Skin barrier function alteration induced by noise and solvent exposure among aircraft maintenance workers

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Abstract

Purpose This study was aimed to investigate whether the single exposure of noise, solvent, and co-exposure of noise and solvents alter skin barrier functions.

Methods Forty-four male airplane maintenance workers were recruited in this study in the middle of Taiwan. All subjects underwent skin barrier function tests, including basal transepidermal water loss (TEWL), basal water content (WC), skin barrier integrity, and skin barrier recovery.

Results We found that organic solvent exposure affected the stratum corneum superficially and raised the basal TEWL ($6.1 \text{ g/m}^2/\text{h}$ (SD $0.8 \text{ g/m}^2/\text{h}$) vs. $4.6 \text{ g/m}^2/\text{h}$ (SD $0.6 \text{ g/m}^2/\text{h}$) in the solvent exposure group and control group, respectively ($p < 0.01$)). In addition, noise exposure showed the increasing pattern of barrier integrity (78.8 (SD 9.2) vs. 48.9 (SD 13.8) in noise exposure group and control group, respectively ($p < 0.01$)) and decreasing pattern of 6h recovery (20.4% (SD 5.6%) vs. 43.6% (SD 11.5%) in noise exposure group and control group, respectively ($p < 0.01$)).

Conclusion These results indicated that noise and solvent exposure might affect skin health or cause skin disorders among workers. Further study about the relationship between noise, solvent, and skin barrier function should point to potential mechanisms caused by stratum corneum exposures.

Introduction

The skin is one of the essential organs of the body. It provides the significant functions to supply the protection against the external environment substances and maintain the balance of water by avoiding the water loss from the skin in the human body. The stratum corneum of skin supplies these functions, and the protection function was called the skin barrier function (Schaefer and Redelmeier 1996). Regarding the laborers, skin barrier functions are connected with skin diseases and the absorption rate of chemicals in workplaces. Previous studies have shown that the prolonged damage of skin barrier function triggered inflammation and skin diseases (Elias 2018; Suárez et al. 2012). In addition, the impairment of the skin barrier function accelerated the absorption rate of chemicals either (Chou et al. 2004). Therefore, skin barrier functions are the critical considerations among workers in industrial settings worldwide.

Noise is one of the most widespread sources of environmental stress in living environments (Münzel et al. 2017). The noise exposure could be precisely measured and quantified, and the amount of exposure by using many kinds of noise meters in modern periods. Numerous studies have demonstrated that the hormone secretions changed after noise exposure (Ising and Braun 2000). It has been reported that the hypothalamic-pituitary-adrenal axis hormone such as epinephrine and norepinephrine and cortisol was elevated after the exposure to highly in-tense noise, and the cumulative exposure of prolonged noise increased the secretions of epinephrine and cortisol (Fouladi et al. 2012; Zare et al. 2019). There is evidence that hormonal change caused by noise might induce health effects like hypertension, increasing cardiovascular risk, and skin diseases (Babisch 2003; Ising and Kruppa 2004).

The laborers of the airport expend at least eight hours to stay at the workplace, and many health issues of workers were related to the occupational environments. Depending on the survey, the airport's surrounding was almost 70 decibels caused by the taking off and landing of airplanes, but the workers sometimes exposed over 100 decibels in the airport's apron. Moreover, the airplane maintenance workers were exposed to noise. They used enormous organic solvents such as n-hexane and methyl ethyl ketone to eliminate the paint and regularly clean the plane's components. However, to our knowledge, previous research broadly explored the effect of hearing loss caused by a single exposure of noise, organic solvents, and co-exposure of noise and solvents. Skin barrier function alteration has not been postulated after single noise exposure, solvent exposure, and co-exposure of noise and solvents. Therefore, this study was aimed to investigate whether the single exposure of noise, solvent, and co-exposure of noise and solvents alter skin barrier functions.

Materials And Methods

Forty-four male airplane maintenance workers were recruited with informed consent in this study from members of an airplane maintenance factory in mid-Taiwan. All subjects work from 8:00 am to 5:00 pm, and occasionally they may work overtime due to extra work. Except for the noon break, all workers must work on the job site, so all workers' exposure time is about 8 to 9 hours a day. According to the actual working conditions observed, subjects' work content and working periods are stable, so the relevant exposure status is also relatively stable. Subjects who had skin disease on the measurement site and long-term drug users were excluded from this study. The information collected by questionnaire included demographic characteristics, lifestyle (such as cigarette smoking and skincare habit), job task, personal hygienic habits (use of mask, glove, and earplug), and health history (skin disease, drug use). The study procedure was approved by the Institutional Review Board (IRB) of China Medical University Hospital before the research proceeded. Each subject in this study conducted a questionnaire with informed consent.

The noise group's job operated the airplane maintenance machinery. The organic solvent group used n-hexane and methyl ethyl ketone (both concentrations > 90%) to soak the cloth and directly clean the paint of aircraft and components. The co-exposure group was operation and cleaning of engines and the section of aircraft. All subjects had been exposed to the machinery noise or organic solvent for several years (2-21 years). Based on the results of working environment measurement once per six months, the equivalent continuous noise level (L_{eq}) of these groups measured by the sound level meter (Lutron SL-4001, Taiwan) was 84-129 dB(A) in the task exposed to noise during several daily work shifts and 48-73 dB(A) in the task without noise exposure. Therefore, all subjects from the factory were divided into four groups depending on the field investigation results: noise exposure group, organic solvent exposure group, co-exposure of noise and solvent group, and control group.

All subjects underwent skin barrier function tests, including basal transepidermal water loss (TEWL), basal water content (WC), skin barrier integrity, and skin barrier recovery at the end of the workday. Each subject should rest at least 15 to 30 minutes before measurement. The barrier function tests were

measured on the dominant forearm at room temperature at 22 °C to 25 °C, and the relative humidity ranged from 40% to 60% (du Plessis et al. 2013).

TEWL measurement is the outward diffusion of water through the skin. The Tewameter® TM 300 (CK, Germany) was used to measure TEWL, and the probe touched on the forearm skin perpendicularly for 1-2 minutes to measure the water loss from the surface skin until the standard deviation less than 0.05 g/m²/h.

WC measurement was used the Corneometer® CM 825 (CK, Germany), and touched to the subject's forearm skin 15 times successively. The last five measurements were averaged as the stratum corneum water content.

Skin barrier recovery is the repair rate of the stratum corneum after acute disruption (Yosipovitch et al. 2007). The sticky book tape disrupted the measurement site sequentially (Scotch No.845 book tape, 3M, USA) until a TEWL level of at least 20 g/m²/h. TEWL was measured immediately after tape stripping and 3 hours, 6 hours, and 24 hours later. The evaluation of recovery rate is based on the percent change compared with basal TEWL (Tsai et al. 2001).

$$\text{Recovery (\%)} = \frac{\text{TEWL after acute disruption} - \text{TEWL after 3,6,24 hours later}}{\text{TEWL after acute disruption} - \text{TEWL basal}} \times 100\%, \quad (1)$$

Skin barrier integrity was the number of successive tape stripping required to disrupt stratum corneum (TEWL at least 20 g/m²/h) in this study,

Shapino-Wilks' W test was performed to examine whether skin barrier function indices were normal distribution. Demographic information and variables comparison among difference exposure groups were computed using one-way ANOVA for the continuous variables and chi-square test for the categorical variables. The skin barrier functions comparison among the four groups were used as one-way ANOVA and the Spjotvoll/Stoline test (Tukey HSD for unequal N test) was used for post hoc comparison. Statistica Software release 6.0 (StatSoft, Tulsa, OK, USA) was used in the statistical analysis. The significance level was set at $p < 0.05$.

Results

All 44 participants were male, and the demographic information, including BMI, smoking, skincare habit, and personal hygienic habits, revealed no significant differences between all groups (Table 1). In addition, although age showed the difference between groups, other factors potentially influencing skin barrier function showed comparability.

The distribution and difference of skin barrier functions are presented in Table 2. Group differences in TEWL indicated a higher value in solvent than the control group (6.1 vs. 4.6 g/m²/h, $p < 0.01$), and it was

also higher in the combined exposure than the control group (6.0 vs. 4.6 g/m²/h, $p < 0.01$). There were no significant differences in WC among the three groups compared with the compared group. Skin barrier integrity of noise exposure and combined exposure groups was significantly higher than the control group (78.8 vs. 48.9, $p < 0.01$ in the noise group, and 69.0 vs. 48.9, $p < 0.05$ in the combined exposure group). In addition, the noise group showed a lower level of 6h recovery than each group, which differed significantly from the control group (20.4% vs. 43.6%, $p < 0.01$).

Although the recovery rate of all groups increased significantly in the first three hours, the recovery rate of the noise exposure group in the sixth hour had a delayed effect (Fig 1A). In comparing the 6h recovery of each group, it was evident that the response rate of the noise exposure group is significantly lower than that of the other three groups (Fig 1B). The results show that the skin recovery rate in the noise exposure group has a delayed effect compared to the other groups. In contrast, the recovery rate of the other three groups is not much different.

Discussion

In the study, we demonstrated that noise exposure affects skin barrier integrity, and solvent exposure causes the elevation of basal TEWL. Besides, we found that the organic solvents exposure changes the inhibition tendency of skin barrier recovery caused by noise exposure among the co-exposed workers to noise and organic solvent. The previous study has revealed that psychological stress disrupted skin barrier function in animal models and humans (Altemus et al. 2001; Denda et al. 1998). Therefore, we considered that noise is a psychological but physio-logical stress source in the workplace and environments. This study is the first to find the relationship between noise and skin barrier function and co-exposure to noise and organic solvents with skin barrier recovery. Although the 8 hours time-weighted average of noise did not reach 85 decibels in the airplane maintenance factory, the noise exposure level of the intermittent work shift was more than 110 decibels largely. According to field survey results, the workplaces were too ventilating to collect the air sample of organic solvents; however, we considered the maintenance workers exposed to a significant amount of n-hexane and MEK. Therefore, the maintenance and operation workers were considered a high-risk population of noise and organic solvent exposure.

Our study found that organic solvent exposure elevated basal TEWL was consistent with animal and human data, which showed that several organic solvents such as acetone, the mixture of hexane methanol, and CS₂ exposure could elevate the skin basal TEWL in animal, the skin in vitro study, and field study of workers (Abrams et al. 2001; Chou et al. 2004; Tsai et al. 2001). Moreover, acetone's repeated application extracted the intercellular lipid in the stratum corneum of the skin (Monteiro-Riviere et al. 2001). Thus, the extraction of intercellular skin might be the mechanism by which n-hexane and MEK caused the damage of basal TEWL among workers in this study.

We also found that noise increased the number of skin barrier integrity for airplane maintenance workers in this study. There was no research to investigate the correlation between noise stress and skin barrier integrity. Still, several data showed that skin barrier integrity was significantly lower than the control

group after psychological stress exposure in rats. There was a lower tendency of the psychological stress group's skin integrity in humans (Choi et al. 2005; Robles 2007). An animal study of psychological stress showed that the desmoglein1 protein decreased compared with the control group. Skin biopsy samples of mice showed that the fragmented and shorted corneodesmosomes were found in the psychological stress group were demonstrated to be the mechanism by which psychological stress exposure reduced the number of skin barrier integrity (Ishida et al. 2003). Our study result of integrity was opposite to the previous psychological stress study. However, most psychological stress studies with skin barrier integrity were animal models. Only a few studies explored human skin barrier integrity. Previous studies' almost psychological stress sources belonged to short-term (hours-days-months) stress exposure such as crowding, sleep deprivation, or interview stress (Altemus et al. 2001). In this study, different from the previous study is the long-term (2-21 years) noise stress exposure to the workers in the workplace. It might be the possibility that caused the different result of skin barrier integrity from previous studies. Also, rats underlined the crowding stress caused the increase of epinephrine and norepinephrine hormones, which reduced the bloodstream of skin, caused the defective differentiation of stratum corneum, and thickened the skin (Ishida et al. 2003). In this study, the potential mechanism of noise exposure increased the skin barrier integrity could be that the elevated levels of epinephrine and norepinephrine hormones induce the thickening of the skin.

We found a borderline significance ($p < 0.1$) of higher basal TEWL in the noise exposure group than the control group. This tendency is consistent with the results of the previous study. Although not significant, the study of psychological stress, such as interview stress, elevated the basal TEWL after pressure (Altemus et al. 2001). In addition, the basal TEWL among students did not change after the psychological stress of period tests (Garg et al. 2001). Compared with our result, there was a borderline significance of higher basal TEWL. We considered that the long-term exposure of extremely high noise caused higher stress influence to the skin than short-term psychological stress. In the previous study of the murine model, the inter-cellular lipid of the stratum corneum became thinner after exposure to psychological stress (Choi et al. 2005). Therefore, it might be the potential mechanism that stresses elevated basal TEWL. Whereas organic solvents did not affect the skin barrier integrity was consistent with the previous result, the study about acetone application on human skin only showed the structured change but no damage to the corneodesmosomes in stratum corneum (Fartasch 1997).

Abundant evidence pointed out that inhibition of skin barrier recovery after acute disruption indicated that both rodent and human models showed psychological stress disturbed barrier recovery. The potential mechanism was the glucocorticoid hormone, reducing the lamellar body's number and secretion in the stratum corneum (Kao et al. 2003). There was a parallel adverse trend of 6h recovery caused by noise in this study. According to our result in the co-exposure group of noise and organic solvent, solvent exposure balanced the adverse effect of 6h recovery delay caused by noise exposure. To our knowledge, this study is the first to find the correlation of skin barrier recovery between noise and solvent. A previous study conducted by Menon et al. found that after the disruption of acetone on hairless mice's skin showed damage of intercellular lipid and an increasing number of lamellar bodies that included immature ones replenish the damaged skin barrier function immediately (Menon et al. 1992). Moreover, a recent study

also showed that acetone treatment to the stratum corneum might lead to the permeability decreasing of epidermis then improved skin barrier function (Barba et al. 2016). Therefore, we presumed that the potential mechanism that organic solvent alters the correlation between noise and 6h recovery could be explained by the lamellar body and permeability change in the stratum corneum. However, this study still has some limitations. The number of cases in this study is small. Although the employees are stable and representative, a larger sample size is still needed to confirm the results of this study. Due to the stability and representatively of exposure conditions, the actual air concentration of solvents was not be measured in this study. Further investigation of direct environmental exposure assessment should be warranted to estimate the dose-response relationship of noise exposure, solvent exposure, and skin barrier function alteration. In addition, due to feasibility limitations, the employee skin test can only be presented in one test result, and there is no follow-up tracking data. Still, the results of this study can provide a data basis for future follow-up tracking studies to understand the employees' long-term exposure to the skin impairment of barrier function.

Conclusion

In summary, organic solvent exposure affected the stratum corneum superficially and raised the basal TEWL. Noise exposure was the risk of barrier integrity alteration and 6h recovery. These results indicated that noise and solvent exposure might affect the health of the skin or cause skin disorders among workers. Further study about the relationship between noise, solvent, and skin barrier function should point to potential mechanisms caused by stratum corneum exposures.

Declarations

Author Contributions: Conceptualization, TCC, JFH and YHL; methodology, YHL formal analysis, TCC and JFH; writing—original draft preparation, TCC, JFH and YHL; writing—review and editing, TCC, JFH and YHL. All authors have read and agreed to the published version of the manuscript.

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Data availability: The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board of China Medical University Hospital (DMR97-IRB-179).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. Written informed consent has been obtained from the subjects to publish this paper.

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Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study, in the collection, analyses, or interpretation of data, in the writing of the manuscript, or in the decision to publish the results.

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Table 1. Demographic information of study subjects

		Control Group	Noise Exposure	Solvents Exposure	Combined Exposure	p*
N		16	4	9	15	
Age		25.3(3.0)	34.7(2.9)	32.6(9.7)	30.3(4.5)	<0.01
BMI		25.9(5.1)	24.0(3.3)	26.3(3.2)	24.7(4.3)	0.72
Smoking	Y	2(13%)	1(25%)	5(56%)	7(47%)	0.10
	N	14(87%)	3(75%)	4(44%)	8(53%)	
Skin care	Y	7(44%)	2(50%)	3(33%)	4(27%)	0.72
	N	9(56%)	2(50%)	6(67%)	11(73%)	
Mask	Y	2(13%)	1(25%)	2(22%)	8(53%)	0.09
	N	14(87%)	3(75%)	7(78%)	7(47%)	
Glove	Y	2(13%)	0(0%)	1(11%)	6(40%)	0.13
	N	14(87%)	4(100%)	8(89%)	9(60%)	
Earplug	Y	2(13%)	0(0%)	2(22%)	2(13%)	0.75
	N	14(87%)	4(100%)	7(78%)	13(87%)	

Continuous variables were described as means (SD), and categorical variables were expressed as number (percentage)

BMI, body mass index

*: tested by one-way ANOVA and chi-square test.

Table 2. The comparison results of TEWL, water content, skin integrity, and recovery among different exposure groups

	Control Group	Noise Exposure	Solvents Exposure	Combined Exposure	p*
N	16	4	9	15	
TEWL	4.6(0.6) ^{a, b}	5.4(1.4)	6.1(0.8) ^a	6.0(1.0) ^b	< 0.01
WC	37.8(6.5)	35.0(3.0)	38.4(6.6)	36.2(5.5)	0.69
Integrity	48.9(13.8) ^{c, d}	78.8(29.2) ^c	50.0(23.1)	69.0(36.1) ^d	0.05
3h Recovery	38.1(8.1)	29.3(15.5)	29.1(16.4)	26.9(9.9)	0.07
6h Recovery	43.6(11.5) ^e	20.4(5.6) ^e	39.5(11.4)	38.0(11.2)	< 0.01
24h Recovery	54.6(10.9)	36.0(5.7)	50.2(23.5)	53.0(15.8)	0.21

Continuous variables were described as means (SD), *: tested by one-way ANOVA and Spjotvoll/Stoline test (Tukey HSD for unequal N test) as post hoc comparison

TEWL, transepidermal water loss; WC, water content

a: p<0.01 compared between control group and solvents exposure group

b: p<0.01 compared between control group and combined exposure group

c: P<0.01 compared between control group and noise exposure group

d: p<0.05 compared between control group and combined exposure group

e: p<0.01 compared between control group and noise exposure group

Figures

A.

B.

Figure 1

The results of recovery comparison among different exposure groups. (A) time-series recovery results. (B) 6h recovery results.