

Can simultaneous contact allergies to phenyl glycidyl ether and epoxy resins of the bisphenol A/F-types be explained by contamination of the epoxy resins?

ANN PONTÉN, ERIK ZIMERSON AND MAGNUS BRUZE

Department of Occupational and Environmental Dermatology, Lund University,
Malmö University Hospital, SE-20502 Malmö, Sweden

Background: Simultaneous contact allergies to epoxy resins based on diglycidyl ether of bisphenol A (DGEBA-R) or epoxy resins of the bisphenol F-type and the reactive diluent phenyl glycidyl ether (PGE) have been reported. The reason might be cross-reactivity, exposure to an epoxy resin system with PGE as a component, or contamination by PGE in the epoxy resin.

Aims: To study contamination by PGE, 20 commercial epoxy resins were analysed for the presence of PGE. To study contact allergy to PGE and its relation to epoxy resins by inserting PGE in the standard series.

Results: Among 2227 patients, 7 reacted to PGE. Of 23 (30%) patients, 7 with contact allergy to DGEBA-R and 7/19 (37%) with contact allergy to an epoxy resin of the bisphenol F-type reacted to PGE. All 7 patients with contact allergy to PGE reacted both to the DGEBA-R and to the epoxy resin of the bisphenol F-type. PGE was found in 90% of the investigated resins. The amounts of PGE ranged between 0.004% w/w and 0.18% w/w.

Conclusion: Most probably, the presence of PGE as a contaminant in epoxy resins is of minor importance for the sensitization, but possibly the contamination of PGE might elicit contact dermatitis in individuals with a high reactivity to PGE.

Key words: chemical analysis; contact allergy; delayed hypersensitivity; epoxy resin; patch testing; phenyl glycidyl ether; reactive diluent. © Blackwell Munksgaard, 2008.

Accepted for publication 10 May 2008

Epoxy resin systems (ERSs) are often modified by the addition of ingredients such as reactive diluents. These are used mainly to reduce the viscosity of the epoxy resin. Reactive diluents are epoxy compounds and may be mono-functional, e.g. contain one reactive epoxy group or poly-functional, and they may be aromatic or aliphatic (1). Several different epoxy-based reactive diluents are known to cause occupational contact allergy (2). Phenyl glycidyl ether (PGE, Fig. 1) is an epoxy-based aromatic reactive diluent, which is reported as an occupational contact allergen in workers exposed to ERSs (3–8). The most common epoxy resin is based on bisphenol A and contains the monomer diglycidyl ether of bisphenol A (DGEBA). Many cases with contact allergy to PGE simultaneously have contact allergy to epoxy

resin based on bisphenol A (DGEBA-R), which is present in the European standard patch test series, but several cases without simultaneous contact allergy to DGEBA-R have also been reported (3–5, 9). Contact allergy to PGE can be found in workers exposed to ERSs where no obvious source of PGE exposure is found (10). It has been reported that PGE has rarely been used in ERSs the past few years (8). The partially overlapping patterns of contact allergies to DGEBA-R and PGE might be explained by simultaneous exposure to PGE present as a reactive diluent in an ERS, the presence of PGE as a contaminant in the epoxy resin itself, or by cross-reactivity between DGEBA and PGE. PGE is chemically similar both to the monomers in DGEBA-R and to the main constituents in epoxy resins of the

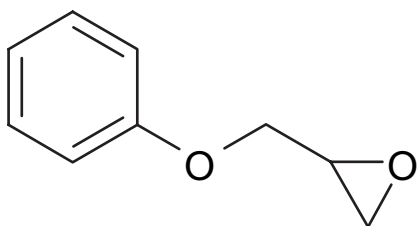


Fig. 1. Chemical structure of phenyl glycidyl ether (PGE).

bisphenol F-type. The latter types of epoxy resin contain the diglycidyl ether of bisphenol F (DGEBF), which has three different isomers. These are *p,p'*-DGEBF, *o,p'*-DGEBF, and *o,o'*-DGEBF (Figs 1 and 2) (11, 12). The epoxy resins of the bisphenol F-type can be produced from reacting epichlorohydrin either with bisphenol F or with phenolic novolacs (DGEBA-R and DGEBA-R, respectively). DGEBA-R, on the other hand, is manufactured so as to contain virtually only one isomer of the monomer diglycidyl ether of bisphenol A (*p,p'*-DGEBA) (Fig. 2) (11). Because of similarities in the chemicals used for the production, it could be suspected that PGE would be present as a contaminant in epoxy resins. Possibly, that would be the case especially for epoxy resins based on phenolic novolac. These resins are described to have a repetitive unit of one aromatic ring compared with epoxy resins based on bisphenol A in which the monomer has two aromatic rings (Fig. 3) (11). PGE would then

hypothetically correspond to the smallest repetitive unit of DGEBA-R.

To evaluate the frequency of simultaneous contact allergies to epoxy resin and PGE in consecutive dermatitis patients, PGE was included in our baseline patch test series, which already contained an epoxy resin of the bisphenol F-type. Furthermore, nine patients with previously known contact allergy to DGEBA-R and an epoxy resin of the bisphenol F-type were investigated with respect to simultaneous contact allergy to PGE. To evaluate the possibility of sensitization to PGE because of the presence of PGE as a contaminant in epoxy resins, a selection of commercial epoxy resins not declared to contain PGE were analysed. Patch test substances used for detecting contact allergy to DGEBA-R in standard patch test series were also analysed with respect to PGE.

Materials and Methods

Substances

PGE 0.25% w/w in petrolatum (pet.) (Chemo-technique, Tygelsjö, Sweden) was used for patch testing in our baseline series. For patch testing, patients with dilution series, PGE (Acros Organics, Geel, Belgium), were bought. According to the manufacturer of the latter chemical, the concentration was 99%. The purity of this substance was investigated by high-performance liquid chromatography (HPLC). The DGEBA-R test substance

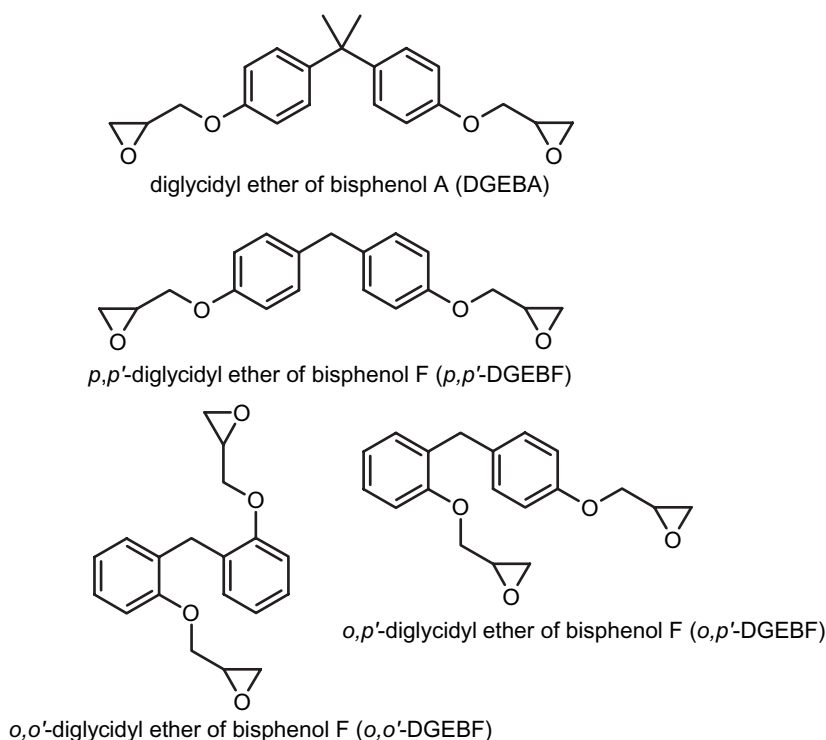


Fig. 2. The main components in epoxy resins based on bisphenol A and F.

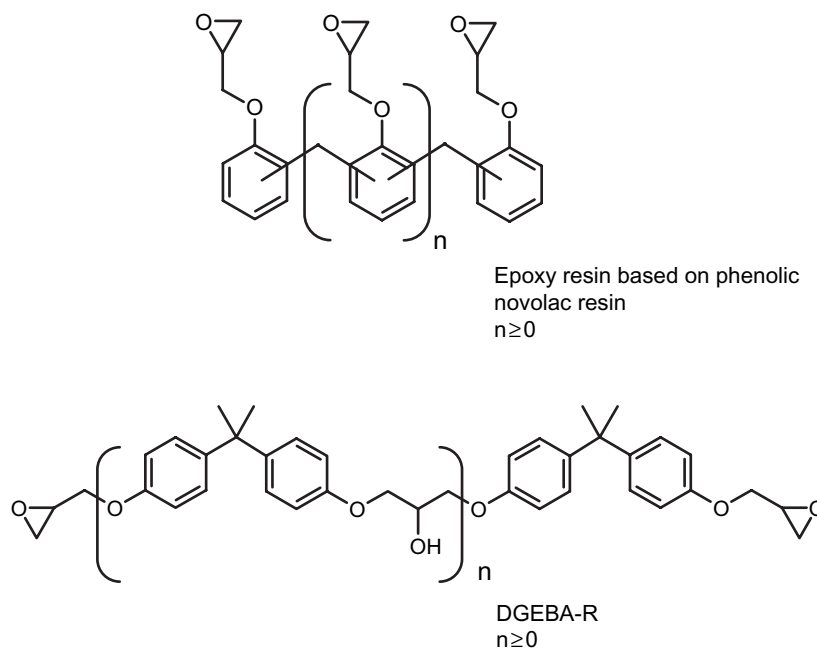


Fig. 3. Chemical structures of epoxy resins based on phenolic novolac resins and epoxy resins based on bisphenol A (DGEBA-R).

(Chemotechnique) has been analysed by us and found to contain 92.1% w/w DGEBA and no detectable levels of the isomers of DGEBF (13). This DGEBA-R was used in the present study for preparing dilution series in acetone for patch testing. Methods for analyses of the concentrations of PGE and DGEBA in the patch test preparations in pet. bought from Chemotechnique had not been developed at the time of the study. The analysed epoxy resins were obtained from three main commercial producers: Ciba Specialty Chemicals (Västra Frölunda, Sweden), Dow Epoxy Products (Stockholm, Sweden), and Shell Chemicals (Bromma, Sweden). The resins were declared to be DGEBF-R, DGEBF(n)-R, DGEBA-R, or mixtures of DGEBA-R and DGEBF-R (Table 3). An older DGEBF-R (Rütapox 0161), kept at our department and provided by Bakelite Gesellschaft mbH, Duisburg, Germany, was also analysed. Patch test chemicals used within standard patch test series for the detection of contact allergy to DGEBA-R were obtained from Chemotechnique Diagnostics (Tygelsjö, Sweden), Hermal (Reinbek, Germany), Pharmacia & Upjohn Hillerød AS (Hillerød, Denmark) and from two producers of baseline patch test series outside Europe and the USA. All these resins are previously described in detail with respect to monomer content, including the epoxy resins of the bisphenol F-type used in our standard series (12). In the present study, D.E.N. 431 was used for patch testing DGEBF(n)-R in dilution series.

The following chemicals were used for chemical analyses: ethyl acetate, acetonitrile, and heptane

from Lab Scan (Dublin, Ireland), ethanol from Kemetyl AB (Haninge, Sweden), methanol from Mallinckrodt Baker B.V. (Deventer, the Netherlands), and sodium sulfate anhydrous from Acros Organics.

Patients

During the period 2001 to June 2004, 2227 (39% male and 61% female) patients with suspected contact allergy were consecutively patch tested with the baseline patch test series at the Department of Occupational and Environmental Dermatology, Malmö, Sweden, in which PGE and an epoxy resin of the bisphenol F-type were inserted. They were tested either as part of an investigation of suspected occupational dermatitis [1381 (62%) patients] or non-occupational contact allergy [846 (38%) patients]. Furthermore, nine patients retrospectively found to have contact allergy to DGEBA-R and DGEBF-R were patch tested simultaneously with DGEBA, the DGEBF isomers and PGE. The results from patch testing with the epoxy resin monomers are described elsewhere (13).

Patch testing

Epoxy resins of the bisphenol F-type were patch tested in 0.25% pet. in the standard series (14). Within the group of nine patients with previously known contact allergy to the epoxy resins, three patients with already established contact allergy to PGE were patch tested with five 10-fold serial dilutions with highest concentration 0.25% w/v

of PGE in acetone. Finn chambers[®] (Epitest Ltd Oy, Tuusula, Finland) on Scanpor (Norgesplaster A/S, Vennesla, Norway) were used. 15 µl of the solutions was applied on a filter paper disc in each test chamber with a micropipette. The other six patients were tested with PGE 0.25% pet. bought from Chemotechnique. The Ethics Committee of Lund University Medical Faculty approved the study of the patients enrolled for additional patch testing with components in epoxy resins. The patch test reactions were scored according to International Contact Dermatitis Research Group criteria and read on D3 or D4 and D7 or D8.

Chemical analyses

Analysis of epoxy resin samples. The epoxy resin samples, 0.3–0.5 g, were accurately weighed and dissolved in around 5 ml ethyl acetate and diluted to a final volume of 50.0 ml with ethanol. For resins that could not be diluted in ethanol, ethyl acetate was used. Prior to the HPLC analysis, these solutions were diluted 10–500 times with the eluent used for the analysis. Because of different substances in the investigated epoxy resins that interfered with the PGE peak, we used two analytical methods to enhance the reliability of the results.

Analysis of PGE in resins with method 1. The analysis was performed with an HPLC system, which is described elsewhere (15). Linear gradient elution with solvent A (acetonitrile/water 40/60) and solvent B (acetonitrile) was used. The linear gradient elution was maintained at 0% B for 15 min, reached 100% B at 16 min, and was maintained at 100% for another 6 min before returning to 0% B in 1 min. The detector was operated at a wavelength of 280 nm. The retention times of the sample peaks were compared with the retention time of the reference substance (PGE) peak. The area or height of the sample peak and the reference substance peak was measured and the concentration of PGE in the sample calculated.

Analysis of PGE in resins with method 2. The analysis was performed with the same HPLC system as in method 1. Linear gradient elution with solvent A (acetonitrile/water 30/70) and solvent B (acetonitrile) was used. The linear gradient elution was maintained at 0% B for 18 min, reached 100% B at 19 min and was maintained at 100% for another 6 min before returning to 0% B in 1 min. The detector was operated at a wavelength of 230 nm. The retention times of the sample peaks were compared with the retention time of the reference substance (PGE) peak. The area or height of the sample peak and the reference substance peak was measured and the concentration of PGE in the sample calculated.

If the sample showed different concentrations of PGE when analysed by method 1 and 2, respectively, the lower result was chosen.

NMR spectrometry. ¹H nuclear magnetic resonance (NMR) spectra were recorded from samples dissolved in CDCl₃ using a Bruker ARX, 500 MHz spectrometer (Bruker BioSpin, Täby, Sweden). Internal reference was chloroform (δ = 7.27 ppm).

Mass spectrometry (MS). A Jeol SX 102 mass spectrometer (Jeol Ltd., Tokyo, Japan) was used with direct inlet to obtain mass spectra [electron impact (EI), 70 eV] of the isolated compound.

Isolation and identification of PGE. The substance indicated to be PGE in the HPLC analysis was recovered from one of the investigated resins (Araldite GY282). About 125 g of the resin was mixed with 70 ml ethyl acetate, 200 ml methanol, and 300 ml water in a distillation flask (1l). The mixture was warmed and maintained at 40°C and vacuum distilled until a resinous residue was formed in the distillation flask. Several distillates were collected and analysed by HPLC. The distillates, which contained most of the suspected PGE, were combined and then extracted twice with 150 ml heptane. The heptane phase was collected, dried by the addition of anhydrous sodium sulfate, and then filtered. Evaporation of heptane phase gave 5 mg substance. ¹H NMR and EI MS data from the isolated substance correspond to published data for PGE (16–19).

Results

Contact allergy to PGE

PGE in the standard series. During 3.5 years of patch testing with PGE included in the baseline series, 7 (0.3%) cases of contact allergy to this substance were found (Table 1). All these simultaneously had contact allergies to DGEBA-R and

Table 1. Simultaneous contact allergies to PGE and epoxy resins in 2227 patients tested with the baseline patch test series with PGE 0.25% pet. and a DGEBF(n)-R 0.25% pet. inserted^a

Patient	PGE	DGEBA-R	DGEBF(n)-R
1	++	+++	+
2	+	++	+
3	+++	++	+++
4	+	++	++
5	+	++	+++
6	++	+++	+++
7	+++	+++	++

DGEBA-R, epoxy resin based on diglycidyl ether of bisphenol A; DGEBF(n)-R, epoxy resin of the bisphenol F-type based on novolac; PGE, phenyl glycidyl ether.

^aThe tests were read on D3 or D4 and D7 or D8. The highest scores recorded are given.

an epoxy resin of the bisphenol F-type. During this period, 23 patients (1%) with contact allergy to DGEBA-R and 19 patients (0.9%) with contact allergy to an epoxy resin of the bisphenol F-type were found. Thus, 7/23 (30%) and 7/19 (37%), respectively, of the epoxy-resin-allergic patients had simultaneous reactions to PGE and the epoxy resins in question.

Patients with known contact allergy to epoxy resin. Among the nine patients previously known to have contact allergies both to DGEBA-R and to an epoxy resin of the bisphenol F-type, 7 reacted to PGE. Three of these 7 patients had strong (+++) reactions to PGE on D3 or D7 (Table 2). Among the three patients patch tested with the dilution series, the lowest concentration of PGE to elicit a positive reaction was 0.025% w/v on D7. The same patient reacted to DGEBA-R 0.10% w/v and to the DGEBF-R 0.0010% w/v on D7.

Chemical analyses

PGE (Acros) was not found to contain DGEBA or DGEBF (detection limits <0.0002% w/w DGEBA and <0.002% w/w DGEBF). The results of the analyses with respect to PGE in commercial epoxy resins and patch test substances used for detection of contact allergy to DGEBA-R in standard series are given in Table 3. The DGEBA-Rs in which PGE could be detected contained 0.004–0.035% w/w PGE, and 0.016–0.18% w/w PGE was detected in the epoxy resins of the bisphenol F-type. The amounts of PGE in the patch test chemicals ranged from 0.008% to 0.04% w/w PGE.

Discussion

Although PGE could be anticipated to be present in the occupational and non-occupational environment to a lesser degree than the monomers in liquid epoxy resins, contact allergy to PGE can be judged to be comparatively common in patients with contact allergy to DGEBA-R and epoxy resins of the bisphenol F-type. Possibly, simultaneous contact allergies to PGE and these epoxy resins can be explained by cross-reactivity because of the chemical similarity (Figs 1 and 2). PGE might penetrate the skin easier because of its lower molecular weight (MW 150). The reactive diluent, *o*-cresyl glycidyl ether (*o*-CGE, MW 165), which also contains one epoxy group and an aromatic ring, has been shown to penetrate through human skin *in vitro* easier than DGEBA (MW 340) (20). After 24 hr, approximately 75 times more *o*-CGE than DGEBA had penetrated human dermatomed skin. Occlusion doubled the penetration rate for *o*-CGE but had no effect on

Table 2. Contact allergy to PGE in nine patients with contact allergy to DGEBA-R and an epoxy resin of the bisphenol F-type

Patient	DGEBA-R 1.0% ac ^a	DGEBF(n)-R 1.0% ac ^a	PGE 0.25% pet.	PGE 0.25% ac ^a
1	++ ++ (+) –	NT ^c	–	NT
2	+++ +++ +++ ++ –	+++ +++ ++ +	+++	NT
3	++ (+) –	++ (+) –	+ ^b	++ –
4	– ^d	– ^d	+ ^b	–
5	++ ++ –	+++ ++ ++ +	+ ^b	++ + –
6	+++ +++ +++ –	+++ +++ (+) –	+++	NT
7	+++ +++ +++ (+) –	+++ +++ +++ ++ –	+++	NT
8	+++ ++ (+) –	+ + –	–	NT
9	+++ +++ ++ –	+++ +++ ++ –	++	NT

D, day; DGEBA-R, epoxy resin based on diglycidyl ether of bisphenol A; DGEBF-R(n), epoxy resin of the bisphenol F-type based on novolac; NT, not tested; PGE, phenyl glycidyl ether. The tests were read D3 and D7. The highest scores recorded are given.
^aReactions to five 10-fold serial dilutions in acetone beginning with the concentration given in the head of the column.

^bPatients 3–5 were patch tested with PGE 0.25% pet. prior to the study and were tested with serial dilutions. The results for PGE 0.25% pet. from these earlier occasions are given.

^cPatient 1 had a + reaction to the epoxy resin of the bisphenol F-type in the baseline series and was not tested with the dilution series because of lack of space on the back.

^dPatient 4 reacted with a ++ reaction to both epoxy resins in the baseline series.

DGEBA. This was thought to be because of the fact that occlusion prevented evaporation of *o*-CGE (20). It can be assumed that the same difference exists for PGE compared with DGEBA. The calculated log_{P_{o/w}} for PGE and *o*-CGE is 1.48 and 1.98, respectively, and the log_{P_{o/w}} of DGEBA is 3.84 (21). Based on the presence of the reactive epoxy group and the greater penetration because of a lower MW, PGE can be suspected to be a stronger or at least as strong sensitizer as DGEBA and the DGEBF isomers.

Table 3. Analysis of PGE in epoxy resins and patch test substances

Epoxy resins	PGE (% w/w) ^a
DGEBF-R	
Araldite Gy 285	0.049
Araldite Gy 281	0.18
Araldite Gy 282	0.16
Epikote 862	0.025
Rütapox	0.12
DGEBF(n)-R	
Araldite EPN 1179	0.016
Araldite EPN 1180	0.03
Epikote/epon 154	0.16
D.E.N. 431	0.038
D.E.N. 438	0.02
DGEBA-R/DGEBF-R	
Araldite Py 304	0.067
Araldite Py 302-2	0.18
Epikote 232	0.01
D.E.R. 351	0.027
D.E.R. 352	0.019
DGEBA-R	
Araldite Gt 6071	<0.016
Araldite Gy 280	0.004
Araldite Gy 250	0.019
Epikote 828	<0.006
D.E.R. 331	0.035
Patch test substances	
Chemotechnique	0.008
Pharmacia Upjohn	0.04
Hermal	0.018
A	<0.02
B	<0.007

DGEBF-R, epoxy resins based on bisphenol F; DGEBF(n)-R, epoxy resin of the bisphenol F-type based on novolac; DGEBA-R/DGEBF-R, mixtures of epoxy resins based on bisphenol A and F; DGEBA-R, epoxy resin based on bisphenol A; <, detection limit. A and B, patch test chemicals obtained from patch test producers outside the EU and the USA.

^aThe content of PGE was analysed with two different HPLC systems. The lowest value obtained is listed.

The sensitizing capacity and cross-reactivity of PGE have been investigated, and the results show that PGE is a strong sensitizer and that the primary sensitizer may be of importance for the cross-reactivity pattern (22). A case report on active sensitization to PGE in a patient who previously had contact allergy to DGEBA-R has been published (23). PGE might also be a stronger irritant compared with the epoxy resin monomers. Based on older studies in humans, DGEBA-R is known to be a minor or no irritant at 10–25% pet. (24, 25). Because of its higher vapour pressure, PGE is more volatile compared with DGEBA, and it is suspected to cause airborne contact allergy. Contact urticaria to PGE has also been described (26).

The epoxy group contains a chiral carbon atom and therefore – similar to DGEBA and the DGEBF isomers – PGE is a mixture of stereoisomers, but if or how this contributes to the sensitizing capacity is unknown.

There are several reports of contact allergy to PGE without simultaneous reaction to DGEBA-R, and approximately 40–50% of the patients described did not react to DGEBA-R in the standard series (3–5, 9). Among the patients patch tested with our standard series, 3/7 PGE-allergic patients had previous or present occupational exposure to ERSs, but whether they had been exposed to PGE or not could not be confirmed. A few of our nine patients with previously known contact allergies to the epoxy resins who were patch tested with PGE had worked with epoxy resins many years ago and information about their work material could not be procured. Six of these patients (all females) had no obvious source that explained their contact allergy to the epoxy resins and PGE. In a study of workers exposed to ERS, 4 individuals among 325 patch-tested workers reacted to PGE (10). At the time of that study, no ERSs to which the workers were exposed were declared to contain PGE. All four workers had simultaneous contact allergy both to DGEBA-R and to the tested epoxy resins of the bisphenol F-type, and thus 4/26 (15.4%) of those who had contact allergy to the latter type of resin reacted to PGE (10). It can be hypothesized that the primary exposure of either PGE or monomers of the epoxy resins could be of importance for the pattern of simultaneous contact allergies to these allergens.

Compared with the concentrations of known sensitizers, i.e. DGEBA and the DGEBF isomers, the presence of PGE in the commercial epoxy resins is judged to be of marginal importance for the sensitizing capacity of these resins. In a patient with a high reactivity (0.025% w/v) to PGE, the contamination with this substance (0.18% w/w; Table 1) could be suspected to elicit dermatitis and possibly airborne dermatitis. Especially, if sensitized only to PGE or with a higher sensitivity to PGE than to DGEBA, it could be of clinical importance. Although not tested with the dilutions series of PGE within the present study, it can be anticipated that the patients with strong (+++) reactions might react to an even lower concentration of PGE. In the present study, comparisons between reactions to the epoxy resins and PGE are difficult because PGE was not tested in an equimolar concentration compared with the epoxy resins. Furthermore, the patients tested with dilution series are too few to allow any conclusions on the relation between the reactivity to the tested epoxy resins and PGE.

There was no obvious relation between the content of PGE in the studied epoxy resins and the total content of epoxy resin monomers in the same epoxy resins according to the results published earlier (12). Theoretically, epoxy resins of the

bisphenol F-type based on novolacs have a smaller repetitive unit than epoxy resins based on bisphenol A or F (Fig. 3). Therefore, it was suspected that they could contain comparatively more PGE. However, only slightly more PGE was found in the epoxy resins of the bisphenol F-type than in the DGEBA-Rs, and no obvious difference between DGEBA-R and DGEBAF(n)-R was found (Table 1). The reason for PGE being present at all in the investigated resins is unknown but assumed to be a contaminant resulting from the manufacturing processes, which most probably contain phenol and epichlorohydrin.

Conclusion

For primary sensitization to PGE, the presence of this substance as a contaminant in DGEBA-R and epoxy resins of the bisphenol F-type seems to be of minor importance. In some patients, previously sensitized to PGE either through cross-reactivity with DGEBA-R and epoxy resins of the bisphenol F-type or primarily to PGE, the contamination of PGE in epoxy resins might be of importance for eliciting contact dermatitis, including airborne dermatitis. Therefore, PGE and other reactive diluents to which the patient is exposed should be tested separately.

Acknowledgements

The authors thank Margareta Bjerkemo and Lena Persson for skilful technical assistance; Ciba Specialty Chemical, Dow Epoxy Products, and Shell Chemicals for kindly providing the epoxy resin samples; and Chemotechnique Diagnostics; Hermal, and Pharmacia Upjohn & Hillerød AS (Hillerød, Denmark) for kindly providing the patch test chemicals. The study was supported by grants from the Swedish Council for Work Life Research and the Vårdal Foundation for Health Care Sciences and Allergy Research.

References

- Shaw S J. Additives and modifiers for epoxy resins. In: *Chemistry and Technology of Epoxy Resins*, Ellis B (ed.): Glasgow, Blackie Academic & Professional, 1993: 117–120.
- Jolanki R, Kanerva L, Estlander T. Epoxy resins. In: *Handbook of Occupational Dermatology*, Kanerva L, Elsner P, Wahlberg J E, Maibach H I (eds): Berlin, Heidelberg, New York, Springer-Verlag, 2000: 574–582.
- Rudzki E, Rebandel P, Grzywa Z, Jakiminska B. Dermatitis from phenyl glycidyl ether. *Contact Dermatitis* 1983; 9: 90–91.
- Jolanki R, Kanerva L, Estlander T, Tarvainen K, Keskinen H, Henriks-Eckerman M L. Occupational dermatoses from epoxy resin compounds. *Contact Dermatitis* 1990; 23: 172–183.
- Angelini G, Rigano L, Foti C, Grandolfo M, Vena G A, Bonamonte D, Soleo L, Scorpiniti A A. Occupational sensitization to epoxy resin and reactive diluents in marble workers. *Contact Dermatitis* 1996; 35: 11–16.
- Conde-Salazar L, Gonzalez de Domingo M A, Guimaraens D. Sensitization to epoxy resin systems in special flooring workers. *Contact Dermatitis* 1994; 31: 157–160.

- Holness D L, Nethercott J R. The performance of specialized collections of bisphenol A epoxy resin system components in the evaluation of workers in an occupational health clinic population. *Contact Dermatitis* 1993; 28: 216–219.
- Geier J, Lessmann H, Hillen U et al. An attempt to improve diagnostics of contact allergy due to epoxy resin systems. First results of the multicentre study EPOX 2002. *Contact Dermatitis* 2004; 51: 263–272.
- Jolanki R, Estlander T, Kanerva L. Contact allergy to an epoxy reactive diluent: 1,4-butanediol diglycidyl ether. *Contact Dermatitis* 1987; 16: 87–92.
- Pontén A, Carstensen O, Rasmussen K, Gruvberger B, Isaksson M, Bruze M. Epoxy-based production of wind turbine rotor blades: occupational contact allergies. *Dermatitis* 2004; 15: 33–40.
- Ellis B. The synthesis and manufacture of epoxy resins. In: *Chemistry and Technology of Epoxy Resins*, Ellis B (ed.): Glasgow, Blackie Academic & Professional, 1993: 16–36.
- Pontén A, Zimerson E, Sörensen Ö, Bruze M. Chemical analysis of monomers in epoxy resins based on bisphenols F and A. *Contact Dermatitis* 2004; 50: 289–297.
- Pontén A, Zimerson E, Bruze M. Contact allergy to the isomers of diglycidyl ether of bisphenol F. *Acta Derm Venereol* 2004; 84: 12–17.
- Pontén A, Bruze M. Contact allergy to epoxy resin based on diglycidyl ether of bisphenol F. *Contact Dermatitis* 2001; 44: 98.
- Pontén A, Zimerson E, Sörensen Ö, Bruze M. Sensitizing capacity and cross-reaction pattern of the isomers of diglycidyl ether of bisphenol F in the guinea pig. *Contact Dermatitis* 2002; 47: 293–298.
- Dorsey J G, Dorsey G F, Rutenberg A C, Green L A. Determination of epoxide equivalent weight of glycidyl ethers by proton magnetic resonance spectrometry. *Anal Chem* 1977; 49: 1144–1145.
- Brown R M, Creaser C S. The electron impact and chemical ionization mass spectra of some glycidyl ethers. *Org Mass Spectrom* 1980; 15: 578–581.
- Liu Z Z, Chen H C, Cao S L, Li R T. A novel method for synthesis of aryl glycidyl ethers. *Synth Commun* 1994; 24: 833–838.
- Waagen V, Hollingsæter I, Partalia V, Thorstad O, Anthonsen T. Enzymatic resolution of butanoic esters of 1-phenyl, 1-phenylmethyl, 1-[2-phenylethyl] and 1-[2-phenoxyethyl] ethers of 3-methoxy-1,2-propanediol. *Asymmetry* 1993; 4: 2265–2274.
- Boogaard P J, Denneman M A, Van Sittert N J. Dermal penetration and metabolism of five glycidyl ethers in human, rat and mouse skin. *Xenobiotica* 2000; 30: 469–483.
- ChemDraw Ultra Cambridge Soft Corporation, Cambridge, MA, 2003.
- Pontén A, Zimerson E, Bruze M. Sensitizing capacity and cross-reactivity of phenyl glycidyl ether (abstract). *Contact Dermatitis* 2004; 50: 166.
- Kanerva L, Estlander T. Simultaneous active sensitization to multiple chemicals. *Contact Dermatitis* 1998; 38: 174–5.
- Lea W, Block W, Cornish H. The irritating and sensitizing capacity of epoxy resins. *AMA Arch Derm* 1958; 78: 304–308.
- Kligman A. The identification of contact allergens by human assay. *J Invest Dermatol* 1966; 37: 393–409.
- Sasseville D. Contact urticaria from epoxy resin and reactive diluents. *Contact Dermatitis* 1998; 38: 57–58.

Address:

Ann Pontén, MD, PhD
Department of Occupational and
Environmental Dermatology
Malmö University Hospital
SE-20502 Malmö
Sweden
Tel: +46 40 33 78 33
Fax: +46 40 33 62 13
e-mail: ann.ponten@skane.se