloves had a lower overall elastic modulus (0.8–1.2 MPa) compared to the nitrile gloves (1.2–2.4 MPa). After six repeated treatments with ABHR, the percent changes in elastic modulus were not significant ($p > 0.05$) for four types of gloves, with a 30% reduction for one type of latex glove (L-B4-F) and a 31% reduction for one type of nitrile glove (N-B3-F), as shown in Table 2.

After six repeated treatments, all the gloves performed within the established ±40% criterion for acceptability. After 10 repeated treatments with ABHR, the percent changes in elastic modulus were not significant ($p > 0.05$) for two types of gloves, ranged from 15% to 23% loss for three types of gloves, and showed a 44% increase for one type (L-B3-F) of latex glove (Table 2). Only one type of latex glove (L-B3-F) did not meet the established ±40% criterion for acceptability.

Dilute bleach

The elastic modulus data for all six glove types after dilute bleach treatments are summarized in Table 3. After 10 repeated treatments with dilute bleach, the percent changes in elastic modulus were not significant ($p > 0.05$) for four gloves and showed a 31% drop for one nitrile glove (N-B2-F) (Table 3). One type of nitrile gloves (N-B1-F) had a 47% drop that did not meet the established ±40% criterion for acceptability. The 47% drop in elastic modulus can be observed in Figure 2 and is accompanied by a 40% loss in tensile strength from 24.8 to 14.8 MPa, and a slight increase (5.5%) in ductility (i.e., percent elongation at failure) from 565% to 596%.

Soap and water

The elastic modulus changes for all six glove types after the soap and water treatments are summarized in Table 4. After 10 repeated treatments with soap and water, the percent changes in elastic modulus were not significant ($p > 0.05$) for two latex gloves, showed a 16% increase for one type of latex gloves (LB3-F), and between 34% and 43% decrease for all types of nitrile gloves. Two types of the nitrile gloves (N-B1-F and N-B3-F) did not meet the established ±40% criterion for acceptability.

Discussion

Alcohol-based hand rub

For the latex exam gloves, six repeated treatments with ABHR provided a more acceptable outcome than 10 treatments, with either no significant change in elastic modulus or a change of less than 31%. These findings were consistent with those of Gao et al. (2016) for an ethanol-based ABHR. After up to six repeated treatments, the authors reported no reductions in latex tensile strength in excess of 14%. Almost all their results were not significant, except for one glove brand.

For the nitrile exam gloves, the elastic modulus results after both six and 10 repeated treatments with ABHR were all within the acceptability threshold, with either no significant change or no change in excess of 24%. These results were somewhat consistent

Table 4. Effect of dilute bleach treatment on the elastic modulus (mean ± standard deviation) of latex and nitrile exam gloves.

	Elastic modulus (MPa)		
Glove code	Control	Ten treatments	Percent change (%)
L-B3-P	1.06 ± 0.27	0.99 ± 0.17	NS
L-B3-F	0.86 ± 0.14	1.03 ± 0.20	NS
L-B4-F	0.80 ± 0.16	0.78 ± 0.13	NS
N-B1-F	2.36 ± 0.30	1.26 ± 0.37	−46.6[a]
N-B2-F	1.79 ± 0.18	1.24 ± 0.31	−30.7
N-B3-F	2.02 ± 0.40	1.84 ± 0.18	NS

[a]Outside the established acceptability criterion of a ± 40% percent change in elastic modulus
NS = not significant; $p > 0.05$.

with those of Gao et al. (2016), who reported significant losses in tensile strength of 12% to 46% after six treatments with an ethanol-based ABHR. From the Gao et al. (2016) study, only one nitrile glove brand did not meet the proposed ±40% criterion with six repeated treatments, but all gloves conformed to the criterion with five repeated treatments.

The observed changes in elastic modulus were also consistent with another study that reported a 27% reduction in tensile strength for a single nitrile glove brand treated one time with an ethanol-based ABHR (Garrido-Molina et al. 2021). In contrast, Esmizadeh et al. (2021) reported no significant change in tensile strength or elastic modulus in a nitrile glove brand exposed up to 20 repeated treatments with an alcohol-based spray. However, the variation in results reported in Esmizadeh et al.'s (2021) study was excessive and a significant drop in the average elastic modulus occurred after five repeated treatments (Figure 3 in Esmizadeh et al. 2021). The presented changes appeared to be within ±40% after five treatments (Esmizadeh et al. 2021).

Consequently, based on the analysis of all available and published results among a number of nitrile exam glove brands, it appears that a maximum of five repeated treatments would produce acceptable changes in elastic modulus with either no significant change or no change in excess of ±40%.

Given prior evidence and our new findings, it appears that the CDC-recommended threshold of six repeated treatments with ethanol-based ABHR is appropriate for latex exam gloves, but it may be prudent to limit the number of repeated treatments to five for nitrile exam gloves.

Dilute bleach

Latex exam gloves were least affected by dilute bleach. No significant changes in elastic modulus were observed after 10 repeated treatments. Nitrile exam gloves, on the other hand, showed mixed results after dilute bleach treatments: One brand showed no significant change in elastic modulus, another brand exhibited a reduction of 31%, and one brand exhibited a 47% reduction. The 47% drop in elastic modulus can be observed in Figure 2, and is accompanied by a 40% loss in tensile strength from 24.8 to 14.8 MPa, and a slight increase (5.5%) in ductility (i.e., percent elongation at failure) from 565% to 596%.

These findings are fairly consistent with the literature. Garrido-Molina et al. (2021) reported a 17% reduction in tensile strength for a single nitrile glove brand treated one time with a dilute bleach solution, which indicates that a lower number of treatments may be more acceptable. In contrast, Esmizadeh et al. (2021) reported no significant change in tensile strength or elastic modulus in a nitrile glove brand exposed up to 20 repeated treatments with a 2% bleach spray. As previously mentioned, the observed variation in reported changes in mechanical properties were significant, and an important reduction in the average elastic modulus can be visually observed after 10 repeated treatments (Figure 3 in Esmizadeh et al. 2021). On average, the results reported by Esmizadeh et al. (2021) still appeared to be within ±40% after 10 treatments, but were in excess of a 50% reduction in elastic modulus after 20 treatment cycles (Figure 3 in Esmizadeh et al. 2021).

This data supports that the CDC-recommended 10 repeated treatments with dilute bleach is appropriate for latex exam gloves, but not for nitrile exam gloves. Further research is needed to investigate the effects of diluted bleach on the mechanical integrity of nitrile exam gloves.

Soap and water

For the latex exam gloves, 10 repeated treatments with soap and water resulted in either no significant change in elastic modulus (two brands) or an increase of 16% (one brand). The results were all within the established acceptability criterion of ±40%.

Conversely, nitrile exam gloves did not perform as well with 10 repeated treatments of soap and water. Significant reductions in elastic modulus, in excess of 40%, were observed for two brands. The other brand exhibited a reduction in elastic modulus of 34%. Hence, two of the three glove brands were outside the established criterion of ±40%. These results suggest that further research is needed to determine the appropriate limit for repeated soap and water treatments of nitrile exam gloves (Table 5).

Based on the observed reduction in elastic modulus after treatment with both dilute bleach and soap and

Table 5. Effect of soap and water treatment on the elastic modulus (mean ± standard deviation) of latex and nitrile exam gloves soap and water.

	Elastic modulus (MPa)		
Glove code	Control	Ten treatments	Percent change (%)
L-B3-P	1.06 ± 0.27	0.97 ± 0.19	NS
L-B3-F	0.86 ± 0.14	1.00 ± 0.13	+16.3
L-B4-F	0.80 ± 0.16	0.74 ± 0.26	NS
N-B1-F	2.36 ± 0.30	1.35 ± 0.30	−42.8[a]
N-B2-F	1.79 ± 0.18	1.18 ± 0.26	−34.1
N-B3-F	2.02 ± 0.40	1.17 ± 0.23	−42.1[a]

[a]Outside the established acceptability criterion of a ± 40% change in elastic modulus.
NS = not significant; $p > 0.05$.

water, it appears that further research on the effect of water, and aqueous-based treatments in general, on nitrile exam gloves should be investigated.

A number of previous studies reported detrimental effects of water on most polymers, thus corroborating these findings (Cassidy et al. 1983; Jabarin and Lofgren 1986; Pai et al. 1989; Agarwal and Farris 1999; Nogueira et al. 2001; Butler et al. 2003; Saha and Hamaguchi 2006; Startsev et al. 2018). The water-induced drop in mechanical properties depends largely on the availability within the polymer chain of hydrophilic functional groups with which water molecules can bond (Barraza et al. 2003; Guloglu et al. 2020). Nitrile and latex polymer structures offer contrasting hydrophilic behaviors. Nitrile mechanical properties have been reported to decrease drastically upon water absorption (Jabarin and Lofgren 1986; Saha and Hamaguchi 2006), while latex is reported to show low to moderate changes after water exposure (Agarwal and Farris 1999; Butler et al. 2003). Similarly, a study on the influence of hand movement on the permeation/penetration of captan fungicide through disposable nitrile rubber gloves reported catastrophic failure of one of three disposable nitrile gloves in the presence of an aqueous solution and simulated hand movement (Phalen and Hee 2008).

The results support that the CDC recommendation of 10 repeated treatments with soap and water is appropriate for latex exam gloves, but not for nitrile exam gloves. Further research is needed to investigate the effects of soap and water, as well as water alone, on the mechanical integrity of nitrile exam gloves.

Conclusions

The unprecedented COVID-19 pandemic forced many healthcare providers to contemplate extended use of exam gloves. The CDC-proposed guidelines for this crisis scenario indicate a number of maximum treatments for widely available disinfectants. This study investigates the effects of repeated disinfectant treatment on mechanical performance of latex and nitrile gloves, synthesizes the prior literature, and proposes an acceptability threshold for changes in tensile property as an indication of degradation.

Based on the results of this study and a review of the available literature, it appears that latex gloves perform well within the CDC-recommended guidelines of six repeated treatments for ethanol-based ABHR and 10 repeated treatments of either dilute bleach or soap and water.

The results of the current study and the available literature for nitrile exam gloves were less definitive, especially for dilute bleach and soap and water. Further research is needed to investigate the effects of water and water-based products on the mechanical integrity of nitrile exam gloves. At this time, it appears that a maximum of five repeated treatments of an ethanol-based ABHR should be used with nitrile exam gloves.

Recommendations

Occupational safety and health professionals involved in the selection of disposable exam gloves for infection control should consider the compatibility of the glove polymer type with available disinfectants, especially if extended use with repeated disinfection becomes necessary.

Significant changes in elastic modulus can be an indicator of degradation that can affect the mechanical integrity of the glove. Based on the results of this study and a review of the available literature, latex exam gloves performed best in combination with disinfection using dilute bleach, followed by soap and water. As an alternative, up to six treatments with an ethanol-based ABHR appeared acceptable for latex exam gloves. Until further investigations are performed, limited disinfections with an ethanol-based ABHR, not to exceed five repeated treatments, should be considered for nitrile exam gloves.

Physical integrity is another important factor of consideration when selecting an appropriate glove-disinfectant combination. The companion paper (Part 1) provides useful details on the physical integrity of these glove products that can aid in the selection process.

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Data availability

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

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