

Concomitant contact allergy to the resins, reactive diluents and hardener of a bisphenol A/F-based epoxy resin in subway construction workers

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An outbreak of suspected contact dermatitis among subway construction workers was suspected to be due to a new bisphenol A/F-based epoxy resin system (ERS). The construction workers used ERSs during the insertion of iron bars into concrete walls. The objective of the study was to determine the components (if any) of the ERS responsible for the contact allergy. Patch testing was performed on 20 of the 22 construction workers who had had contact with the ERS, and to the various subcomponents of component A on 5 of the 7 who reacted to this component. 9 patients (9/22, 40.9%) had clinical symptoms and signs of suspected contact dermatitis at presentation. 7 of these 9, but none of the 11 asymptomatic individuals, were positive to component A, while all were negative to component B. Of the 5 cases receiving further patch testing, all reacted to *m*-xylylene diamine, 4 to 1,6-hexanediol diglycidyl ether, 3 to epoxy resins of the bisphenol F-type and trimethylolpropane triglycidyl ether 0.25% petrolatum, and only 1 to epoxy resins of the bisphenol A-type. Contact allergy to ERSs may involve hardeners and diluents as well as resins, and patch testing for reaction to all components should be performed.

Key words: 1, 6-hexanediol diglycidyl ether; allergic contact dermatitis; bisphenol A; bisphenol F; epoxy resin; hardener; *m*-xylylene diamine, reactive diluents; trimethylolpropane triglycidyl ether.

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Epoxy resin systems (ERSs) are one of the most frequent causes of occupational allergic contact dermatitis (ACD) (1, 2). Sensitization can develop to one or more of the components of ERSs, such as epoxy resins, hardeners or reactive diluents (3–5). The majority of cases of occupational ACD among workers exposed to ERSs are caused by the main constituent in the most common epoxy resin, specifically the diglycidyl ether of bisphenol A (DGEBA) (1, 2, 4–6). Epoxy resins based on DGEBA (DGEBA-R) are used as the standard epoxy resin for detecting contact allergy to this allergen (7, 8). In addition to bisphenol A, epoxy resins can be based on other substances, including bisphenol F (7–9). Epoxy resins based on both bisphenol F (DGEBF-R) and phenolic novolac resin (DGEBF(n)-R) contain diglycidyl ether of bisphenol F (DGEBF), which has 3 isomers (9–12). DGEBF-R is less viscous than DGEBA-R and is used when greater resistance is needed (7, 8).

In 2004, an outbreak of suspected contact dermatitis was noted among the workers in one construction company for the new subway system in Taipei. The construction workers used ERSs during the insertion of iron bars into concrete walls to enhance the adhesion between the iron bars and the walls. The company had used several glues including Fischer injection Mortar FIS V 360 S/FIS V 950 S, Upat injection Mortar UPM 44 (both are methacrylate glues composed of ethylene glycol dimethacrylate, Portland cement and benzoyl peroxide), and other ERSs containing DGEBA-R, for anchorage between building materials. Since July 2003, a new bisphenol A/F-based ERS (Hilti HIT-RE 500, Hilti Entwicklungs GmbH, Kaufering, Germany) was introduced into the company in addition to the old glues and ERSs containing DGEBA-R. A new onset of severe itching skin rash was noted in the following 7 months. The component A of Hilti HIT-RE 500 is a bisphenol A/F-based

epoxy resin containing 30%–40% bisphenol A-epoxy resin, 10%–20% bisphenol F-epoxy resin, <15% hexanediol glycidylether, <10% trimethylolpropane triglycidyl ether (TMPTGE). The component B of Hilti HIT-RE 500 contains 30%–40% *m*-xylylene diamine (Table 1). The aim of the present study was to provide information on the causes of occupational ACD to the ERSs used by the workers constructing the new subway system in Taipei.

Materials and Methods

Patients

The dermatological investigation involved 22 employees of a small construction company involved in building new subway stations in Taipei. These workers were assigned to different workplaces with various exposures to cement, iron bars and ERSs used for the insertion of the iron bars into concrete walls. All the construction workers in the company had worked for at least 3 months in contact with ERSs containing DGEBA-R and cement. For further analysis of clinical symptoms, exposure and patch testing results, we divided them to 2 groups: group A with suspected contact dermatitis and group B without. Before the clinical investigation and patch testing, all the investigated workers answered an organized questionnaire including basic personal information, past medical history, occupational history, exposure time, work habits and protection methods.

Workplace

The workplace of these workers was usually in the basement of the new subway stations, which were more than 10 meters underground, with high temperatures, high humidity and poor ventilation (Fig. 1). Because of the high temperatures in Taipei (around 35°C in summer), all the workers wore T-shirts and trousers during work. They used only headgear for protection (Fig. 2).

Table 1. Composition of the Hilti HIT-RE 500 epoxy resin system

Composition	CAS number	Content (%)
Component A		
Bisphenol-A-epoxy resin	25068-38-6	30–40
Bisphenol-F-epoxy resin	28064-14-4	10–20
1,6-hexanediol diglycidyl ether	16096-31-4	<15
Trimethylolpropane triglycidyl ether	30499-70-8	<10
Component B		
<i>m</i> -xylylene diamine	1477-55-0	30–40



Fig. 1. The workplace of these workers was in the basement, which was more than 10 meters underground with high temperature, high humidity, and poor ventilation.

Some of them wore textile (cotton) gloves occasionally during work.

Definitions

The diagnoses were classified according to the occupational skin disease which was believed to be the most significant. Atopy was defined as having a personal or family history of allergic



Fig. 2. The workers wore T-shirt and trousers without good protection from the epoxy resin systems during work.

rhinitis, asthma or atopic dermatitis. Duration of exposure was defined as the time from the beginning of work-related skin contact with ERSs to the time of dermatological investigation. Exposure time was defined as the time from the beginning of work-related skin exposure with ERSs to the onset of skin symptoms which were considered to be due to ERSs (4). Both clinical inspection and anamnestic data were used to record the localization of the dermatitis suspected to be due to ERSs (4).

Patch testing

The test substances were applied to Finn Chambers (Epitest Ltd, Helsinki, Finland), which were fixed to the upper back with Scanpor tape and secured by 3M tapes. The patches were removed after 2 days, and the sites were examined for evidence of reaction at 2 and 4 or 5 days after initial application. The reading at D4 or D5 was considered positive if the reaction was equal to, or stronger than, a palpable erythema, according to the guidelines of the International Contact Dermatitis Research Group (ICDRG) (13). Those with positive reactions at the D2 reading only but negative at the D4 or D5 reading were considered to have an irritant reaction.

When a doubtful patch-test reaction to any test preparation occurred on D4 or D5, the preparation in question was retested.

2 workers without skin symptoms refused to receive patch testing. The other 20 were patch tested with the European standard series, dental series (including benzoyl peroxide 1% petrolatum (pet.) and bisphenol A 1% pet.), methacrylate series (including ethylene glycol dimethacrylate 2% pet., bisphenol-A-dimethacrylate 2% pet., ethoxylated bisphenol-A-dimethacrylate 1% pet., bisphenol-A-glycidyl methacrylate 2% pet, epoxy acrylate 0.5% pet. (all from Chemotechnique Diagnostics AB, Malmö, Sweden), as well as components A (3% pet. and 1% pet.) and B (0.3% pet. and 0.1% pet.) of Hilti HIT-RE 500 (Hilti Entwicklungs GmbH). Because the component A of Hilti HIT-RE 500 is a bisphenol A/F-based epoxy resin containing 30%–40% bisphenol A-epoxy resin, 10%–20% bisphenol F-epoxy resin, <15% hexanediol glycidylether and <10% TMPTGE, we patch tested the workers with the component A in 3% pet. and 1% pet. The component B of Hilti HIT-RE 500 contains 30%–40% *m*-xylylene diamine; therefore, we used diluted component B in 0.3% pet. and 0.1% pet. for patch testing. Furthermore, patients who were suspected of contact allergy to Hilti HIT-RE 500 were subsequently patch tested with D.E.N. 431

(a bisphenol F-type epoxy resin produced by the reaction between phenolic novolac resin and epichlorohydrin (DGEBF(n)-R), containing 43.1% DGEBF and less than 0.1% DGEBA) 0.25% pet., Epicote 862 (a bisphenol F-based epoxy resin produced by the reaction between bisphenol F and epichlorohydrin (DGEBF-R), containing 74.4% DGEBF and 1.9% DGEBA) 0.25% pet., 1,6-hexanediol diglycidyl ether 0.25% pet. and alkyl glycidylether 0.25% pet. (the above were provided by Dr Pontén, Malmö University Hospital, Malmö, Sweden) (10). In addition, they were patch tested with bisphenol F 0.25% pet., Aldrich 406775 (a bisphenol F-type epoxy resin, DGEBF(n)-R) 0.25% pet., TMPTGE 0.25% pet., and *m*-xylylene diamine 0.1% pet. (the above chemicals were purchased from Sigma-Aldrich GmbH, Steinheim, Germany).

Control study

After obtaining informed consent, a total of 12 normal healthy volunteers were enrolled in a control study of patch testing with D.E.N. 431 0.25% pet., Epicote 862 0.25% pet., 1,6-hexanediol diglycidyl ether 0.25% pet., Aldrich 406775 0.25% pet., TMPTGE 0.25% pet. and *m*-xylylene diamine 0.1% pet.

Ethics

Informed consent was obtained from each volunteer and worker before patch testing. The patch testing procedures followed the guidelines of ICDRG. This study was approved by the Ethics Committee of National Taiwan University Hospital.

Statistics

The mean age, duration of exposure to other ERSs and duration of exposure to Hilti HIT-RE 500 were calculated and compared between the two groups of workers. For this comparison, a Wilcoxon Rank Sum test was used for comparisons of paired differences. A two-tailed *P*-value of 0.05 or less was considered to indicate significance. The prevalence of atopy, frequency of wearing gloves during work and frequency of immediate wash after skin contact with ERSs were compared between the two groups by Fisher's Exact tests. A one-tailed *P*-value of 0.05 or less was considered to indicate significance. All the analyses were performed with the use of SAS software (version 8.02; SAS Institute, Cary, NC, USA).

Results

Patients

A total of 22 employees were interviewed and evaluated. 9 of them had clinical symptoms and signs of suspected contact dermatitis at presentation. We therefore divided the employees into group A with suspected contact dermatitis and group B without. All were males. The duration of exposure to ERSs was at least 3 months (range 3 months–120 months). The mean age, prevalence of atopy, duration of exposure to other ERSs, duration of exposure to Hilti HIT-RE 500 and frequency of wearing gloves during work were not statistically different between groups A and B (Tables 2 and 3). However, all of the group B employees claimed that they always removed the contactants by washing immediately after direct skin contact with ERSs, while only 2 of the 9 patients in group A did so, and then only occasionally ($P < 0.0002$). The above information was independently obtained before clinical investigation and patch testing as described in *Materials and Methods*.

Location of the dermatitis

The location of the dermatitis was usually the exposed sites, including hands, forearms, face,

neck and lower legs. All the symptomatic patients had skin lesions on their forearms or arms (100%). In 7 patients (77.8%), skin symptoms were also located on the hands, and in 6 patients (66.7%), skin symptoms were also present on the neck. There were 3 patients (33.3%) with skin lesions on the face.

Patch testing results

Patch testing was performed on 20 of the 22 construction workers. All the 9 symptomatic cases, who were suspected to have contact dermatitis to Hilti HIT-RE 500, as well as the other 11 asymptomatic individuals, received patch testing.

7 of the 9 suspected contact allergy cases were positive to the 3% pet. and 1% pet. dilutions of component A and negative to component B, while none of the 11 asymptomatic individuals were reactive to components A or B. 2 of the 9 patients with clinical dermatitis showed + to ++ reactions to component A at the D2 reading and showed negative reactions to component A at the D4 reading. They were negative to all testing materials in the European standard series, the dental series and the methacrylate series at the D4 reading. These 2 patients were diagnosed as having irritant contact dermatitis. Only 1

Table 2. Clinical characteristics and exposure analysis of the workers exposed to the epoxy resin systems. All the workers were males

Patient number	Age	Atopy: own/family	Duration of exposure (months)		Exposure time to Hilti HIT-RE 500 before symptoms (months)	Location of the dermatitis	Use of textile gloves
			ERS	Hilti HIT-RE 500			
Patients with clinical symptoms of suspected contact dermatitis							
1	37	No/no	24	11	0.5	H, Fa, N, L	+
2	47	No/no	14	14	2	H, Fa, N	+
3	46	No/no	48	12	1	H, A, N, Fh	+
4	28	No/no	4	4	1	H, A, N, Fh	+
5	47	No/no	6	6	1	Fa, L	+
6	18	No/yes	5	5	2	H, Fa, L	+
7	18	No/yes	6	6	2	H, Fa, L	+
8	29	No/no	72	9	7	Fa, N	+
9	41	No/no	120	12	1	H, Fa, N, Fh	–
Patients without clinical symptoms of contact dermatitis							
1	19	No/no	12	10	–	–	+
2	40	No/no	48	12	–	–	+
3	47	No/no	36	10	–	–	+
4	26	No/no	36	12	–	–	+
5	32	No/no	18	12	–	–	+
6	68	No/no	24	9	–	–	–
7	29	No/no	26	12	–	–	+
8	29	No/no	5	4	–	–	+
9	57	No/no	5	5	–	–	+
10	26	Yes/no	3	3	–	–	+
11	40	No/no	6	3	–	–	+
12	33	No/no	12	12	–	–	+
13	45	No/yes	3	3	–	–	+

A, arms; ERS, epoxy resin system; Fa, forearms; Fh, forehead; H, hands; L, legs; N, neck.

Table 3. Comparison between group A and group B workers

	Group A ^a	Group B ^a	P-value
Age	34.6 ± 11.8	37.8 ± 13.8	0.789 ^b
Prevalence of atopy	2/9	2/13	0.834 ^c
Duration of exposure with other ERSs (months)	33.2 ± 40.1	18 ± 14.9	0.546 ^b
Duration of exposure with Hilti HIT-RE 500 (months)	8.8 ± 3.6	8.2 ± 4.0	0.658 ^b
Frequency of wearing gloves during work	8/9	12/13	0.662 ^c
Immediate wash after skin contact with ERSs	2/9	13/13	0.0002 ^c

^aGroup A were workers with suspected contact dermatitis; group B were workers without suspected contact dermatitis.

^bThe mean age, duration of exposure with other epoxy resin system (ERSs), and duration of exposure with Hilti HIT-RE 500 were calculated and compared between the 2 groups of workers by a Wilcoxon Rank Sum test. A two-tailed *P*-value of 0.05 or less was considered to indicate significance.

^cThe prevalence of atopy, frequency of wearing gloves during work, and frequency of immediate wash after skin contact with ERSs were compared between the 2 groups by Fisher's Exact tests. A one-tailed *P*-value of 0.05 or less was considered to indicate significance.

patient in group A had a positive reaction to the epoxy resin based on DGEBA-R in the standard series (Table 4).

The other positive reactions showed by patch testing in these workers were potassium dichromate (3/9 in group A, 0/11 in group B), parateritary butylphenol formaldehyde resin (1/9 in group A), as well as balsam of Peru and fragrance mix in one worker of group B.

Among the 7 workers who were reactive to component A, 5 received subsequent patch testing for D.E.N. 431 0.25% pet., Epicote 862 0.25% pet., bisphenol F 0.25% pet., Aldrich 406775 0.25% pet., 1,6-hexanediol diglycidyl ether 0.25% pet., TMPTGE 0.25% pet., C13/C15 alkyl glycidylether 0.25% pet. and *m*-xylylene diamine 0.1% pet. 3 were found to have contact allergy to epoxy resins of the bisphenol F-type (D.E.N. 431, Epicote 862, and Aldrich 406775). These workers were also reactive to TMPTGE 0.25% pet. 4 of the 5 workers had contact allergy to 1,6-hexanediol diglycidyl ether. None showed positive reactions to bisphenol F 0.25% pet. or C13/C15 alkyl glycidylether 0.25% pet. (Table 4).

Surprisingly, all the 5 patients showed reactions to *m*-xylylene diamine 0.1% pet. To clarify whether the reactions to *m*-xylylene diamine were due to active sensitization by the first patch-testing, we retested these 5 workers with 0.3% pet. and 0.1% pet. dilutions of component B. All showed negative reactions to both preparations of component B. A control study performed on the 11 group B workers and 12 normal healthy persons showed that none had positive reactions to *m*-xylylene diamine 0.1% pet.

Discussion

The construction workers investigated in this study used an ERS in the form of a 2-component

adhesive during insertion of iron bars into concrete walls in the construction of new subway stations. ERSs are widely used in many trades and industrial fields due to their unique properties, such as high mechanical, chemical and thermal resistance (3). In these ERSs, the resin component may be a mixture of resins based on DGEBA and DGEBF, because the admixture of DGEBF resin (DGEBF-R) prevents DGEBA resin (DGEBA-R) from crystallizing, thus making the ERSs easier to handle at low temperatures (3, 4). Curing of the resin is usually provided by amine hardeners (aliphatic, cycloaliphatic or aromatic amines), nowadays most frequently in the form of polyamine adducts. The required viscosity is adjusted by reactive diluents, mostly various glycidyl ethers (3). While hardened (cured) epoxies should not elicit allergy, handling epoxy solids that are incompletely cured or in a liquid state exposes the user to potential sensitization and the subsequent development of ACD (8). Although DGEBA-Rs are well-known causes of occupational ACD, contact allergy to DGEBF-R may become more common, because bisphenol F epoxy resins are becoming more widely used due to their greater resistance to wear and tear and their lesser viscosity (7–9).

In this study, we found 3 patients with contact allergy to DGEBF-R, but only 1 allergic to DGEBA-R. The other 19 workers were not sensitized to DGEBA-R, even though all of them had a similar or longer exposure history to DGEBA-R than to DGEBF-R. It has been suggested that reactions to DGEBF-R could be explained by its content of DGEBA-R; however, as there were more reactions found in this study to DGEBF-R than to DGEBA-R, the reactions to DGEBF-R were not thought to result from contamination with DGEBA-R. DGEBA-R was present in our DGEBF-R-test preparations (1.9% in Epicote 862, and less than 0.1% in

Table 4. Results of patch testing in the 9 workers with suspected contact dermatitis^a

Test substances	Patient number (Group A workers) ^b									
	Day ^a	1	2	3	4	5	6	7	8	9
Component A 3% pet. ^c	D2	++	+	+	+	+	+	+	+	++
	D4/5	++	++	++	++	++	++	++	–	–
Component A 1% pet. ^c	D2	+	+	+	?	+	+	+	–	–
	D4/5	++	++	++	+	++	++	++	–	–
Component B 0.3% pet. ^c	D2	–	?	+	–	–	–	–	?	?
	D4/5	–	–	?	–	–	–	–	–	–
Component B 0.1% pet. ^c	D2	–	–	–	–	–	–	–	?	–
	D4/5	–	–	–	–	–	–	–	–	–
Bisphenol F 0.25% pet.	D2	–	–	–	–	–	NT ⁱ	NT ⁱ	NT ⁱ	NT ⁱ
	D4/5	–	–	–	–	–	–	–	–	–
Aldrich 406775 0.25% pet. ^d	D2	+	–	–	–	–	NT ⁱ	NT ⁱ	NT ⁱ	NT ⁱ
	D4/5	++	+	+	–	–	–	–	–	–
D.E.N. 431 0.25% pet. ^e	D2	+	?	–	–	–	NT ⁱ	NT ⁱ	NT ⁱ	NT ⁱ
	D4/5	++	–	+	–	–	–	–	–	–
Epicote 862 0.25% pet. ^f	D2	++	+	–	–	–	NT ⁱ	NT ⁱ	NT ⁱ	NT ⁱ
	D4/5	++	+	+	–	–	–	–	–	–
1,6-Hexanediol diglycidyl ether 0.25% pet.	D2	+	++	+	+	–	NT ⁱ	NT ⁱ	NT ⁱ	NT ⁱ
	D4/5	++	++	++	++	–	–	–	–	–
TMPTGE 0.25% pet. ^g	D2	++	++	++	–	–	NT ⁱ	NT ⁱ	NT ⁱ	NT ⁱ
	D4/5	3+	3+	3+	–	–	–	–	–	–
C13/C15 alkyl glycidylether 0.25% pet.	D2	–	–	–	–	–	NT ⁱ	NT ⁱ	NT ⁱ	NT ⁱ
	D4/5	–	–	–	–	–	–	–	–	–
m-Xylylene diamine 0.1% pet.	D2	+	++	+	+	–	NT ⁱ	NT ⁱ	NT ⁱ	NT ⁱ
	D4/5	++	++	++	++	+	–	–	–	–
European standard series Potassium dichromate 0.5% pet.	D2	+	++	+	?	–	–	–	–	–
	D4	+	3+	?	+	–	–	–	–	–
Epoxy resins 1% pet.	D2	++	–	–	–	–	–	–	–	–
	D4	++	–	–	–	–	–	–	–	–
PTBP 1% pet. ^h	D2	–	–	–	?	–	–	–	–	?
	D4	–	–	–	+	–	–	–	–	–

^aAll the patients were patch tested using Finn chamber method on the upper back, with an occlusion time of 48 h. The tests were read according to International Contact Dermatitis Research Group criteria on D2 and D4 or D5 (patient number 4 and 5).

^bGroup A workers were defined as patients with suspected contact dermatitis and group B were employees without suspected contact dermatitis to epoxy resin systems.

^cComponent A of Hilti HIT-RE 500 is a bisphenol A/F-based epoxy resin containing 30%–40% bisphenol A-epoxy resin, 10%–20% bisphenol F-epoxy resin, <15% hexanediol glycidylether, <10% alkylglycidylether. Component B of Hilti HIT-RE 500 contains 30%–40% m-xylylene diamine.

^dAldrich 406775 is a bisphenol F-type epoxy resin, DGEBA(n)-R.

^eD.E.N. 431, a bisphenol F-type epoxy resin produced by the reaction between phenolic novolac resin and epichlorohydrin (DGEBA(n)-R), contains 43.1% DGEBA and less than 0.1% DGEBA.

^fEpicote 862 is a bisphenol F-based epoxy resin produced by the reaction between bisphenol F and epichlorohydrin (DGEBA(n)-R) containing 74.4% DGEBA and 1.9% DGEBA.

^gTMPTGE: trimethylolpropane triglycidyl ether.

^hPTBP: paratertiary butylphenol formaldehyde resin.

ⁱNT: not tested.

D.E.N. 431), but it seems unlikely that reactions to the latter were due to DGEBA-R, because its concentration was too low (3, 7, 10). Concomitant reactions of DGEBA-R and DGEBA(n)-R in 1 patient of this study could be explained by concurrent exposure to both resins during work or to immunological cross sensitization between DGEBA and DGEBA(n)-R (11, 12).

According to the material safety data sheets provided by the manufacturer, Hilti HIT-RE 500 contains 2 reactive diluents, namely TMPTGE and 1,6-hexanediol diglycidyl ether. 3 of the 5 symptomatic workers were reactive to

TMPTGE, and 4 of them had contact allergy to 1,6-hexanediol diglycidyl ether. Guinea pig maximization tests have showed that most glycidyl ethers used as reactive diluents are sensitizers (14–16). 1,6-hexanediol diglycidyl ether is a well-known ERS allergen (3, 4, 6, 17, 18). A multicentre study conducted in Germany from 2002 to 2003 showed that, among the reactive diluents, 1,6-hexanediol diglycidyl ether and 1,4-butanediol diglycidyl ether were the most frequent allergens, with 19.5% and 18.4% positive reactions, respectively (3). However, in the same study, there were only 2 positive reactions to

TMPTGE in 87 tested patients (2.3%). In addition, both reactions were weakly positive (+) reactions, thus made the diagnosis doubtful. In this study, the positive reactions to TMPTGE were all well defined palpable erythema with tiny vesicles (Table 4), indicating these patients had true contact sensitivity to it. There were also 2 cases of contact allergy to TMPTGE in a study of occupational contact allergy from ERSs in workers producing wind turbine rotor blades (18). In another study, 8 of 41 patients with contact allergy to DGEBA-R also had contact allergy to TMPTGE 0.25% (19). In this study, all the 3 patients with contact allergy to TMPTGE were also reactive to DGEBA-R. The concomitant reactions to TMPTGE and DGEBA-R might be due to cross sensitization or concurrent sensitization of both allergens during work. Because sensitization to reactive diluents is common, they should be included in the patch test series if contact allergy to ERSs is suspected (14).

Although all 20 patch-tested workers were not reactive to component B at 0.3% pet. and 0.1% pet. at the first patch testing, the 5 symptomatic patients showed reactions to *m*-xylylene diamine 0.1% pet., which is the main ingredient of component B. The reason for this discrepancy might be inadequate concentrations of component B in the first patch test. According to the material safety data sheets, the component B of Hilti HIT-RE 500 contains 30%–40% *m*-xylylene diamine, and we diluted the component B to 0.3% pet. and 0.1% pet., resulting in patch test concentrations with 0.03%–0.12% pet. *m*-xylylene diamine. The true concentration of *m*-xylylene diamine might be lower than 30%, leading to inadequate concentration in the first patch test. Because there were no volunteers reactive to *m*-xylylene diamine in the control study, a false positive reaction is less likely. The possibility of active sensitization during the first patch testing could also be excluded by the non-reactivity of these 5 workers at the second patch testing with 0.3% pet. and 0.1% pet. of component B.

Among the hardeners, *m*-xylylene diamine was found to be the most frequent allergen in one multicentre study, giving a 13.8% positive rate in 87 patch-tested patients (3). However, *m*-xylylene diamine has been reported to be an ERS allergen only in a few cases (3, 6, 20–22). Because it has been reported to be a relatively common allergen in other fields, and according to the findings of the study conducted by Geier *et al.* (3) and the results of this study, *m*-xylylene diamine should be included in an ER test series.

In one study conducted by Jolanki *et al.*, (4) it was found that 93 of a total of 891 patients (10.4%) were exposed to ERSs at work, and painting, gluing and insulating work in the electrical industry were the most common occupational exposures. However, Geier *et al.* (3) recently showed patients working with ERSs in the building trade were the largest occupational group among the total 92 patients enrolled in their study. In accordance with their findings, we also noted skin protection is 'traditionally' inadequate in the construction trade. In this study, we found all the workers wore T-shirts during work. None of them used laminated multilayered plastic gloves especially developed for ERS work, and only some of them occasionally wore cotton gloves, which are not suitable for protection from ERSs (3, 4).

The locations of the dermatitis in this study is in accord with previous studies, which showed that hands and arms were the most common sites of involvement in occupational contact dermatitis from ERSs, while face and/or neck involvement was frequent, affecting about 50% of those occupationally exposed (3, 4). Face dermatitis may be due to contamination by touching the face with the hands or gloves, or to airborne dusts containing uncured ER, or to volatile ERS components (3, 4). Reactive diluents and hardeners were considered the most probable causes of airborne epoxy dermatitis, because they are more volatile than low molecular resins (4). In our patients, airborne contact dermatitis is less likely due to the close relationship between direct contact and development of skin symptoms, because none of the patients had lesions located only on the face, and washing off contactants immediately after direct contact with ERSs is the most important preventative factor for development of ACD to ERSs.

It is difficult to encourage workers to wear protective clothing and long protective gloves in Taiwan, due to the hot weather. Our patients used cotton gloves occasionally for protection during work. However, textile gloves have been found to give insufficient protection from ERSs, and the permeable gloves probably aggravated inflammation and promoted sensitization (4). Although it is well known that hand dermatitis is significantly lower among workers wearing suitable gloves, the selection of a suitable glove is difficult (3). Pegum (23) has shown that ER penetrates rubber gloves, and that better protection is obtained with vinyl gloves. 4HTM gloves have been found to provide excellent protection against ERSs and the compounds used with them (24). It has also been reported that thick

polyvinyl chloride (PVC) gloves can be useful, as epoxy resins do not penetrate them as easily as they do other types of plastic and rubber gloves (8). Nitrile gloves also offer adequate protection against epoxy resins (8). However, penetration of epoxy resins and hardeners through common protective gloves is relatively slow (hours) compared with that of reactive diluents present (minutes) (14). Therefore, we have encouraged the workers in this company to wear two pairs of disposable PVC gloves and to replace contaminated gloves immediately. We also found that washing off contactants immediately after contamination of the skin with ERSs is the most important preventative factor for developing ACD to ERSs in these workers. The hot weather in Taiwan and profuse sweating in these workers during work might be contributing factors, because both high sweating conditions and high temperatures can enhance skin penetration of contactants (25). Therefore, we also educated the workers to avoid direct contact of the ERSs with their skin; if contamination of the skin with ERSs is noted, it is mandatory to wash off the contactants immediately to prevent skin symptoms.

Contact allergy to DGEBA-R or DGEBF-R may go undetected until the D7 patch test reading (7, 18). In this study, we performed D2 and D4/5 readings in patch-tested workers. The frequency of contact allergy to DGEBA-R or DGEBF-R might therefore be underestimated (18). However, all these 20 workers were followed at our special clinic for at least 3 months, and we did not observe delayed reactions on the patch-tested sites in patients with negative results at D4/5 readings. We surmise that the high temperature/humidity weather in Taiwan and frequent sweating of these workers lead to an enhanced occlusion effect of patch testing and increased positive rates at D4/5 readings. The same factors might also contribute to the lower rates of doubtful patch-test reactions and higher rates of irritant reactions in this study. Because some chemicals in ERSs are also irritants, the occlusion time of 48 h for these allergens might be too long for performing patch testing in Taiwan, as evidenced by the high positivity rates at the D2 reading in group A workers. At the D2 reading, none of the group B workers and normal controls had positive reactions to the ERS chemicals tested in this study, so a non-specific irritant reaction is less likely.

In conclusion, this study presents the development of ACD from a bisphenol A/F-based ERS in subway construction workers. The patch testing results showed that sensitization occurs not

only to the resins (DGEBA-R) but also to the hardener (*m*-xylylene diamine) and reactive diluents (TMPTGE and 1,6-hexanediol diglycidyl ether). Concomitant sensitization to several substances is common in occupational settings (3); therefore, it is of great importance to perform patch testing with all materials to which patients have been exposed (5). Despite the availability of extensive patch test series, testing with patients' own ERSs and each component of the ERS, including the resins, reactive diluents and hardeners, appropriately diluted, remains important (4, 8).

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