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The Use of Aldehyde Indicators to Determine Glutaraldehyde and Alkaline Glutaraldehyde Contamination in Chemical Protective Gloves

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Abstract The aim of this study was to assess the use of aldehyde indicator pads for detection of glutaraldehyde and alkaline glutaraldehyde permeation through chemical protective gloves under simulated in-use conditions. The quantitative analysis of glutaraldehyde permeation through a glove material was determined for Metricide, Wavicide, and 50% glutaraldehyde following a solvent-desorption process and gas chromatographic analysis. All glutaraldehyde solutions exhibited >99% adsorption (including both the glutaraldehyde oligomers of the reaction product and the excess glutaraldehyde) on the pads over the spiking range 0.05–5.0 μL. Breakthrough times for protective gloves were determined using the Thermo-Hand test method, and found to range from 76 to 150, from 170 to 230, and from 232 to 300 min for Metricide, Wavicide, and 50% glutaraldehyde, respectively. Glutaraldehyde recovery was calculated and ranged from 61 to 80% for all glutaraldehyde solutions. The mass of glutaraldehyde in these solutions at the time of breakthrough detection ranged from 17 to 18, from 18 to 19, and from 19 to 20 μg/cm^2 for Wavicide, 50% glutaraldehyde solution, and Metricide, respectively. Aldehyde indicator pads and the Thermo-Hand test method together should find utility in detecting, collecting, and quantitatively analyzing glutaraldehyde permeation samples through chemical protective gloves under simulated in-use conditions.

Glutaraldehyde (1,5-pentanedial) is a colorless, nonflammable liquid at room temperature, and a weak acid. Some glutaraldehyde solutions change color when an activating solution is added. Glutaraldehyde formulations in buffered alkaline solutions (pH 7.5–8.5) are a highly effective microbicidal agent (Goncalo et al. 1984). Glutaraldehyde solution in water and alkaline glutaraldehyde solutions, such as Cidex, Aldesen, Procide, Omnicide, Sonacide, Metricide, Wavicide, and Cytylcide-G, are used widely in a variety of industries. In the chemical industry, glutaraldehyde is used as an intermediate agent to synthesize pesticides, tan soft leathers, and produce adhesives and electrical products (Goncalo et al. 1984). In the health-care industry, glutaraldehyde is used as a cold disinfectant, to process X-ray film, to fix tissues for microscopy, and in dental materials (Goncalo et al. 1984; Hathaway et al. 1996).

Aldehydes are strongly irritating to the nose, eyes, and skin, and can cause allergic contact dermatitis from occasional or incidental occupational exposure (Goncalo et al. 1984; Hathaway et al. 1996; Hansen 1983; Fisher 1981). Chemical-resistant gloves and protective clothing are routinely employed to prevent skin exposure of workers to hazardous chemicals in the workplace (OSHA 1994; Boeniger and Klingner 2002). Chemical-resistant gloves are typically selected based on manufacturers' recommendations. However, many workplace variables influence glove performance, including flexing, increased temperature, and differences between glove manufacturers and

The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health (NIOSH). Mention of company names or products does not constitute endorsement by the NIOSH.

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production lots. Moreover, the absorption of chemicals through the skin varies widely among different chemicals and cannot be fully predicted based on the physical and chemical properties of the chemicals. Limited laboratory test data cannot address all these variables (Ehntholt et al. 1989; Zellers and Sulewski 1993).

An aldehyde indicator pad has been developed (Vo et al. 2007) and is available from our laboratory (NIOSH/NPPTL, Pittsburgh, PA) for research purposes. The aldehyde pad uses a methyl red-glyceryl complex (a methyl red-glyceryl complex containing 0.035% methyl red reagent, 8% glycerine, 0.7 mM NaOH, 42% methanol, and 50% water) and was designed to be responsive to contact by an aldehyde or aldehydes to produce an extended conjugation of the azo complex structure (Vo et al. 2007). The azo-complex compound containing a delocalized positive charge form caused the color change in the indicator from yellow to red. The detailed chemical reaction mechanism and detection limits of the indicator pad have been published elsewhere (Vo et al. 2007). The concept is that if workers wear an indicator pad, they would be able to detect contamination more quickly and learn to protect themselves from increased skin exposure to these toxic chemicals by changing their gloves more frequency. Recently, several laboratory studies on the development and performance of colorimetric indicators have been published that might show promise for use in glove testing (Vo et al. 1999, 2000; Vo and Berardinelli 1999; Klingner 1999; Vo 2002, 2004). In addition to colorimetric indicators, dermal monitoring to simulate workplace conditions could be used to evaluate glove performance under in-use conditions and could bridge the gap between laboratory data and actual workplace performance. Herein, we report test results for the previously developed indicator pad for glutaraldehyde and alkaline glutaraldehyde for application to the permeation of chemical protective gloves under simulated in-use conditions using the Thermo-Hand test method (Vo 2004).

Materials and Methods

Chemicals and Colorimetric Indicator Pads

Metricide (glutaraldehyde, 2.50%; activator, Procide-D, 3.92%; inert ingredients, 93.58%) and Wavicide (glutaraldehyde, 2.65%; inert ingredients, 97.35%) were purchased from Metrex Research Corp. (Romulus, MI). A 50% (wt/wt) glutaraldehyde solution in water was obtained from a commercial supplier (Aldrich Chemical, Milwaukee, WI). Aldehyde indicator prototype sensor pads (circle shape, 1.9-cm diameter) had been previously developed in our laboratory (Vo et al. 2007) and were used for this study.

Selected Gloves and Apparatus

The two types of gloves (nonlatex and copolymer) selected for this study are identified in Table 1. These glove types are known to exhibit faster breakthrough times by polar chemicals (Vo and Berardinelli 1999) and were selected for evaluating aldehyde indicator pad performance. In practice, the thicker gloves are recommended for use when working with particular aldehyde chemicals (www.cdc.gov/niosh/ncpc/ncpc2.html; Recommendations for Chemical Protective Clothing: A Companion to the NIOSH Pocket Guide to Chemical Hazards: Database).

An Ames (Waltham, MA) 214-10 micrometer with a pressure foot of 1 cm was used to determine the thickness of each glove. A CEM (Matthews, NC) MES-100 microwave extraction (ME) system was used to extract glutaraldehyde from pads. Savillex vials (3-mL vials; part no. 221253) were purchased from CEM. These vials can be covered during heating to prevent evaporation loss. A Perkin-Elmer (Norwalk, CT) gas chromatographic (GC) system, which consisted of a PE Nelson Model 1022 Personal Integrator and an AutoSystem gas chromatograph with a flame ionization detector (FID), was used to analyze chemicals. The Thermo-Hand apparatus (Fig. 1) which consisted of a temperature-controlled incubator (Model

Table 1 Results of glove thickness and glove materials used in the glutaraldehyde permeation study

Glove type	Glove material	Batch, lot, or catalog no.	Manufacturer	Thickness (finger; mm)[a]	Thickness (palm & cuff; mm)[a]
Nonlatex gloves	Polyvinyl chloride (PVC)	Lot no. 401222S Cat. no. 484403	Maxxim Medical, Inc. (Clearwater, FL)	0.15 ± 0.02	0.13 ± 0.02
Copolymer gloves	Purple nitrile, polymer-coated (polymerized alkenes), powder-free	Batch no. 712148 Lot no. 7233 Cat. 40101-334	Kimberly-Clark ([Roswell, GA]; distributed by VWR Scientific Products)	0.16 ± 0.02	0.13 ± 0.02

[a] Mean thickness ± SD ($n = 4$)

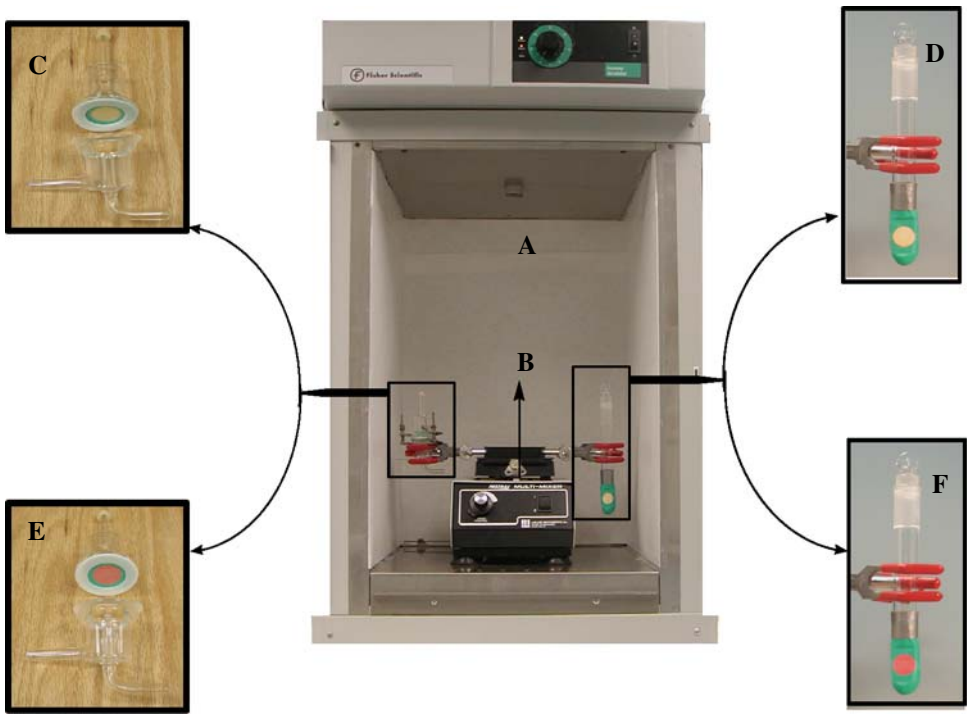

Fig. 1 Chemical permeation test configuration under simulated in-use conditions. The temperature-controlled incubator (**a**) to simulate the hand's skin temperature at 34°C. The multimixer shaker (**b**) to simulate hand movements. The 2.5-cm permeation cell (**c**) used for breakthrough time testing for the palm and cuff of gloves. The glass cylinder (**d**) used for breakthrough time testing for the finger of gloves. Glutaraldehyde indicator sensor pads with a yellow color (**c** and **d**); on exposure to glutaraldehyde, these pads changed color to red (**e** and **f**)

550D; Fisher Scientific, Pittsburgh, PA), a multimixer shaker (Model 4605; Lab-Line Instruments Inc., Melrose, IL), a 2.5-cm-diameter glass cell and a glass cylinder (AMK Glass Company, Vineland, NJ), and colorimetric indicator sensor pads, was used to determine breakthrough detection time for the glove materials. This apparatus simulates human hand temperature and hand movement (Vo 2004).

Assay Development

Spiking Pads and Blank Determination

New pads were removed from sealed packages and the adhesive areas removed with forceps. Known volumes of each glutaraldehyde solution (0.05–5.0 μL; five volume levels were used for each glutaraldehyde solution and sample size for each volume level; $n = 4$; Table 2) were spiked directly onto the surface of the pads (Rowell et al. 1997; Vo et al. 1999) using precision sampling syringes (0–1.0 and 0.1–5.0 μL; Precision Sampling Corp., Baton Rouge, LA). The pads were dipped into 300 μL of distilled water (water was used as an extraction solvent for the entire glutaraldehyde study) in the Savillex vials. The vials were then used for the extraction process and GC analysis. Blank determinations (to determine if there was any pad-media interference) were performed using the same procedure but without exposing the pads to any glutaraldehyde solution.

The ME Process and GC Analysis

The ME-GC procedure was run according to the method of Vo (2002) as follows. The closed vials of each glutaraldehyde solution were immersed in 25 mL of water in extraction vessels. The vessels were then placed in the MES-100 system and extracted for 15 min at 100°C, 70 psi, and 60% power. The extracted solutions were allowed to cool to room temperature for 20 min before opening the vial caps for GC analysis in order to obtain maximum recovery of these chemicals without evaporation loss. The optimum GC conditions were as follows: column, 3.05 m × 3.18-mm id, 3% SP-1500 on 80- to 120-mesh Carbopack B (Supelco, Bellefonte, PA); helium flow rate, 25 mL min^{-1}; oven temperature, 180°C; column temperature, 180°C; temperature of the flame ionization detector (FID), 240°C; and data collection time, 0–15 min. Volumes of 5 μL of extracted samples of spiked glutaraldehydes were injected into the GC column using a syringe.

Efficiency of Adsorption During Glutaraldehyde Spiking

To assess whether complete adsorption of each glutaraldehyde (including the glutaraldehyde oligomers of the reaction product and the excess glutaraldehyde) was accomplished during spiking on pads, two Savillex vials were used. In the first vial, 0.05–5.0 μL of each glutaraldehyde solution was added onto a pad and the vial was

Table 2 Percentage recovery of three commonly used glutaraldehyde and alkaline glutaraldehyde solutions

Glutaraldehyde solution (retention time)	Volume of glutaraldehyde solution applied to pads (μL)	Volume of glutaraldehyde in solution applied to pads (μL)	Mean of spiked peak areas (×100)	Recovery (%; mean ± SD; $n = 4$)
Wavicide; 2.65% glutaraldehyde solution, pH 6.20 (10.68 min)	1.00	0.026	8.10	64 ± 2
	2.00	0.052	20.4	67 ± 2
	3.00	0.078	32.6	71 ± 2
	4.00	0.104	45.6	75 ± 2
	5.00	0.130	59.2	80 ± 3
50% glutaraldehyde solution in water, pH 3.76 (10.68 min)	0.05	0.025	7.40	63 ± 2
	0.10	0.050	18.5	66 ± 2
	0.15	0.075	29.4	70 ± 2
	0.20	0.100	41.6	73 ± 2
	0.25	0.125	53.3	78 ± 3
Metricide-G; 2.50% glutaraldehyde solution, pH 7.92 (10.68 min)	1.00	0.025	6.50	61 ± 2
	2.00	0.050	16.8	63 ± 2
	3.00	0.075	26.4	67 ± 2
	4.00	0.100	38.1	71 ± 2
	5.00	0.125	48.1	76 ± 3

Note. Five-hundredths microliter to 5 μL of each glutaraldehyde solution was added to pads ($n = 4$); 300 μL of water was used to extract glutaraldehyde solution; 5 μL of the extracted solutions was analyzed by GC

covered with the vial cap. The vial was left at room temperature for 20 min before the pad was dipped into 300 μL of distilled water in the second vial. Then 300 μL of distilled water was added directly to the first vial to extract excess glutaraldehyde, which did not adsorb on the spiked pad. These vials were then used for the extraction process and GC analysis.

Glutaraldehyde Recovery

Standard glutaraldehyde determinations were performed using the same spiked glutaraldehyde procedure, but without using pads. The known volume of each glutaraldehyde solution (0.05–5.0 μL) was added directly to 300 μL of distilled water in the vials. These vials were then used for the extraction process and GC analysis. The areas of the standard peaks in the resulting gas chromatograms were used for standard glutaraldehyde determinations. Glutaraldehyde recovery was calculated as the percentage of spiked glutaraldehyde peak area (the area of the desorbed-glutaraldehyde peak with the indicator pad) divided by the standard glutaraldehyde peak area (the area of the glutaraldehyde peak without the indicator pad).

Glove Thickness Measurement and Glove Breakthrough Time Determination

Glove Thickness Measurement

The thickness of each glove was measured at three positions: the palm, the entire middle finger, and the cuff (3 cm from the open end). These three positions are the areas of highest glove abrasion, which enhances chemical permeation. Four thickness measurements ($n = 4$) for each position on the glove were recorded, and the mean thickness and variation were calculated. All measurements were made to the nearest ±0.01 mm.

Glove Breakthrough Time Determination

The Thermo-Hand method was chosen for glove breakthrough time determination over the modified ASTM F739 method (Vo et al. 2001). Unlike the ASTM F739 method, the Thermo-Hand method was designed to simulate human hand temperature and hand movement (Vo 2004). Second, in previous work in our laboratory using the ASTM F739 permeation method, a significant visible color change was detected for glutaraldehyde about 5 min before the infrared analyzer responded (Vo et al. 2007). Glutaraldehyde with a low vapor pressure gave the impression of longer than actual breakthrough times because it took longer time to travel along closed loop before reaching the IR analyzer detector (Vo et al. 1999).

Breakthrough times of glove sections from the palm and the cuff were determined. The permeation cell is divided into two chambers, called the 'challenge side chamber,' which contains the test chemicals, and the 'collection side chamber,' which contains an indicator pad (Fig. 1c). A glove membrane (sections from the palm and the cuff of the gloves) separated the two side chambers of the cell, with the outer surface toward the challenge side chamber of the cell. An indicator pad was attached to the inner surface of the

glove section with clear plastic tape (the parafilm was placed under the plastic tape, so the pad could be easily removed from the glove for quantification). The chemical permeation test system was kept in a temperature-controlled incubator at 34°C (Fig. 1a). A 15-mL volume of each glutaraldehyde or alkaline glutaraldehyde solution was injected into the challenge side chamber of the cell using a 30-mL glass syringe. A multimixer shaker (Fig. 1b) used to simulate hand movements (Vo 2004) was operated at a controlled speed (the glove materials in the Thermo-Hand method are simply shaken without stretching glove materials). Then a timer was immediately started (within 15 s). Permeation of each glutaraldehyde solution through glove sections from the palm and the cuff was detected by the change in the color of the pads (Fig. 1e). Breakthrough time was recorded, and the pads were immediately removed (within 10 s) from the glove for the extraction process and GC analysis.

Breakthrough detection times of the finger portion of gloves were also determined. A finger of the gloves was turned inside out and a pad was attached to the finger. The glove finger was then fastened to a glass cylinder (2 × 15 cm) with duct tape at the open end of the glove finger as the attachment area. The glass cylinder served as a fill tube (Fig. 1d). A 10-mL volume of each glutaraldehyde solution was injected into the glass cylinder, and a timer was immediately started (within 15 s). Permeation of each glutaraldehyde solution through the glove finger was detected by the change in color of the pads (Fig. 1f). Breakthrough time was recorded, and the pads were immediately removed (within 10 s) from the glove for the extraction process and GC analysis.

Quantitative Determination of Glutaraldehyde

Each glutaraldehyde or alkaline glutaraldehyde solution (including the excess glutaraldehyde and the glutaraldehyde oligomers of the reaction product) in the closed vials collected under the Thermo-Hand test method were extracted, and 5 μL of extracted samples was subjected to GC analysis as described above. The concentration of each glutaraldehyde solution was determined against a known concentration of spiked glutaraldehyde solution based on its linear equation and the degree of each glutaraldehyde solution recovery.

Results

Pad Sensitivity and GC Data Analysis

Results from this study showed that the aldehyde indicator pad was very sensitive for detecting the presence of glutaraldehyde or alkaline glutaraldehyde solutions with the small amount of 0.05 μL of glutaraldehyde solutions applied onto the pads. This volume level represents 0.025 μL for glutaraldehyde in each solution (Table 2). Glutaraldehyde causes the pads to change color from yellow to red. The pad was designed to be responsive to contact by glutaraldehyde to produce a visible color indication.

Good resolution (peaks did not overlap) of glutaraldehyde, activator, and alkaline ingredients was achieved by setting the optimum GC conditions as described above. None of the blanks (unexposed pads in the extraction solvent) produced chromatograms containing peaks corresponding to glutaraldehyde used in this study. The GC retention times and peak areas for each glutaraldehyde and alkaline glutaraldehyde solution obtained under these conditions are listed in Table 2.

Efficiency of Adsorption During Glutaraldehyde Spiking

The amount of glutaraldehyde which did not adsorb on the spiked pads in the first vial was low, being <1% for all glutaraldehyde solutions (the area peaks found in vial 2 were 0.10, 0.15, and 0.12% of the area peaks found in vial 1 for Metricide, Wavicide, and 50% glutaraldehyde, respectively). Generally, all glutaraldehyde and alkaline glutaraldehyde solutions exhibited >99% adsorption (including the excess glutaraldehyde and the glutaraldehyde oligomers of the reaction product [Vo et al. 2007]) on the pads at spiking levels of 0.05–5.0 μL for each solution.

Glutaraldehyde Recovery

The relationship between signals (peak area) on the gas chromatograms and volumes over the range 0.05–5.0 μL of each glutaraldehyde solution applied onto pads was analyzed using Microsoft Excel software. These volumes represent 0.025–0.130 μL for glutaraldehyde in each solution (Table 2). The best linear correlation for glutaraldehyde in each solution was obtained over the range 0.025–0.130 μL ($n = 4$). The best straight-line fit from linear analysis of the data is also shown in Fig. 2 (Fig. 2a, Wavicide, $R^2 = 0.9967$; Fig. 2b, 50% glutaraldehyde, $R^2 = 0.9964$; Fig. 2c, Metricide, $R^2 = 0.9968$). For experiments performed with the extraction process and GC measurements, recoveries from 61 to 80% (RSD < 4%) were obtained over the range 0.05–5.0 μL for each glutaraldehyde solution applied to the pads (Table 2).

Glove Thickness Measurement and Glutaraldehyde Permeation Determination

Table 1 summarizes the results obtained for the mean thickness of four thickness measurements for each type of

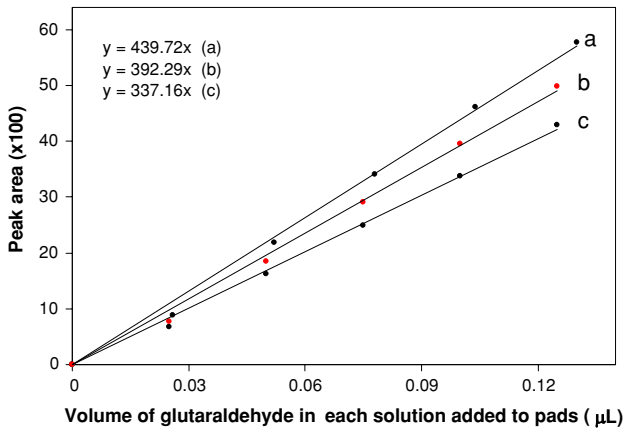

Fig. 2 Calibration plots of peak areas against volumes of glutaraldehyde in each solution added onto pads following the extraction process (the source of the data in Table 2). Volumes of 5 µL of extracted solution were subjected to GC analysis. The best linear correlation for glutaraldehyde in each solution was obtained over the range 0.025–0.130 µL ($n = 4$). The best straight-line fit from linear analysis of the data is also shown. (a) Wavicide, $R^2 = 0.9967$; (b) 50% glutaraldehyde, $R^2 = 0.9964$; (c) Metricide, $R^2 = 0.9968$

glove. Table 3 reports the breakthrough times for all of the gloves tested using the Thermo-Hand method. Permeation of each glutaraldehyde solution through the gloves was detected by the change in color of the pads. Different breakthrough times were obtained for different glove materials or glutaraldehyde solutions. PVC and polymerized alkene glove materials exhibited slow permeation with Wavicide and 50% glutaraldehyde but showed faster permeation with Metricide (Table 3).

Quantitative Determination of Each Glutaraldehyde Solution

The volumes of each glutaraldehyde solution on a circular pad at the point of permeation detection were determined, ranging from 0.028 to 0.029, from 0.029 to 0.03, and from 0.03 to 0.031 µL for Wavicide, 50% glutaraldehyde solution, and Metricide, respectively (based on glutaraldehyde recoveries and their linear equations in Fig. 2). These volumes represent 17–18, 18–19, and 19–20 µg/cm^2 for Wavicide, 50% glutaraldehyde solution, and Metricide, respectively (1.9-cm-diameter circular pads were used for this study; Fig. 1).

Discussion

The aldehyde indicator pad contains a methyl red-glyceryl complex which reacts directly with aldehydes to produce a color change from yellow to red. Results of this study showed that the aldehyde indicator pad was very sensitive for detecting the presence of glutaraldehyde or alkaline glutaraldehyde solutions applied onto pads with as little as 0.025 µL of glutaraldehyde in each solution.

The results (Table 2, rightmost column) obtained with the solvent desorption-GC procedure were consistent in reproducible recovery, with results ranging from 61 to 80% (RSD $< 4\%$) for the test glutaraldehyde solutions over the spiking range 0.05–5.0 µL. The recovery of each glutaraldehyde solution was dependent on the volume of each glutaraldehyde solution applied onto the pads. The recovery was low at a small volume of each glutaraldehyde solution applied onto the pads, but increased with increasing volume. A possible explanation for the low recovery at small volumes is that the glutaraldehyde could undergo self-aldol condensation and react with the indicator to contribute the color change and to yield the glutaraldehyde oligomers and other products (Vo et al. 2007). It is also probable that the glutaraldehyde bound strongly with the indicator pad (the indicator-glycerine complex) or the pad materials such as polysaccharides (Vo et al. 2007), either binding or hydrogen-bonding to give low desorption of glutaraldehyde. Even with the lower than expected recoveries, excellent linear correlations were obtained over the spiking range 0.05–5.0 µL on pads for these glutaraldehyde solutions using 5.0 µL of the extracted solutions for GC analysis.

The results of the permeation experiments demonstrated that, within a given material type of the gloves tested, the

Table 3 Breakthrough time (BT) and the mass of Metricide, Wavicide, and 50% glutaraldehyde on indicator pads at BT

Glove type	Finger-glove BT[a] of Metricide (palm-cuff BT)[b]	Mass of glutaraldehyde in Metricide (µg/cm^2)	Finger-glove BT[a] of Wavicide (palm-cuff BT)[b]	Mass of glutaraldehyde in Wavicide (µg/cm^2)	Finger-glove BT[a] of 50% glutaraldehyde (palm-cuff BT)[b]	Mass of glutaraldehyde in 50% solution (µg/cm^2)
Nonlatex gloves	150 ± 6 min (129 ± 5 min)	19 ± 1	230 ± 6 min (198 ± 5 min)	17 ± 1	300 ± 8 min (250 ± 7 min)	18 ± 1
Copolymer gloves	96 ± 6 min (76 ± 6 min)	20 ± 1	210 ± 5 min (170 ± 6 min)	18 ± 1	288 ± 7 min (232 ± 8 min)	19 ± 1

[a] BT of the finger portion of the gloves was detected by the change in color of indicator pads

[b] BT of the palm and the cuff sections of the gloves was detected by the change in color of indicator pads

thicker gloves had the longer breakthrough time for the glutaraldehyde solution. Differences in glove materials or different glutaraldehyde solutions yielded different breakthrough times. For both PVC and polymerized alkene glove materials, slow permeation by a 50% glutaraldehyde solution was observed, whereas Metricide showed faster permeation. The slow permeation by the 50% glutaraldehyde solution can be explained by the presence of the hydrogen bond between water and glutaraldehyde molecules (each molecule of glutaraldehyde can form four hydrogen bonds to water molecules). These hydrogen bonds account for some of the essential and unique properties of the glutaraldehyde solution by forming a larger water-glutaraldehyde complex. The larger water-glutaraldehyde complex directly limits the glutaraldehyde molecule to travel freely in the solution and permeate easily through chemical protective glove surfaces, which would decrease the glutaraldehyde permeation rate (for the Wavicide solution with 2.65% glutaraldehyde and 97.35% inert ingredients, the inert ingredients do not change the physical and chemical properties of the Wavicide solution). The faster permeation by Metricide can be explained by the presence of 3.92% activator in the Metricide® solution because the alkaline glutaraldehyde activator would dissolve quickly in the solution and allow the glutaraldehyde molecule to travel freely in the solution, which would increase the glutaraldehyde permeation rate.

The data obtained from GC analysis for test glutaraldehyde solutions on the indicator pads, ranging from 17 to 18, from 18 to 19, and from 19 to 20 μg/cm^2 for Wavicide, 50% glutaraldehyde solution, and Metricide, respectively, indicated that these glutaraldehyde solutions can be detected on the pads at the breakthrough times. The fact that the amounts of permeant detected in each glove test for different glutaraldehyde solutions were consistent indicates that the aldehyde indicator pads performed consistently in collecting similar amounts of glutaraldehydes during the time before breakthrough detection occurred, regardless of glove type. The amounts of glutaraldehyde (17–20 μg/cm^2) permeated evenly over the whole surface of the pad in this study were also consistent with the data on glutaraldehyde detected using a liquid-glutaraldehyde spiking procedure from our previous study (5 μg/one spot or about 20 μg/cm^2 with a spot diameter = 0.56 cm [Vo et al. 2007]).

Based on the promising results described, future research is necessary to determine whether pads placed on the inside of the glove and used by a worker in the actual workplace can be used to detect, collect, and quantify a permeating chemical. It is important to evaluate these pads for these uses in the workplace. Use of an aldehyde indicator pad for the detection of glutaraldehyde and alkaline glutaraldehyde permeating through chemical protective gloves is a relatively new technology and should be explored further by major chemical protective glove manufacturers.

Conclusions

The results presented in this research indicate that the aldehyde indicator pad was very sensitive in detecting the presence of glutaraldehyde or alkaline glutaraldehyde solutions. These pads can be easily affixed to the palm, cuff, and finger of gloves under simulated in-use conditions, and a permeating aldehyde chemical can be detected and collected. Pads exposed to the glutaraldehyde solutions can be successfully analyzed by solvent desorption and GC analysis. The new aldehyde indicator pads and the Thermo-Hand test method together should find utility in detecting, collecting, and quantitatively analyzing glutaraldehyde permeation samples through chemical protective gloves under simulated in-use conditions.

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References

Boeniger M, Klingner T (2002) In-use testing and interpretation of chemical-resistant glove performance. Appl Occup Environ Hyg 17:368–378. doi:10.1080/10473220252864978

Ehntholt D, Bodek I, Valentine JR (1989) The effects of solvent type and concentration on the permeation of pesticide formulations through chemical protective glove materials. In: Perkins JL, Stull JO (eds) Chemical protective clothing performance in chemical emergency response, ASTM STP 1037. American Society of Testing and Materials, Philadelphia, PA

Fisher AA (1981) Reaction of glutaraldehyde with particular reference to radiologists and X-ray technicians. Cutis 28:113–122

Goncalo S, Brandao M, Pecegueiro M, Moreno A, Sousa I (1984) Occupational contact dermatitis to glutaraldehyde. Contact Dermat 10:183–184. doi:10.1111/j.1600-0536.1984.tb00033.x

Hansen KS (1983) Glutaraldehyde occupational dermatitis. Contact Dermat 9:81–82. doi:10.1111/j.1600-0536.1983.tb04639.x

Hathaway GJ, Proctor NH, Hughes JP (1996) Proctor and Hughes' chemical hazards of the workplace, 4th edn. John Wiley and Sons, New York

Klingner T (1999) Device and method for detecting chemical breakthrough of protective clothing. US Patent 5,976,881, 2 Nov 1999

OSHA (1994) U.S. Occupational Safety and Health Administration: personal protective equipment for general industry, final rule. CFR 59, No. 66, pp. 16334–16364

Rowell FJ, Fletcher A, Pachham C (1997) Recovery of some common solvents from an adhesive commercial skin adsorption pad by thermal desorption-gas chromatography. Analyst 122:793–796. doi:10.1039/a700917h

Vo E (2002) A new technique to determine organic and inorganic acid contamination. Analyst 127:178–182. doi:10.1039/b106282b

Vo E (2004) Application of colorimetric indicators and thermo-hand method to determine base permeation through chemical protective gloves. J Occup Environ Hyg 1:799–805. doi:10.1080/15459620490887048

Vo E, Berardinelli S (1999) Determination of alkylamine permeation through protective gloves using aliphatic amine pads. J Environ Monit 1:545–548. doi:10.1039/a906477j

Vo E, Berardinelli S, Hall R (1999) Recovery of some common solvents from protective clothing breakthrough indicator pads by microwave-solvent extraction and gas chromatography. Analyst 124:941–944. doi:10.1039/a809248f

Vo E, Berardinelli S, Hall R, Ayouby N (2000) A quantitative study of aromatic amine permeation through protective glove using amine adsorptive pads. Am Ind Hyg Assoc J 61:837–841. doi:10.1202/0002-8894(2000)061<0837:AQSOAA>2.0.CO;2

Vo E, Berardinelli S, Boeniger M (2001) The use of 3M porous polymer extraction discs in assessing protective clothing chemical permeation. J Appl Occup Environ Hyg 16:729–735. doi:10.1080/10473220152403655

Vo E, Murray D, Scott T, Attar A (2007) Development of a novel colorimetric indicator for detecting aldehydes. Talanta 73:87–94. doi:10.1016/j.talanta.2007.03.014

Zellers E, Sulewski R (1993) Modeling the temperature dependence of *N*-methylpyrrolidone permeation through butyl-and natural rubber gloves. Am Ind Hyg Assoc J 54:465–479. doi:10.1080/15298669391354991