STUDY

Optimizing Skin Protection with Semipermeable Gloves

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Background: **Occlusion due to gloves is one important cause of glove irritation. Macerated softened skin gives poor protection against microbes and chemical injuries. The introduction of a breathable protective glove material would represent a significant step toward improved prevention of occupational skin disease.**

Objective: **Performance levels of semipermeable and occlusive gloves were examined under conditions typical of the hairdressing profession. In two studies, tests comparing breathable semipermeable gloves to single-use gloves made of occlusive materials were conducted.**

Methods: **In an initial study, a user survey was carried out in conjunction with bioengineering examinations. Values at baseline and values after gloves were worn were recorded by measuring transepidermal water loss (TEWL), skin humidity (SH), and skin surface hydrogen ion concentration (pH) in 20 healthy volunteers. In a second study, the gloves were tested for penetrability and permeability with three chemical compounds typically used in the hairdressing profession.**

Results: **Bioengineering examination objectively confirmed users' reports of reduced hand perspiration when semipermeable gloves were worn. The TEWL, SH, and skin surface pH values remained largely stable after 20 minutes of wearing semipermeable gloves, in contrast to the reactions observed with gloves of occlusive materials. Permeability tests indicated that the semipermeable material is effective, with some restrictions. Air leakage testing revealed that all 50 gloves tested were not airtight.**

Conclusion: **Following the optimization of manufacturing methods, additional tests of the penetrability of semipermeable gloves will be necessary.**

MEMBERS OF "WET-WORK" PROFESSIONS that involve frequent contact with water and other fluids (eg, health care professionals, hairdressers, cleaning personnel) are exposed to a number of potentially skin-damaging substances, which can lead to the development of irritant and/or allergic contact dermatitis.[1] Wearing protective gloves is one prophylactic measure for protecting the skin.[2–4] Irrespective of their resistance to chemicals, all materials used for chemical-resistant protective gloves have one considerable disadvantage: wearing these watertight protective gloves for extended periods leads to a buildup of warmth and moisture, the occlusion effect resulting from a virtually airtight seal.[5] The prolonged wearing of protective gloves can also cause alkalization of sweat, resulting in secondary damage to the skin (maceration of the tissue).[6,7] Occlusion alone can thus provoke skin irritation and often exacerbates cases of existing dermatosis.[5,8–10] One method of limiting the occlusive effect of protective gloves is to wear cotton gloves under them.[11] In practice, however, few find this solution acceptable as it significantly restricts dexterity and the sense of touch. Perspiration can also be reduced to some degree by applying preparations containing tannin or aluminum chlorohydrate before donning gloves.[12,13] A breathable protective glove material could allow condensation to evaporate through the glove's membrane while preventing water and chemicals from passing through the membrane and coming into contact with the skin. The successful introduction and establishment of a breathable protective glove material would represent a significant step toward improved prevention of occupational skin disease. This study was aimed at testing a semipermeable glove material with regard to its suitability for use in protective gloves used in the hairdressing profession.

Materials and Methods

Study 1: Penetration and Permeation Testing

"Penetration" refers to the passage of chemicals through macroscopic holes or pores (defects or seams). Penetrability can result from a manufacturing process (a material defect) or from faulty or lengthy storage. "Permeation" refers to the migration of chemicals through the protective

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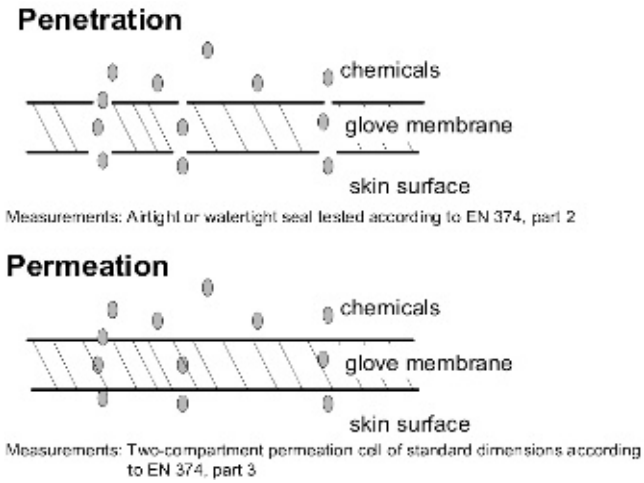


Figure 1. Test parameters for barrier function of protective gloves (penetration and permeation).

glove material on a molecular level (sorption, diffusion, and desorption). This process takes place in three steps: (1) the substance is absorbed and released in the glove membrane, (2) individual molecules are diffused into the glove's interior, and (3) the substance is released into the glove's interior and into the layer of accumulated perspiration on the skin's surface (Fig 1).[14]

The tests were carried out in the research laboratories of the company KCL, in Eichenzell, Germany, according to the European Standard EN 374, "Protective Gloves against Chemicals and Micro-organisms," established by the European Committee for Standardization.[14–16]

Four types of disposable gloves made of nitrile rubber, neoprene rubber, powder-free natural rubber, and latex with a hydrogel-polymer interior coating were tested, along with glove prototypes made of semipermeable material with welded seams (Table 1 lists the manufacturers and names of products used).

Gloves were tested for penetrability and chemical resistance (permeability) when in contact with the following compounds commonly used in the hairdressing profession: "alkaline permanent-wave solution" (consisting of aqua, ammonium thioglycolate, ammonium bicarbonate, ammonia, polyethylene glycol 35 [PEG-35] castor oil, perfume, coceth-10, styrene/polyvinylpyrrolidone copolymer, polyquaternium-6, and sorbic acid);[17] "blonding formula," ammonium persulfate powder and hydrogen peroxide, mixed 1:1 for use (aqua, potassium persulfate, hydrogen peroxide, sodium silicate, disodium phosphate, magnesium carbonate hydroxide, salicylic acid, paraffinum liquidum, phosphoric acid, ammonium persulfate, sodium stearate, methylhydroxyethylcellulose, xanthan gum, *Oryza sativa*, disodium ethylenediaminetetraacetic acid [EDTA], silicia, and CI 77007);[17] and "oxidative hair dye" (aqua, cetaryl alcohol, hydrogen peroxide, glyceryl stearate SE, toluene-2,5-diamine sulfate, sodium laureth sulfate, disodium phosphate, salicylic acid, phosphoric acid, lanolin alcohol, ammonia, resorcinol, 2-amino-4-hydroxyethylaminoanisole sulfate, m-aminophenol, glycol distearate, perfume, sodium cocoyl isethionate, sodium sulfite, ascorbic acid, disodium EDTA, benzoic acid, and tocopherol).[17]

Table 1. Results of Penetration and Permeation Testing with Hairdressing Solutions

Chemical/Product		*Nitrile**	*Neoprene*†	*Latex*‡	*Latex*§	*Semipermeable Membrane*‖
Alkaline permanent-wave solution	BT (min)	> 480	> 480	> 480	> 480	> 480
	Level	6	6	6	6	6
Blonding formula with oxidation solution (1:1)	BT (min)	> 480	> 480	> 480	> 480	60
	Level	6	6	6	6	3
Oxidation hair dye	BT (min)	> 480	> 480	> 480	> 480	45
	Level	6	6	6	6	2
Penetration test results	Leaky (of 100)	—	1	2	2	50 of 50#
	AQL/	0.65	1.5	4.0	4.0	4.0
	Level	3	2	1	1	1

AQL = acceptance quality level; BT = breakthrough time; Level = performance level according to EN 374, parts 2 and 3.
*Dermatril 740 (KCL- Kächele-Kama-Latex, Eichenzell, Germany).
†Derma Prene 85-1119-0 (Ansell Professional Healthcare, Cergy, France).
‡Solo Plus 995 (Mapa-Professionel, Neully-Sur-Seine Cedex, France).
§Protech (Marigold Industrial, Mönchengladbach, Germany).
‖ Prototype (W.L. Gore, Putzbrunn, Germany).
#Only 50 prototypes of the semipermeable gloves were available for testing.

Testing of the penetrability of the protective gloves was based on an air leakage test performed according to European Standard EN 374, part 2. These results determined acceptance quality level (AQL) values as described in EN 374, part 1, based on the maximum number of faulty (ie, penetrable) gloves in a lot.[15] Table 2 lists the AQL values demanded for each level of performance. Fifty semipermeable gloves and 100 gloves of each other type were tested to determine the AQL values. The lower number of semipermeable gloves used in the testing resulted from the limited availability of the prototypes.

Tests to determine breakthrough times for the above-mentioned chemical compounds were conducted according to EN 374, part 3, using standard test cells containing nitrogen.[15] A flame ionization detector was used to detect permeation of molecules from the chemical compounds. Each chemical compound and glove type was subjected to three permeation tests. The levels of performance reached, including the breakthrough times, are listed in Table 3.

Study 2: Bioengineering Parameters

In the course of the research with various glove materials, the skin's reactions to 20 minutes of glove occlusion were observed with regard to relevant bioengineering parameters.

Twenty healthy volunteers (18 female, 2 male) aged 23 to 56 years (average, 33 years) took part in testing. Before research was started, each member of the test group was advised, both orally and in writing, of the World Medical Declaration of Helsinki–Ethical Principles for Medical Research involving Human Subjects.[18] All members of the test group consented in writing to participation in the study.

Protective gloves made of four different materials (powder-free latex, powdered latex, polyvinyl chloride [PVC], and nitrile) were selected for testing. Gloves made of these materials are commonly used in professions involving typical ''wet work'' (eg, hairdressing, health care, cleaning), with the exception of powdered latex gloves, which were recently abandoned (German regulation TRGS 531, for example, prohibits the use of powdered latex gloves).[19] In addition, prototype gloves made with semipermeable membranes were tested.

Table 2. Penetration Testing and Air/Water Leakage Test: Performance Levels* and Acceptance Quality Level Values

Performance Level	*AQL*
3	0.65
2	1.50
1	4.00

AQL = acceptance quality level.
*According to EN 374, part 2 (maximum number of faulty gloves in a lot).[15]

Table 3. Permeation Testing: Protection Indexes and Performance Levels* with Reference to the Determined Breakthrough Times of Tested Chemicals through Glove Membranes

Performance Level	*Protection Index (min)*
6	480
5	240
4	120
3	60
2	30
1	10

*According to EN 374.[15]

A Tewameter TM 210 (Courage + Khazaka Electronic GmbH, Cologne, Germany) was used to determine transepidermal water loss (TEWL), according to the guidelines from the Standardization Group of the European Society of Contact Dermatitis.[20,21]

Electrical capacitance, which indicates the hydration level of the epidermis (skin humidity [SH]), was measured by standard procedures with a Corneometer CM 820 PC (Courage + Khazaka).[22] To determine skin surface hydrogen ion concentration (pH) levels, a Skin pH Meter PH 900 (Courage + Khazaka) was used. The measuring methods used have been described in detail by Post and colleagues[23] and by Tronnier.[24]

One protective glove was tested per test session and test person (a maximum of two test sessions per test person per week, five sessions per test person). The glove to be tested during a given session was chosen through random selection. Following an acclimatization phase of 30 minutes, baseline values of TEWL, SH, and pH were measured on the dorsal and palm areas of the hand. All above-mentioned test parameters were measured directly after occlusion (removal of gloves) as well as at 5-, 10-, 20-, and 30-minute intervals subsequent to occlusion.

Survey of Users

The 20 volunteers were asked to carry out various tasks (eg, picking up small objects) while wearing the protective gloves. The glove users filled out a standardized structured questionnaire during and after each practical test and again following the completion of the test cycle. The questions addressed each glove's fit, along with the sense of touch while wearing it, rated according to a scale from 1 (excellent) to 6 (poor). Further, self-reported levels of perspiration inside the gloves, as well as incompatibility

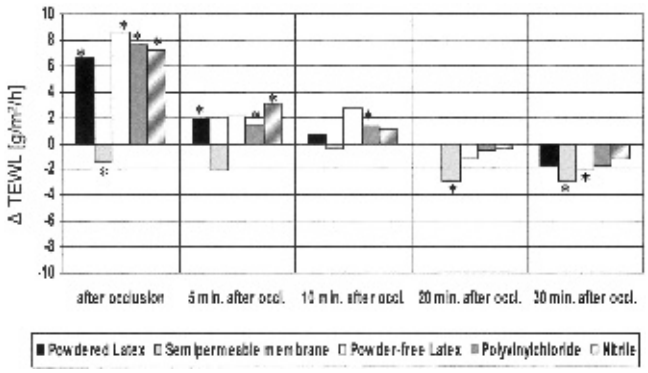


Figure 2. Changes in transepidermal water loss (TEWL). Graphs show differences from baseline values (Δ TEWL) immediately, 5, 10, 20, and 30 minutes after glove occlusion ($n = 20$) ($^*p < 0.01$).

and discomfort, were recorded during and after the wearing of the gloves. A final survey was conducted subsequent to the completion of the test cycle, aimed mainly at establishing preferences for (and deficits of) individual materials in direct comparison.

Statistics

Statistical analysis was conducted with *SPSS* software (SPSS Inc., Chicago, IL) for *Windows 8.0* (Microsoft Corporation, Redmond, WA). The median and the interquartile range were chosen as the standards for the descriptive statistics. As the distribution of data did not result in a normal distribution curve, differences between baseline values and values measured after occlusion were checked for significance by using the Wilcoxon test for paired data. For the graphic illustration of differences between values measured before and after wearing the gloves, Δ values were established for the physiologic parameters of the skin. Baseline values were subtracted from the values indicated by test results. Positive Δ values thus characterize increases in relation to baseline values whereas negative Δ values indicate decreases compared to baseline values. The chosen level of significance was $p \leq 0.01$. The evaluation of the questionnaires was conducted by manual counting; the resulting data were then structured in descriptive statistical form.

Results

Penetration and Permeation Testing

Table 1 offers an overview of penetration and permeation test results. The penetration test results reveal that four of five gloves tested failed to reach the highest performance level (level 3) with regard to AQL values according to EN 374, part 2. Material-specific penetrability could not be determined; gloves made of neoprene, latex, and latex with a hydrogel-polymer interior lining all performed unsatisfactorily. Gloves made with the following three materials received the poorest rating (level 1) for penetration: latex, latex with a hydrogel-polymer interior lining, and the semipermeable membrane. One glove, made of neoprene, reached the middle rating (level 2). Only the nitrile glove proved impenetrable and was given the highest rating (level 3).

Results of permeation tests with chemical compounds used in the hairdressing profession indicate that all currently available disposable gloves tested are suitable for handling the products used in testing. In no case did the test chemicals permeate the glove material during 480 minutes of testing. The prototypes made of the semipermeable material also proved impermeable to the ''alkaline permanent-wave solution'' over a 480-minute test period. In this case, the semipermeable gloves were also rated 6 for protection, the highest performance level for the permeation test parameter. In testing with the chemical ''blonding formula'' (mixed 1:1 with hydrogen peroxide), permeation of the glove membrane was observed after 60 minutes, for a protection level rating of 3. A breakthrough time of 45 minutes was observed with oxidative hair dye, corresponding to performance/protection level 2.

Bioengineering Parameters

The results of the TEWL, SH, and pH measurements are presented in Figures 2 to 4 as differences from baseline values (Δ values). All data (median values) for the dorsal aspect of the hand are shown in Table 4.

With the exception of the semipermeable membrane, use of all materials tested (powdered latex, powder-free

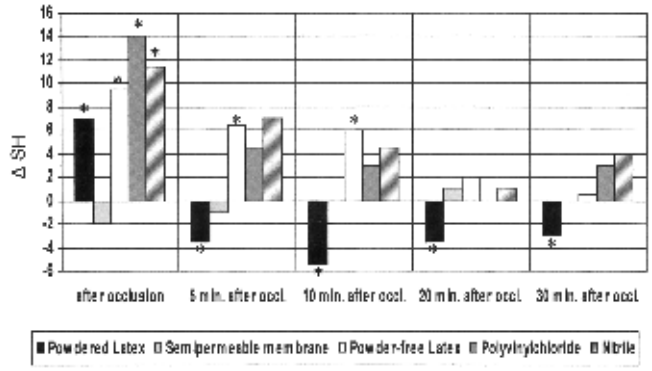


Figure 3. Changes in skin humidity (SH). Graphs show differences from baseline values (Δ SH) immediately, 5, 10, 20, and 30 minutes after glove occlusion ($n = 20$) ($^*p < 0.01$).

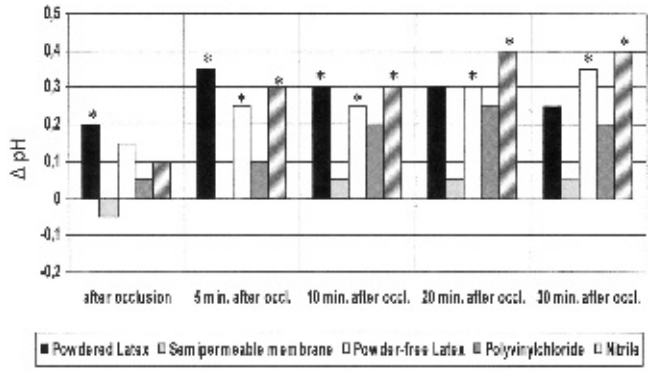


Figure 4. Changes in skin surface hydrogen ion concentration (pH). Graphs show differences from baseline values (Δ pH) immediately, 5, 10, 20, and 30 minutes after glove occlusion ($n = 20$) (*$p < 0.01$).

latex, nitrile, and PVC) led to a significant increase in TEWL values on the dorsal aspect of the hand after 20 minutes of occlusion ($p < 0.01$). TEWL values observed on this area of the hand 30 minutes subsequent to occlusion were lower (insignificantly) than the baseline values measured prior to occlusion. None of the materials tested led to a statistically significant increase in TEWL values on the palm after occlusion (these data are not shown).

Use of all tested materials other than the semipermeable membrane resulted in a significant increase in relative SH values on the dorsal and palm areas of the hand (data for palms are not shown) as compared with baseline values measured prior to occlusion ($p < 0.01$). The SH values on the palm and dorsal aspects of the hand measured before and after the subjects wore the semipermeable gloves remained relatively constant, varying by a maximum of 2.5 SH units (insignificant). With the other materials, a gradual decrease in SH values after occlusion was observed.

With powder-free latex, nitrile, and PVC gloves, SH values returned to baseline value levels. A marked decrease in SH values to below baseline levels, especially on the palm, was noteworthy in the case of the powdered latex gloves (see Fig 3).

The use of protective gloves made of latex (powdered and powder free) and nitrile led to a significant increase in skin surface pH after occlusion ($p < 0.01$). Occlusion with vinyl and semipermeable protective gloves did not significantly influence skin surface pH. Figure 4 shows median values along with the differences between baseline values and skin surface pH values observed at various points in the course of testing.

Table 4. Resulting Median Transepidermal Water Loss, Skin Humidity, and pH Values for Dorsal Aspects of the Hand

			Minutes after Occlusion				
Glove Material	*Parameter*	*Basis*[†]	*0*[‡]	*5*	*10*	*20*	*30*
Powdered latex	TEWL	11.95	18.6*	13.8*	12.65	11.9	10.3
	SH	69.5	76.5*	66.0*	64.0*	66.0*	66.5*
	pH	5.45	5.65*	5.8*	5.75*	5.75	5.7
Powder-free latex	TEWL	11.1	19.75*	13.15	13.8	9.9	9.05*
	SH	65.5	75.0*	72.0*	71.5*	67.5	66.0
	pH	5.15	5.3	5.4*	5.4*	5.45*	5.5*
Polyvinyl chloride	TEWL	11.05	18.7*	17.5*	12.35*	10.5	9.35
	SH	66.0	80.0*	70.5	69.0	66.0	69.0
	pH	5.25	5.3	5.35	5.45	5.5	5.45
Nitrile	TEWL	10.25	17.45*	13.3*	11.3	9.85	9.05
	SH	66.0	74.0*	69.5	67.0	63.5	66.5
	pH	5.2	5.3	5.5*	5.5*	5.6*	5.6*
Semipermeable membrane	TEWL	11.7	10.25*	9.6	11.4	8.75*	8.7*
	SH	70	68	69	70	71	70
	pH	5.2	5.15	5.2	5.25	5.25	5.25

pH = hydrogen ion concentration; SH = skin humidity; TEWL = transepidermal water loss.
*$p < 0.01$.
[†]Baseline = after 30 minutes' acclimatization.
[‡]Immediately following 20-minute occlusion.

User Questionnaire Responses

The test users judged the latex gloves to be the best-fitting gloves (average ratings of 2.1 and 2.25 for powdered and powder-free latex gloves, respectively); gloves made of nitrile received a somewhat lower rating for fit (average rating of 2.5). The vinyl gloves and semipermeable prototypes were rated lowest for fit, with an average score of 3.85. With regard to the test parameter of perspiration under the protective glove, the semipermeable gloves received the best rating. Only three members of the test group reported perspiration (described as ''minor'') inside the semipermeable gloves worn during testing. A decisive majority of test users observed increased perspiration inside the glove when wearing gloves made of the other materials tested. Most members of the test group described perspiration inside the powdered latex glove as ''minor'' and as ''moderate'' in the case of the powder-free latex glove. Perspiration inside the PVC glove was mostly described as ''heavy.'' Perspiration inside the nitrile glove was described as ''moderate.'' The latex and nitrile protective gloves received the highest overall ratings, between 2.4 and 2.55. At an average rating of 2.98, the semipermeable protective gloves were rated somewhat lower in this category. The PVC protective gloves were judged least satisfactory by far, with an average rating of 4.75.

Discussion

Penetration and Permeation Test Performance

Because of the irregular welded seams of the prototypes tested, the semipermeable glove cannot be regarded as a fully developed marketable product (leakage was observed in all 50 prototypes tested). If the integrity of the welded seams were significantly optimized, however, application as a disposable glove for use with the hairdressing chemicals tested could become feasible as the earliest breakthrough of the oxidation hair dye occurred after 45 minutes. Results among the ''conventional'' gloves tested indicate that the nitrile disposable glove is most suitable for use in the hairdressing profession because it is the only glove that achieved the highest performance level in both permeation and penetration tests. Results for the nitrile glove correspond with those seen by Peter and colleagues,[25] according to whom nitrile gloves provided the best protection against glyceryl monothioglycolate (a component in acidic permanent-wave solutions), p-phenylenediamine (a component in oxidation hair dyes), and ammonia persulfate (a component in blonding solutions) when compared with latex gloves and gloves made of an unspecified ''bipolymer membrane.'' In a previous study, disposable gloves made of PVC, latex, and polyethylene membrane were tested for degradation, penetration, and permeation. Water, permanent-wave solution (alkaline), developer solution, hydrogen peroxide, and ammonia solution were used as test chemicals. Details of the nonstandardized test methods can be found in the report by Wulfhorst and colleagues.[26] Results revealed the PVC glove to be the ''lesser evil'' as it was permeable only by the developer solution. The permeability of PVC by hydrogen peroxide has been described by Savaides and colleagues.[27] In this case, gloves made of latex, neoprene (polychloroprene), and PVC were tested for resistance to ammonia thioglycolate (a component in alkaline permanent-wave solutions) and hydrogen peroxide. Test results indicated a superior resistance of latex and neoprene gloves to all test chemicals when compared with PVC gloves.

The experimental conditions under which the above data were collected were rigorous. However, the following points should be taken into consideration. Skin temperature is about 35°C, about 10°C higher than the temperatures at which the permeation tests were made; permeation is invariably higher at elevated temperatures.[28] In addition, in vivo tests in guinea pigs have shown that breakthrough times (for different solvents) correspond well for the two test systems (cell permeation vs guinea pig skin exposure/solvent blood concentration), but the relative absorption rates and relative steady-state permeation rates varied considerably, and no definitive relationship between the two sets of test results could be seen.[2,29] (A guide for the selection of gloves and inclusive information about performance in standardized in vivo testing can be found in the manual edited by Boman and colleagues.)[30]

Skin Bioengineering

Results confirm that diverse conventional glove materials (all of which are occlusive) can influence various physiologic parameters of the skin in specific manners. With the exception of the semipermeable material, 20-minute occlusion with all of the other materials tested (powdered latex, powder-free latex, nitrile, and PVC) resulted in a significant increase in TEWL values on the dorsal aspect of the hand. Parallel to these findings, the majority of test glove users reported increased perspiration inside gloves made of latex (powdered and unpowdered), nitrile, and PVC. This suggests that the significant increase in TEWL values observed with these materials is mainly the result of the increased evaporation of water accumulated on the skin and not primarily an indication of damage to the epidermal

permeation barrier. The relatively fast return to baseline TEWL values reinforces this hypothesis. Regeneration of the barrier from damage severe enough to cause an increase in TEWL would be impossible within such a short time.[31] Damage to the epidermal permeation barrier does, however, occur when protective gloves are worn repeatedly as is the case in practical use.[5,9–11] The fact that the TEWL values observed on the back of the hand 30 minutes after occlusion were lower than those observed previous to occlusion could be the result of swelling of the stratum corneum, which at least partially limits the evaporation of water. This swelling of the stratum corneum could also explain the absence of a statistically significant increase in TEWL values after occlusion on the palm (where the concentration of sweat glands is considerably higher) with all of the materials tested. The aim of this study was to use TEWL values only for measurements of desorption. The effects of long-term glove occlusion have been shown by Ramsing and Agner: glove occlusion on normal skin 6 hours per day for 14 days had a significant negative effect on skin barrier function as measured by TEWL.[11] In contrast to occlusion by latex and nitrile, occlusion with the PVC gloves or semipermeable protective gloves did not significantly influence the skin surface pH. Glove users reported the heaviest perspiration inside PVC gloves, suggesting that the increased pH values observed with the other materials (powdered latex, powder-free latex, and nitrile) were not caused by the alkalization of sweat. The findings suggest that sweat dissolves additives or residual chemicals used in the manufacture of gloves made of these materials, leading to a temporary increase in pH values. As it is currently believed that long-term increases in epidermal pH are a major cause of subtoxic cumulative eczema of the hands,[32] it is advisable to avoid the use of materials that cause an increase in pH whenever possible. Other studies have shown powdered latex gloves to be especially likely to cause significant long-term increases in epidermal pH values, further reinforcing the necessity of legislation (already in effect) prohibiting the use of such gloves. The ruling was based on the increased risk of sensitization to latex proteins through the interior powdering of latex gloves.[5,19]

Test Glove Users' Responses

With regard to the materials tested, the responses given in the user questionnaires countered a frequently raised objection to the use of protective gloves, namely, that they limit dexterity and the sense of touch. Schöbel and Schwanitz[33] and Freigang[34] reached similar conclusions. In terms of fit, latex was judged best. Its positive rating is primarily due to its elasticity and flexibility, which enables it to adapt well to the individual hand. The poorest fit (with an average rating of 3.85) was recorded for PVC gloves and gloves with the semipermeable membrane. The test glove users reported a wide range of shortcomings with regard to the fit of these materials. However, it must be considered that the semipermeable gloves tested were prototypes whose fit remains to be fully developed. The test glove users rated the semipermeable gloves highest for the study parameter of perspiration inside the protective glove. Only three members of the test group reported perspiration (described as ''minor'') while wearing these gloves. The test results underscore the complexity of selecting protective gloves for a specific application. For example, use of the nitrile glove, which scored highest in penetration and permeation testing, led to a significantly higher increase in skin surface pH values than those recorded for PVC, a material found in earlier studies to be less satisfactory than nitrile with regard to permeability by hairdressing chemicals.[25] However, test users found latex gloves (powdered and powder-free) to have the best fit, but the potential for sensitization resulting from contact with latex protein through the powder used in such gloves has led to legislation prohibiting their professional use.[19]

Conclusion

The use of semipermeable glove membranes may minimize the role of gloves as a cause of occupational dermatoses and in the worsening of dermatoses from other causes.

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