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Changes in Chemical Permeation of Disposable Latex, Nitrile and Vinyl Gloves Exposed to Simulated Movement

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Abstract

Glove movement can affect chemical permeation of organic compounds through polymer glove products. However, conflicting reports make it difficult to compare the effects of movement on chemical permeation through commonly available glove types. This study was aimed to evaluate the effect of movement on chemical permeation of an organic solvent through disposable latex, nitrile, and vinyl gloves. Simulated whole-glove permeation testing was conducted using ethyl alcohol and a previously designed permeation test system. With exposure to movement, a significant decrease ($p \leq 0.001$) in breakthrough time was observed for the latex (-23%) and nitrile gloves (-31%). With exposure to movement, only the nitrile glove exhibited a significant increase ($p \leq 0.001$) in steady-state permeation rate (+47%) and cumulative permeation at 30 min (+111%). Even though the nitrile glove provided optimum chemical resistance against ethyl alcohol, it was most affected by movement. With exposure to movement, the latex glove was an equivalent option for overall worker protection, because it was less affected by movement and the permeation rate was lower than that of the nitrile glove. In contrast, the vinyl glove was the least affected by movement, but did not provide adequate chemical resistance to ethyl alcohol in comparison with the nitrile and latex gloves. In conclusion, glove selection should take movement and polymer type into account. Some glove polymer types are less affected by movement, most notably the latex glove in this test. With nitrile gloves, at least a factor of three should be used when attempting to assign a protection factor when repetitive hand motions are anticipated. Ultimately, the latex gloves outperformed nitrile and vinyl in these tests, which evaluated the effect of movement on chemical permeation. Future research should aim to resolve some of the observed discrepancies in test results with latex and vinyl gloves.

Keywords

chemical protective clothing; personal protective equipment; exam gloves; dermal protection

Introduction

It has been shown that glove movement affects the chemical permeation of volatile organic compounds through various polymer glove products. Perkins and Rainey reported significant decreases in breakthrough time (BT) and increases in steady-state permeation rate (SSPR) with 20-30 mil chemical-resistant neoprene and polyvinyl chloride (vinyl) gloves exposed to acetone and heptane, respectively.[(1)] Phalen and Wong reported similar results with the permeation of ethyl alcohol through disposable nitrile rubber (herein referred to as nitrile) gloves exposed to simulated movement.[(2)] Conflicting evidence has been presented on the effect of movement on permeation of semi-volatile and/or non-volatile chemical compounds through glove materials. Colligan and Horstman reported no effect of movement on the BT with natural rubber latex (herein referred to as latex) and vinyl gloves exposed to antineoplastic drugs.[(3)] However, a disposable latex exam glove exhibited a doubling of the permeation rate associated with exposure to movement. In contrast, Phalen and Que Hee reported no influence of simulated hand movement on the permeation of captan through disposable nitrile gloves.[(4)] The observed differences are likely due to the properties of the polymers, with some being more flexible than others,[(5)] as well as differences in product thickness and test conditions (e.g., challenge chemical, collection solvents, and test method).

These conflicting reports make it difficult to compare the effects of movement on chemical permeation through commonly available glove types, such as latex, neoprene, nitrile and vinyl glove choices. One study on the permeability of cytotoxic agents through various glove types exposed to movement reported neoprene, latex and nitrile gloves as superior choices to vinyl gloves.[(6)] More research in this area is needed to help industrial hygienists and occupational health professionals make informed choices regarding polymer type, especially when the worker job classification requires repetitive hand movements and manipulations likely to stress the glove material. This need is evident with respect to thinner, disposable gloves used by workers as a barrier against chemical hazards. These gloves are more likely to be recommended when manual dexterity is critical and polymer type is a decision factor when evaluating hand activity and dexterity associated with glove use and repetitive motions. [(7-11)]

The purpose of this study was to evaluate the effect of movement on the chemical permeation of a volatile solvent through different disposable glove materials, with similar thicknesses. The glove materials tested included latex, nitrile, and vinyl. Simulated whole-glove permeation testing was conducted using ethyl alcohol and a previously designed permeation test system used to simulate hand movement.[(12)] The goal was to determine which glove materials were least affected by movement, to aid occupational health professionals in the selection of glove materials when repetitive hand motions are anticipated.

Materials and Methods

Gloves and Chemical

The gloves were disposable, powder-free exam gloves with a reported length of 24 cm and palm thickness of 0.10-0.13 mm (4-5 mil). The brands tested (Table I) were Fisherbrand Latex, Safety Choice Nitrile, and Safety Choice Vinyl gloves (Fisher Scientific, Pittsburgh, PA, USA). Latex, nitrile and vinyl gloves were chosen for comparison because they are common and available glove choices, inexpensive, and their material compatibility charts from a glove supplier (http://www.coleparmer.com/Chemical-Resistance) indicated that protection would be likely against ethyl alcohol. Preliminary degradation testing indicated no significant weight or thickness change ($p \leq 0.05$) or observable signs of material degradation with the three glove materials following a 2 hour exposure to ethyl alcohol. Chemical permeation was conducted using 200 mL ethyl alcohol, denatured (Fisher Scientific, Pittsburgh, PA, USA) as a representative test chemical.

Permeation Testing

A previously designed test system was used to expose gloves to simulated whole-glove movement and measure permeation parameters.[2, 12] Closed-loop permeation monitoring for ethyl alcohol was conducted within a permeation chamber using a datalogging Minirae 2000 photoionization detector (PID) (Rae Systems, San Jose, CA, USA). Chamber concentrations were averaged and recorded every 30 seconds by the PID. The permeation chamber was a 29.2 cm × 25.4 cm × 30.5 cm stainless steel and glass Boekel 1340 environmental chamber (Fisher Scientific, Pittsburgh, PA, USA). The PID was calibrated at the beginning of the day and checked at the end of each run. The PID was recalibrated if readings exceeded ± 3% of the 100 ppm isobutylene calibration check standard. Permeation runs were invalidated if the calibration check exceeded ± 5%. All PID readings were corrected using a measured response factor for ethyl alcohol, based on a standard curve from known concentrations of ethyl alcohol in Tedlar® bags.

The permeation parameters were determined using Microsoft Excel, to evaluate test chamber concentrations and changes in concentration over time. The BT was determined as the first increase of 0.4 μg/cm^2, where all subsequent measures continued to increase. The rationale for this determination is provided in a previous study.[2] The SSPR was calculated using at least ten data points within the linear region of the permeation curve. A third measure, cumulative permeation (in units of μg/cm^2) at 30 minutes (CP_{30}), was determined to aid in the comparison of permeation results with studies incorporating standardized measures in accordance with American Society for Testing and Materials (ASTM) Method F739 *Standard Test Method for Resistance of Protective Clothing Materials to Permeation of Liquids or Gases under Conditions of Continuous Contact*.[13]

For simulated whole-glove movement, inflation and deflation of the glove was controlled using a GeoControl Pro pneumatic controller (Geotech Environmental Equipment, Inc., Denver, CO, USA) and magnehelic pressure gauge (Dwyer Industries, Inc., Michigan City, IN, USA). The inflation pressure was controlled to within a gauge pressure reading of 0.10 ± 0.02 inches of water. The inflation and deflation cycle time was 30 seconds, in which the gloves were in continual movement more than 80% of the time. As in a previous study,[12] all permeation tests were performed within a fume hood and a Pelican 1500 case (Pelican Products, Torrance, CA, USA) with an installed 5 liter Tedlar® bag was used as an intermediate chamber to separate and protect the pneumatic pump from ethyl alcohol vapors, as previously described.

The no movement and movement runs were matched and paired to control for variations in room temperature (21.4 ± 1.0 °C) and relative humidity (35 ± 15%). Ambient conditions were used for safety and health reasons.

Statistical Analyses

Sample sizes (Table I), ranging from 20 to 26 per test condition (no movement or movement), were adjusted to detect a 10 percent change in permeation parameters upon exposure to movement, using a *t*-test. The total sample sizes ranged from 40 to 52 per glove. Statistical analyses were performed using IBM SPSS Statistics 19 (IBM, Armonk, NY, USA). Histograms, and skewness and kurtosis normality tests indicated that the permeation results were near normally distributed. Because the no movement and movement tests were matched and paired, to account for variations in ambient conditions, paired *t*-tests were used. Results were considered significant if the p value was ≤ 0.05.

Results

Breakthrough Time

The BT data are illustrated in Fig. 1, which shows the average BT data for no movement and movement exposures, plus a statistical comparison of the percent change for each glove product. With exposure to movement, a significant decrease ($p \leq 0.001$) in BT was observed for the latex and nitrile gloves. The decrease in BT ranged from 23 to 31 %, respectively. No significant change in BT (p = 0.12) was observed with the vinyl glove.

Significant variation in BT existed between the glove types. Without movement, the average BT for the nitrile glove was about 3.5 times longer than the latex glove and 10 times longer than the vinyl glove. This effect was similar with the addition of movement; the average BT for the nitrile glove was about 4 times longer than the latex glove and about 14 times longer than the vinyl glove. The differences were slightly larger with the addition of movement.

Steady-State Permeation Rate

The SSPR data are illustrated in Fig. 2, which shows the average SSPR data for no movement and movement exposures, plus a statistical comparison of the percent change for each glove product. With exposure to movement, a significant increase ($p \leq 0.001$) in SSPR was observed only for the nitrile glove, with a 47 percent increase, on average. No significant change in SSPR (all $p > 0.2$) was observed with the latex or vinyl gloves.

Without movement, the average SSPR varied slightly between the glove materials, with percent differences ranging from 12 to 40 percent. However, the effect was more pronounced with exposure to movement, with percent differences ranging from 26 to 70 percent. The primary cause of this increase in effect was with the significant increase in SSPR with the nitrile glove when exposed to movement.

Cumulative Permeation

The cumulative permeation data are illustrated in Fig. 3, which shows the average CP_{30} data for no movement and movement exposures, plus a statistical comparison of the percent change for each glove product. With exposure to movement, a significant increase ($p \leq 0.001$) of 111 percent, on average, in CP_{30} was observed only for the nitrile glove. No significant change in CP_{30} (all $p > 0.05$) was observed with the latex or vinyl gloves.

Without movement, the average CP_{30} values varied significantly between the glove materials, with percent differences ranging from 85 to 270 percent. However, the effect was less pronounced with exposure to movement, with percent differences ranging from 10 to 100 percent. The primary cause of this decrease in effect was with the significant increase in CP_{30} with the nitrile glove when exposed to movement.

Discussion

Simulated Movement

The results shown in Fig. 1, Fig. 2 and Fig. 3 indicated that simulated movement had a significant effect on chemical permeation with the nitrile glove, but not the latex or vinyl gloves. On average, for the nitrile glove, movement resulted in a decrease in BT of about 24%, an increase in SSPR of about 47%, and an overall increase in CP_{30} of 111%. With the nitrile glove, permeation occurred both sooner and at a faster rate with movement. These results are consistent with a similar study evaluating the effect of movement on the permeation of ethyl alcohol through disposable nitrile gloves.[(2)] Phalen and Wong reported comparable results with up to a 33% decrease in BT and up to a 78% increase in SSPR with exposure to simulated whole-glove movement.[(2)] A 3-fold increase in cumulative exposure, as the area under the permeation curve at 30 min (AUC_{30}), was also reported, which does not directly compare with the 1-fold increase in CP_{30} in this current study. It has been shown that area under the permeation curve can provide an improved estimate of worker exposure over time;[(2)] however, both AUC_{30} and CP_{30} are a function of the BT and SSPR. The estimated AUC_{30} for the nitrile glove exposed to no movement can be estimated using the formula:[(2)]

$$\begin{aligned}\mathrm{AUC}_{30} &= 0.5 \times (30\,\mathrm{min} - \mathrm{BT}) \times \mathrm{CP}_{30} \\ &= 0.5 \times (30\,\mathrm{min} - 11.3\,\mathrm{min}) \times 100\mu\mathrm{g/cm}^2 \\ &= 935\,\mathrm{min} \cdot 100\mu\mathrm{g/cm}^2\end{aligned} \quad (1)$$

The equivalent calculation for the AUC_{30} with exposure to movement (BT = 7.8 min and $CP_{30} = 211$ µg/cm^2) is about 2,340 min·µg/cm^2. This equates to about a 2.5-fold increase in estimated AUC_{30}, which is consistent with the previously reported up to 3-fold increase.[(2)] Therefore, for the purpose of assigning a workplace protection factor, at least a 3-fold increase in worker exposure should be assumed with repetitive hand movements over a 30 min period.

The results for the latex glove are not consistent with a previous study evaluating the effect of movement on permeation parameters. Colligan and Horstman studied the permeation of cyclophosphamide through a similar latex exam glove with a reported thickness of 0.16 mm.[3] They found no significant change in normalized BT following exposure to flexure. However, the sample sizes were small at n = 3 to n = 4 and the standard deviations were high, with a calculated coefficient of variation ranging from 82 to 83 percent. In contrast, a significant increase in SSPR of about 50% was reported with exposure to flexure. These results are opposite the findings with ethyl alcohol permeation and simulated whole-glove movement. Colligan and Horstman used a modified Franz cell, which evaluates permeation for a small swatch of material.[3] The amount of glove material flexure was not reported. Only a small volume of air, 7.5 cc, was displaced in the manifold system, but the number of test cells and pressure and vacuum measures were not reported, all which made it difficult to compare the two studies. The likely reasons for the differences include:

1. cyclophosphamide is a non-volatile compound and requires aqueous challenge and collection solvents to complete permeation testing, which can affect BT and SSPR determinations; [14]
2. the Franz test cell design is vertical (one-dimensional) and potentially influenced permeation additionally by gravity, whereas the whole-glove system has liquid contact in multiple planes (x, y and z);
3. the pumping system in the modified Franz cell test design reported pressurization and vacuum in the cycles, using a syringe pump, which was likely to have some influence on the molecular movement of water and cyclophosphamide through the material; and
4. the cyclophosphamide permeations were run at 37°C, which is likely to enhance permeation.[15-16]

Further testing and evaluation of the effects of movement on permeation of latex gloves by volatile and not-volatile chemicals is needed.

For the vinyl glove, the results and conclusions matched well with those of Colligan and Horstman, who found no significant change in normalized BT or SSPR with cyclophosphamide permeation following exposure to flexure for a vinyl glove with a reported thickness of 0.12 mm.[3] The general understanding that vinyl gloves provide good resistance to water and aqueous solutions,[17] due in part to the high plasticizer content,[18] also supports the prior reasoning on how the aqueous challenge and collection solvents may have affected the latex permeation results. In contrast, Perkins and Rainey also evaluated the effect of whole-glove movement on permeation of heptane through thicker 0.51 mm (20 mil) vinyl gloves, but found a decrease in BT and increase in SSPR associated with glove flexure.[1] The primary issue with this study was that vinyl gloves are generally not recommended for protection against heptane, or aliphatic/alicyclic hydrocarbons, due to poor resistance and potential degradation effects.[17, 19] The general conclusion here is that permeation of vinyl gloves is less affected by movement, than the nitrile gloves.

Polymer Type and Performance

Even though the nitrile gloves were affected more by movement than the other two polymer types, they did provide a significantly longer BT, regardless of movement. Without exposure to movement, the nitrile gloves performed well and had the longest BT (3.7-fold to 9-fold longer), an equivalent SSPR, and the lowest overall cumulative permeation (i.e., CP_{30} 2-fold to 4-fold lower). Without exposure to movement, the nitrile glove was an optimal choice for protection against ethyl alcohol. With exposure to movement, the nitrile glove was still an acceptable choice.

With exposure to movement the latex glove was an equivalent option, as it was less affected by movement than the nitrile glove. There was no significant difference ($p = 0.24$) in CP_{30} between the latex and nitrile gloves. For exposures beyond 30 minutes the latex glove is expected to outperform the nitrile glove, especially when repetitive hand movements are present. This is likely due to the reported differences in stiffness and immediate unrecovered stretch between similar disposable latex and nitrile gloves.(5) A previous study evaluating the biomechanical properties of similar disposable latex and nitrile gloves indicated that latex gloves were less stiff and had improved recovery properties following stretching.(5)

Although, the vinyl glove was not affected by movement, it had the lowest BT, a high to moderate SSPR, and the highest CP_{30}, regardless of movement. The likely reason for this is the high plasticizer content, often up to 50%, with vinyl polymers.(18) The high plasticizer content may help modify the plastic vinyl polymer into a more elastic product;(17) however, organic solvents are more likely to interact with the phthalate or often oily plasticizers used with vinyl products.(18)

Limitations of the Study

A major limitation of this study was that only one test chemical was evaluated, which limits the application to different chemical classes with these gloves materials. The findings may be relevant to similar aliphatic hydroxyl compounds, but they may not necessarily apply to different chemical classifications. As discussed earlier, ethyl alcohol was selected because it is known to permeate all three glove products rapidly without significant degradation. Furthermore, the American Conference of Governmental Industrial Hygienists Threshold Limit Value (TLV®) is higher than most other alternatives, which adds a margin of health protection during testing.(20) It would have been ideal to tightly control temperature and relative humidity; however, the matched-pairs study design has been shown to provide reliable results.(12) Use of a heating element with a flammable solvent posed an additional safety and health concern. Lastly, this study only evaluated three disposable glove products for protection against a chemical under light-use conditions (e.g., hospital and dental settings), where thicker chemically-protective gloves are not practical. The decision to use disposable gloves is a critical professional judgment for those practicing industrial hygiene.

Conclusions

Although, the nitrile glove provided optimum chemical resistance against ethyl alcohol, it was most affected by movement. On average, simulated whole-glove movement significantly shortened the BT, increased the SSPR, and increased CP_{30} with the nitrile glove. With movement, the latex glove was an equivalent option for overall protection, because it was less affected by movement and the permeation rate was lower than that of the nitrile glove. It is expected that the latex glove would outperform the nitrile glove with in-use exposures greater than 30 minutes. The vinyl glove was the least affected by movement, but did not provide adequate chemical resistance to ethyl alcohol in comparison with the nitrile and latex gloves. In conclusion, glove selection must take movement and polymer type into account. Some gloves are less affected by movement than others, most notably the latex gloves in these tests. With nitrile gloves, at least a 3-fold factor should be used when attempting to assign a workplace protection factor when repetitive hand motions are anticipated with the work task. Ultimately, the latex gloves outperformed nitrile and vinyl in these tests, which evaluated the effect of movement on chemical permeation. However, additional research is needed, due primarily to a general lack of studies on the effects of movement on glove materials and on permeation with different chemical classes, especially those of low volatility requiring a collection solvent. Future research should aim to resolve some of the observed permeation discrepancies with latex and vinyl gloves.

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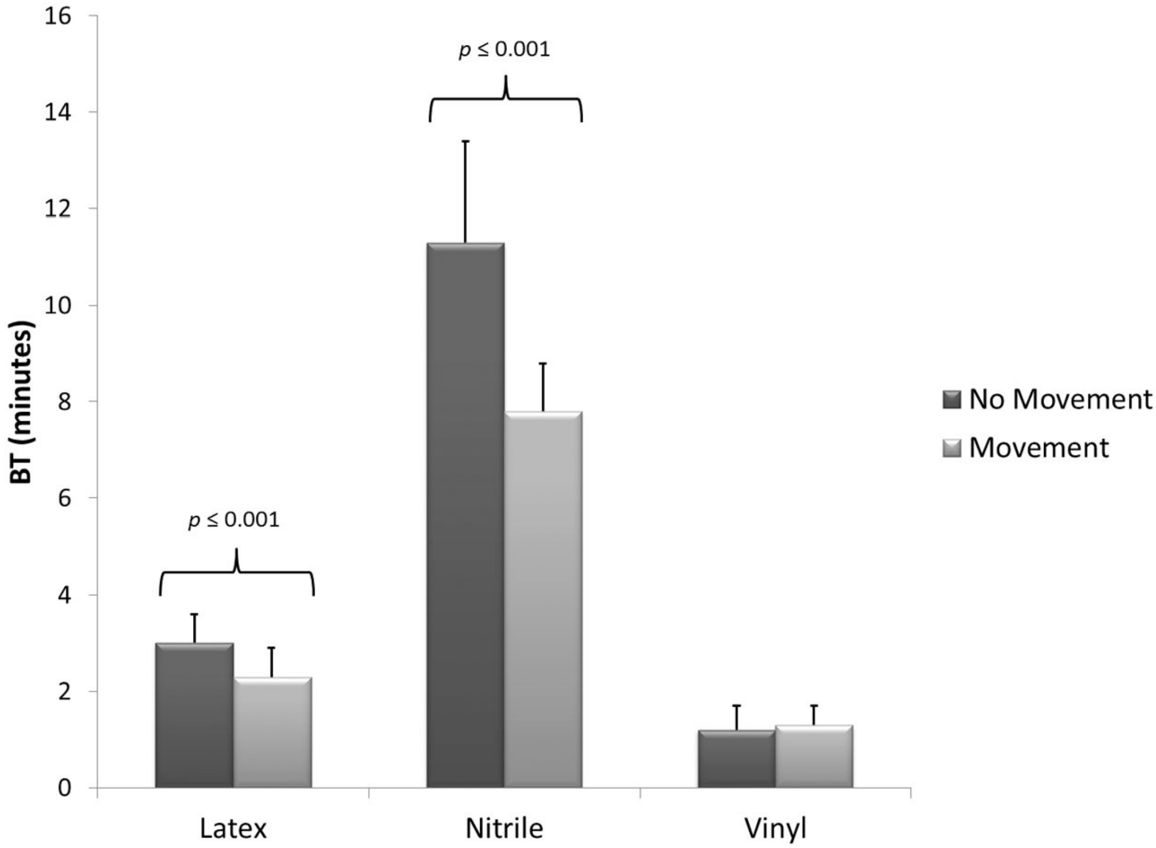

FIGURE 1.
Breakthrough time (BT) for different glove types, no movement versus movement. Significant reductions in BT are shown with brackets. Significant decreases in BT were observed with the latex and nitrile gloves.

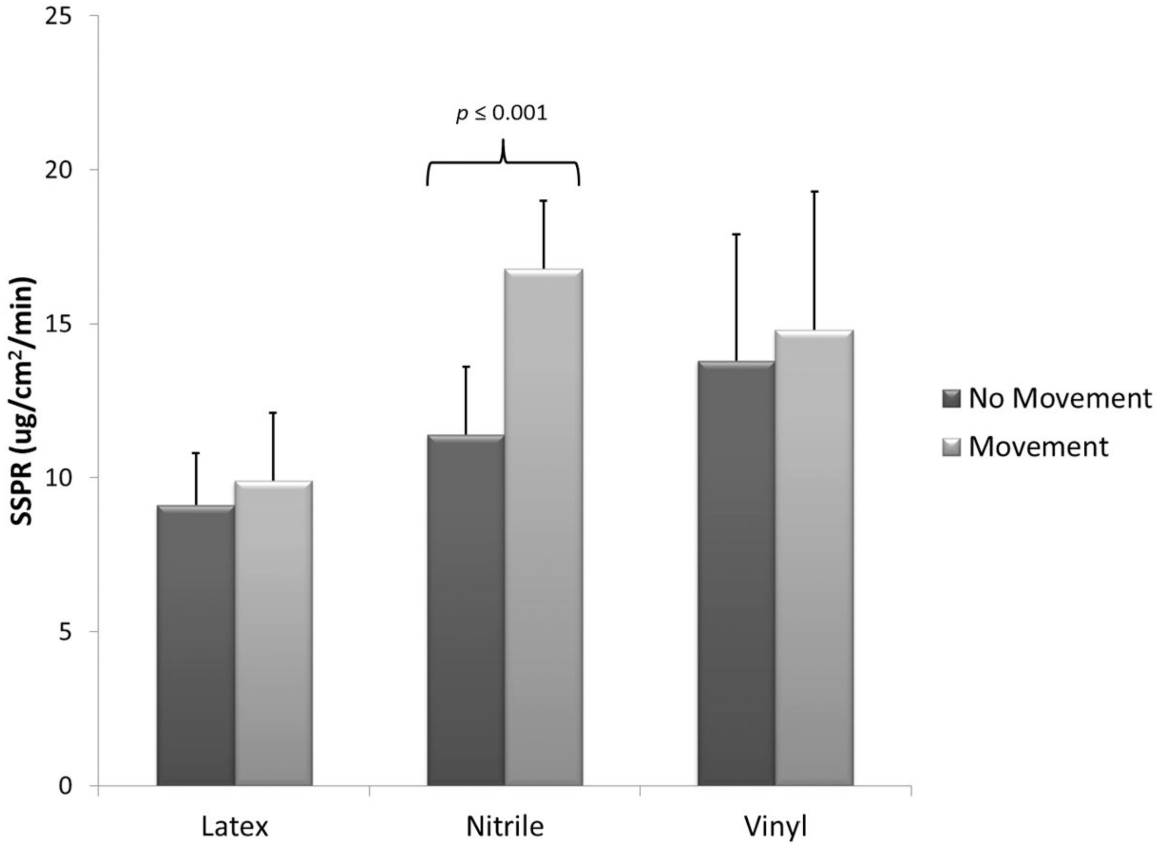

FIGURE 2.

Steady-state permeation rate (SSPR) for different glove types, no movement versus movement. Significant increases in SSPR are shown with brackets. A significant increase in SSPR was only observed with the nitrile glove.

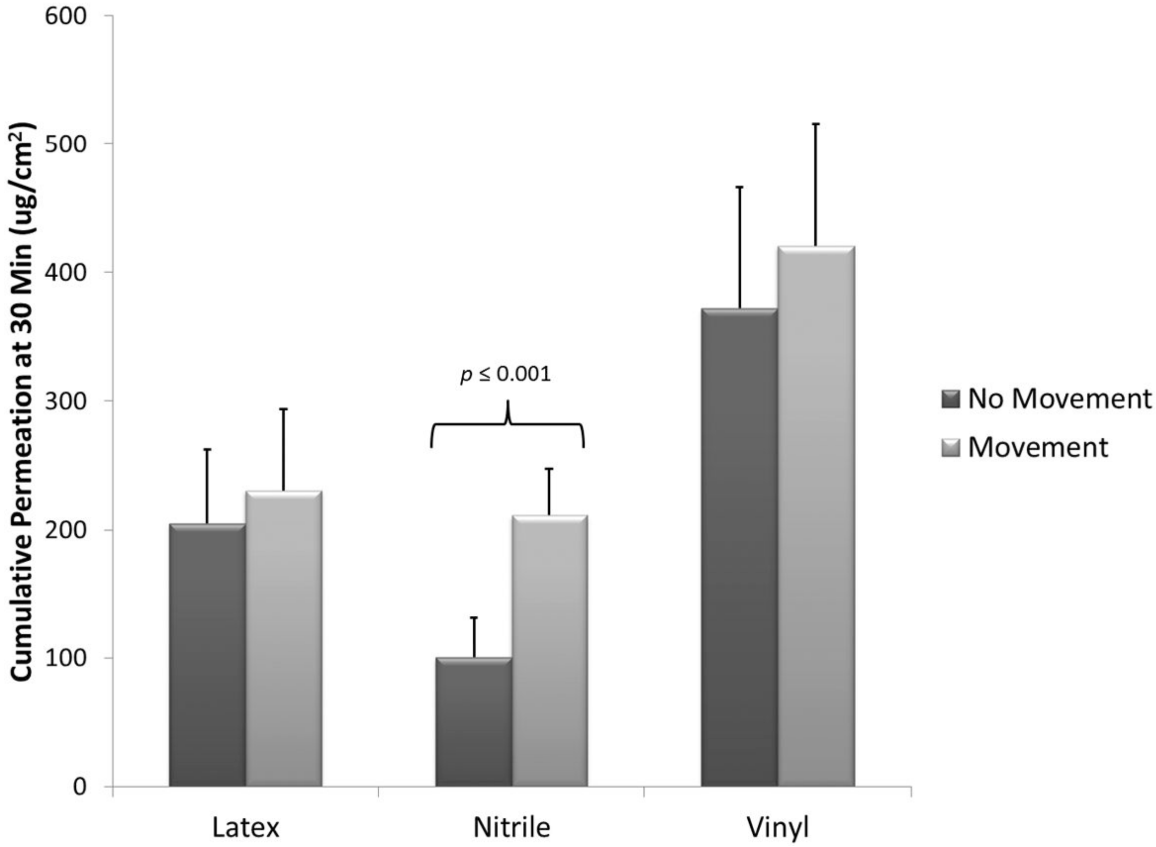

FIGURE 3.

Cumulative permeation at 30 minutes (CP_{30}) for different glove types, no movement versus movement. Significant increases in CP_{30} are shown with brackets. A significant increase in CP_{30} was only observed with the nitrile glove.

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TABLE I

Glove Brand and Thickness

Manufacturer/Brand	Reported Palm Thickness (mil)	Number of Permeation Tests Performed[A]
Fisherbrand® Latex	5	40
Safety Choice Nitrile	4	40
Safety Choice Vinyl	4	54

[A] The sample sizes were adjusted to detect a 10 percent change in permeation parameters upon exposure to movement, using a *t*-test. The tests were matched-paired and 50% were not exposed to movement and 50% were exposed to movement.