



Journal of Toxicology and Environmental Health, Part A: Current Issues

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/uteh20>

The Effect of Clothing Care Activities on Textile Formaldehyde Content

Rachel M. Novick^a, Mindy L. Nelson^a, Meg A. McKinley^a, Grace L. Anderson^a & James J. Keenan^a

^a Cardno ChemRisk, San Francisco, California, USA

To cite this article: Rachel M. Novick, Mindy L. Nelson, Meg A. McKinley, Grace L. Anderson & James J. Keenan (2013) The Effect of Clothing Care Activities on Textile Formaldehyde Content, Journal of Toxicology and Environmental Health, Part A: Current Issues, 76:14, 883-893, DOI: [10.1080/15287394.2013.821439](https://doi.org/10.1080/15287394.2013.821439)

To link to this article: <http://dx.doi.org/10.1080/15287394.2013.821439>

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the "Content") contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms & Conditions of access and use can be found at <http://www.tandfonline.com/page/terms-and-conditions>

THE EFFECT OF CLOTHING CARE ACTIVITIES ON TEXTILE FORMALDEHYDE CONTENT

Rachel M. Novick, Mindy L. Nelson, Meg A. McKinley, Grace L. Anderson, James J. Keenan

Cardno ChemRisk, San Francisco, California, USA

Textiles are commonly treated with formaldehyde-based residues that may potentially induce allergic contact dermatitis in sensitive individuals. This study examined the initial formaldehyde content in clothing and resulting changes due to care activities. Twenty clothing articles were examined and 17 of them did not have detectable levels of formaldehyde. One shirt contained a formaldehyde concentration of 3172 ppm, and two pairs of pants had formaldehyde concentrations of 1391 ppm and 86 ppm. The two highest results represent formaldehyde levels that are up to 40-fold greater than international textile regulations. The two items with the greatest formaldehyde content were washed and dried in a manner similar to that used by consumers, including hand and machine washing in hot or cold water followed by air or machine drying. The washing and drying procedures reduced formaldehyde levels to between 26 and 72% of untreated controls. Differences in the temperature or type of washing and drying did not result in a clear trend in the subsequent formaldehyde content. In addition, samples were hot ironed, which did not affect the formaldehyde content as significantly. Understanding the formaldehyde content in clothing and its potential reduction through care activities may be useful for manufacturers and formaldehyde-sensitive individuals.

Since the 1920s, formaldehyde and formaldehyde-releasing resins have been used on textiles to increase strength, prevent shrinking, and resist wrinkling. The resins impart these properties by cross-linking the cellulose in natural fabrics, such as cotton, linen, and rayon (Scheman et al., 1998). However, under certain conditions such as incomplete cross-linking followed by hydrolysis or degradation of the formaldehyde chemical bonds, free formaldehyde may be released from the fabric (Rao et al., 2004; Vail and Reinhardt, 1981). At sufficient concentrations, formaldehyde may induce contact dermatitis, including allergic contact dermatitis (ACD)

(Boukham and Maibach, 2001; de Groot and Maibach, 2010).

Allergic contact dermatitis is a red, itchy, skin reaction that results from contact with a chemical, and is considered a delayed-type hypersensitivity, as it requires both sensitization and elicitation responses (CDC, 2012; Kimber et al., 2002). Formaldehyde-induced ACD associated with finishes in clothing was first diagnosed in Scandinavia in the 1930s by Marcussen (1959), and case reports were more frequently reported in the literature in the 1950s and 1960s (Scheman et al., 1998). Most reported ACD cases are characterized by skin lesions that are distributed where direct contact

Received 17 May 2013; accepted 26 June 2013.

All of the authors are employed by Cardno ChemRisk, a consulting firm that provides scientific advice to the government, corporations, law firms, and various scientific/professional organizations. Cardno ChemRisk has been engaged by entities involved in the textile industry. This article was prepared and written exclusively by the authors without review or comment by any external entity. Funding for the article was solely provided by the authors' employer, Cardno ChemRisk.

Address correspondence to Rachel M. Novick, Cardno ChemRisk, 101 Second Street, Suite 700, San Francisco, CA 94105, USA.
E-mail: Rachel.Novick@cardno.com

with the article of clothing occurred (de Groot et al., 2009). Several investigators attempted to elucidate the elicitation threshold of ACD in clothing for sensitive individuals. de Groot and Maibach (2010) suggested that formaldehyde levels below 200 ppm in clothing would be safe for most sensitized individuals. Fisher et al. (1962) found that 20 patients with known allergies to formaldehyde did not exhibit ACD after exposure to clothing that reportedly contained 300 to 750 ppm, based on the manufacturers' estimates of free formaldehyde. Berrens et al. (1964) studied formaldehyde-containing clothing in the Netherlands and recognized that for formaldehyde-sensitive individuals, "discarding of clothing with a high level of free formaldehyde (over 0.05% [500 ppm]) invariably [led] to a relief of symptoms" (p. 114).

Formaldehyde levels in clothing have varied during the past 60 years, following changes in the finishes and manufacturing processes (Table 1). Although formaldehyde was first used in the clothing industry in 1926, significant commercial interest for "wrinkle-free" fabrics did not develop until the 1950s and 1960s (Hovding, 1959). Formaldehyde resins used at this time were based on urea formaldehyde, resulting in levels of free formaldehyde between 5,000 and 12,000 ppm in textiles (Brookstein, 2009; Hovding, 1959) (Table 1). During the 1960s, many manufacturers began to use a different formaldehyde-based resin, dimethylol dihydroxyethylene urea (DMDHEU), which yielded fabrics with approximately 500 ppm free formaldehyde (Scheman et al., 1998). Technology continued to improve, and by the 1970s, most manufacturers began using methylated or glycolated resins that resulted in fabrics with less than 300 ppm free formaldehyde. Currently, methylated or glycolated DMDHEU is used for durable press finishes, releasing lower formaldehyde levels (<300 ppm) than their predecessors (Brookstein, 2009; Espada, 1993).

Some studies showed that clothing care activities may reduce formaldehyde levels released from treated fabrics; however, the observed changes are dependent on many

factors. Andrews and Harper (1980) compared formaldehyde release from unwashed and washed clothing and noted higher concentrations of unbound formaldehyde from unwashed clothing. Cronin (1980) and Voncina (2002) reported that washing clothes reduced formaldehyde concentrations, but they also found that levels may increase again as the resin further degrades. In addition, Cronin (1980) reported that formaldehyde levels were reduced by storing clothing in well-ventilated areas for a few weeks. Most recently, a report by the U.S. Government Accountability Office (U.S. GAO) discussed various U.S. Department of Agriculture studies, indicating that the effect of laundering on formaldehyde levels depends on the type of resin, alkalinity, and hardness of the water, as well as on the use of bleach (U.S. GAO, 2010). These reports did not elaborate on which factors reduced formaldehyde levels most effectively. Conversely, Rao et al. (2004) reported that washing textiles one or two times did not alter the formaldehyde content in most items (polyester/cotton and organdy were the exceptions); however, no quantitative data were provided. Rao et al. (2004) concluded that "the majority of the textiles did not show a reduction in their formaldehyde content despite two washes, implying that wearing washed clothes may not be entirely safe" (p. 344).

The aim of this study was to expand the existing body of knowledge regarding the influence of typical treatment activities on formaldehyde content of clothing. In this study, the effects of various washing, drying, and ironing treatments on formaldehyde levels in 100% cotton, durable press items were examined. The influences of specific variables, such as water temperature (hot vs. cold), washing techniques (hand vs. machine), and drying methods (machine vs. ambient air), were determined. For the clothing samples, an extraction technique was employed that was developed to simulate skin contact with clothing (Espada, 1993). Pre- and post-care formaldehyde levels were compared to previously published measurements and our findings are discussed in

TABLE 1. Historical Levels of Formaldehyde in Textiles

Year of publication	Location of study	Test material	Method	Number of textiles tested	Free formaldehyde content of textiles	Reference
1953	United Kingdom	Rayon textiles treated with urea formaldehyde resins	Not reported	260	1 textile was greater than 2000 ppm, the majority were below 250 ppm	(Best-Gobdon, 1953)
1959	Norway	Commercial crease resistant textiles	Sample treated with boiled water and incubated 20 h, liquid was mixed with chromotropic acid and sulfuric acid, measured on spectrophotometer	256	1 textile was between 17,000 and 18,000 ppm, 132 textiles were between 5,000 and 12,000 ppm, 7 textiles were less than 500 ppm, 29 textiles had no detectable formaldehyde	(Hovding, 1959)
1964	The Netherlands	Textiles from patients with contact dermatitis	Modifications to Hovding, 1959	600	Means for various fabric types ranged from 270–4710 ppm	(Berrens et al., 1964)
1974	United States	Textiles from manufacturers and distributors	Same as Berrens, 1964	112	Textiles ranged from 1 to 3517 ppm; 18 textiles were greater than 750 ppm	(Schorr et al., 1974)
1998	United States	Textiles randomly selected from local retailer	Merck test, Japanese Law 112	16	1 textile was greater than 200 ppm (Merck) or 24 ppm (Japanese Law 112), 7 samples were less than 200 ppm (Merck), 8 textiles had no detectable formaldehyde (Merck)	(Scheman et al., 1998)
2004	India	Textiles randomly selected from local retailer	Chromotropic acid test	20	11 textiles had detectable levels of formaldehyde	(Rao et al., 2004)
2008	United States	Khaki pants and dress shirts randomly selected at a variety of retailers	Japanese Law 112	23 (11 pants and 12 dress shirts)	Khaki pants: 6 were less than 20 ppm (nondetect), others were between 49 and 136 ppm; Dress shirts: 8 were less than 20 ppm (nondetect), others pants were between 26 and 126 ppm	(Brookstein et al., 2009)
2010	United States	Textiles (clothing and bed linen) selected from retailers	Japanese Law 112	180	19 textiles between 20 and 50 ppm, 6 textiles between 50 and 200, 10 textiles between 75 and 206 ppm, 135 textiles had nondetectable formaldehyde	(U.S. GAO, 2010)

context of the various international and domestic regulations that have been established to protect the consumer against development of ACD.

METHODS

Materials

An Internet search was performed for the terms “100% cotton wrinkle free pants” or “100% cotton wrinkle free shirt” to identify clothing available for purchase from online vendors, and we purchased the first 10 appropriate men’s pants and shirts identified during the search. Items were deemed appropriate if they advertised durable press characteristics, were 100% cotton, and were available for purchase online. Durable press characteristics were advertised by terms such as “non iron,” “no iron,” “wrinkle free,” “wrinkle resistant,” and “easy care.”

Analysis

Once received, each article of clothing was cut into samples 15 by 15 cm; one sample from each article was placed in an air-tight plastic bag and sent to an independent commercial lab (Manufacturing Solutions Center, Hickory, NC) to be tested for free formaldehyde using the Japanese Law 112, which simulates skin contact (Espada, 1993). Briefly, this method involves using a 5-min, 38°C distilled water treatment to release formaldehyde from the fabric. Next, 5 ml extracted sample was added to 5 ml Nash reagent and read on the spectrophotometer using Spectronic Genesys-5. The limit of detection (LOD) was 20 ppm.

Clothing Care Activities

The shirt and pants with the highest formaldehyde levels detected during the initial analysis underwent further testing to assess the effects of clothing care activities. Controls were placed in airtight plastic bags without any treatment, and tested at the lab concurrently.

TABLE 2. Treatments of Shirt and Pants Samples

Treatment	Type of treatment	Temperature of water/steam	Type of dry
A	Hand wash	Room temperature	Air
B	Hand wash	Hot	Air
C	Hand wash	Room temperature	Dryer
D	Hand wash	Hot	Dryer
E	Machine wash	Hot/cold	Dryer
F	Machine wash	Cold/cold	Dryer
G	Iron	Hot	N/A

Note. N/A, not applicable.

Several treatments were designed to mimic a consumer’s everyday clothing care activities, including hand washing, machine washing, and ironing. Washing and drying treatments (A–F) are outlined in Table 2. Each treatment was performed with duplicate shirt and pants samples. Briefly, for the hand-wash treatments (A–D), 4 glass containers were filled with 500 ml room-temperature or hot (46°C) water (pH 6). Samples were submerged for 10 min with 15 s gentle agitation using a glass rod every 2 min. Samples from treatments A and B were set out on a drying rack to completely dry for approximately 3 h; ambient temperature was approximately 18.5°C. Samples from treatments C and D were placed in a preheated dryer (Kenmore electronic moisture sensing front loading dryer, model 417.93042300) for 20 min on high heat; the temperature of the dryer ranged from 30°C to 40°C over the course of drying.

Regarding machine-wash treatments E and F, samples were run through a hot or cold wash cycle followed by a cold rinse and short spin cycle in a washing machine (Kenmore front loading washer, model 417.44042400). Standard household laundry detergent was also added (Dreft Ultra). The laundry detergent was not tested for formaldehyde content. The water flowing into the machine (pH 6.3) was at 54.4°C and 22.2°C for the hot and cold cycles, respectively. Once the wash cycle for each treatment was completed, the samples were placed in a preheated dryer for 20 min on high heat; the temperature of the dryer prior to loading and prior to removing each sample averaged 39.6°C. In addition, samples

(treatment G) were steam ironed for 30 s on a "cotton steam" setting.

After treatment, all samples were stored in airtight plastic bags and sent to an independent commercial lab for testing as described earlier. Testing results were analyzed by the *t*-test in Excel and considered significant at $p < .05$. Paired *t*-tests were performed to compare the means of treatment groups versus the controls; one-tailed *p* values were evaluated. Independent *t*-tests were performed while comparing the means of combinations of treatment groups of interest (hot vs. cold wash, air dry vs. dryer, etc.); one-tailed *p* values were evaluated under the hypothesis that water temperature increases or machine drying would result in a greater reduction of formaldehyde than would using colder water or ambient air drying treatments.

RESULTS

Ten shirts and 10 pairs of pants were obtained with advertised durable press characteristics such as "non-iron" or "wrinkle free" (Table 3). The clothing varied in color, country of origin, and care instructions, but all were 100% cotton (with one exception) men's dress shirts and pants. Initial analyses indicated that 17 of the samples did not have detectable levels of formaldehyde (LOD = 20 ppm). One shirt contained a formaldehyde concentration of 3172 ppm, and two pairs of pants had formaldehyde concentrations of 1391 ppm and 86 ppm (Table 3). The three garments with detectable formaldehyde were all manufactured in China, although other clothing items in our study manufactured in China were below the LOD (Table 3).

The aforementioned clothing care treatments were conducted on the two articles with the highest detected formaldehyde levels (shirt 5; pants 2). Reanalysis of these garments prior to care treatments indicated formaldehyde levels of 705 ppm and 1125 ppm for the shirt and pants, respectively.

As shown in Figure 1, several of the clothing care treatments resulted in a significant decrease in mean formaldehyde levels for both

the shirt and the pants. For the shirt, the treatments that did not result in a significant fall were the hot machine wash/machine dry (treatment E), cold machine wash/machine dry (treatment F), and the ironing (treatment G) of the sample. For the pants, the treatments that did not result in a significant decrease were the room-temperature hand wash/air dry (treatment A) and the cold machine wash/machine dry (treatment F). The washing and drying procedures reduced formaldehyde content to between 26 and 72% of the untreated control value, resulting in mean post washing/drying values for the shirt of between 186 and 508 ppm, and between 482 and 746 ppm for the pants. The ironing treatment yielded a significant decline in formaldehyde content for the pants, but not the shirt; however, the decrease was significantly less than that observed with washing treatments.

Washing treatment variables such as water temperature (hot, room temperature, or cold water wash), washing method (machine vs. hand), and drying method (ambient air vs. machine dry) appeared to exert little influence on degree of formaldehyde reduction. For either the pants or shirt sample (or both) there was no marked significant difference in treatments A versus B, A versus C, or E versus F. The only clear exception was that for both the shirt and pants samples, hand wash with hot water/machine dry (treatment D) yielded a significantly greater formaldehyde decrease than did hand wash with room temperature water/machine dry (treatment C).

Each of the mean values presented in Figure 1 is the average of two different samples taken from the clothing article, and each sample was independently extracted and analyzed. In general, there was little variability between the two values used to calculate any particular mean; however, a few samples had larger variability (Figure 1).

DISCUSSION

In this study, the formaldehyde content of 20 wrinkle-free cotton clothing items was evaluated; these articles were chosen for

TABLE 3. Formaldehyde Content in Durable Press Textiles

	Fabric composition	Label information	Advertised durable press characteristics	Manufacturing country	Formaldehyde content (first measurements)
Shirt 1	100% Cotton	"Wrinkle Free"	"Wrinkle-Free"	El Salvador	<20 ppm
Shirt 2	100% Cotton			China	<20 ppm
Shirt 3	100% Cotton	"Wrinkle Free"; "Specially developed fabrications contribute to its rugged performance and timeless appearance"	"Wrinkle-Free"	Bangladesh	<20 ppm
Shirt 4	100% Cotton	"Non-Iron"	"No Iron"	Honduras	<20 ppm
Shirt 5	100% Cotton	"No Iron"	"No Iron"	China	3172 ppm
Shirt 6	100% Cotton	"Wrinkle Free" (on receipt, not garment)	"Wrinkle-Free"	China	<20 ppm
Shirt 7	100% Cotton	"Non Iron"	"Wrinkle Free"	Bangladesh	<20 ppm
Shirt 8	100% Cotton	"Non Iron"; "Never needs ironing—simply machine wash and tumble dry"; "Soil Release fabric treatment prevents stains from setting and helps them disappear during normal laundering"	"Starts out wrinkle free and continues to shed wrinkles throughout the day"	Hong Kong	<20 ppm
Shirt 9	60% Cotton, 40% polyester (advertised as "100 percent cotton")		"Wrinkle free"	Bulgaria	<20 ppm
Shirt 10	100% Cotton	"Wrinkle Free"; "Specially developed fabrications contribute to its rugged performance and timeless appearance"		Bangladesh	<20 ppm <?tb>
Pants 1	100% Cotton	"Wrinkle Free"; "Blocks up to 99.9% of ultraviolet rays"; "Wicks away moisture"	"Stays cool"; "Wicks moisture away"; "Wrinkle-Free"	Malaysia	<20 ppm
Pants 2	100% Cotton	"Non Iron"	"Non-iron cotton"	China	1391 ppm
Pants 3	100% Cotton	"Wrinkle Free"; "Permanent Crease"	"Wrinkle-Free"; "Crease resistant"	Dominican Republic	<20 ppm
Pants 4	100% Cotton		"Resists wrinkles"; "Permanent crease"	Cambodia	<20 ppm
Pants 5	100% Cotton		"Wrinkle- and stain-resistant cotton"	China	<20 ppm
Pants 6	100% Cotton	"No Iron"; "Permanent Crease"	"No Iron"	"Made in Mexico of US fabric"	<20 ppm
Pants 7	100% Cotton	"Minimizes Wrinkles"	"Wrinkle free"	Bangladesh	<20 ppm
Pants 8	100% Cotton		"Wrinkle Resistant"	Nicaragua	<20 ppm
Pants 9	100% Cotton	"Easy Care Finish"; "Wrinkle Resistant"		Thailand	<20 ppm
Pants 10	100% Cotton	"Wrinkle Free"	"Wrinkle-free"	China	86 ppm

Note. For each purchased item, the formaldehyde content was measured by Japanese Law 112. The advertised durable press characteristics were recorded from the product website; however, they were recorded after the items were purchased and not all of the information was still available at the making of this table. The manufacturing country and durable press characteristics on the product label were also recorded.

analysis because garments marketed as durable press or wrinkle free have often been treated with formaldehyde. Most (17 of 20) of the clothing articles did not contain detectable

levels of formaldehyde (LOD 20 ppm) (Table 3). This finding was expected, since recent surveys have typically reported that many permanent press clothing articles do not contain detectable

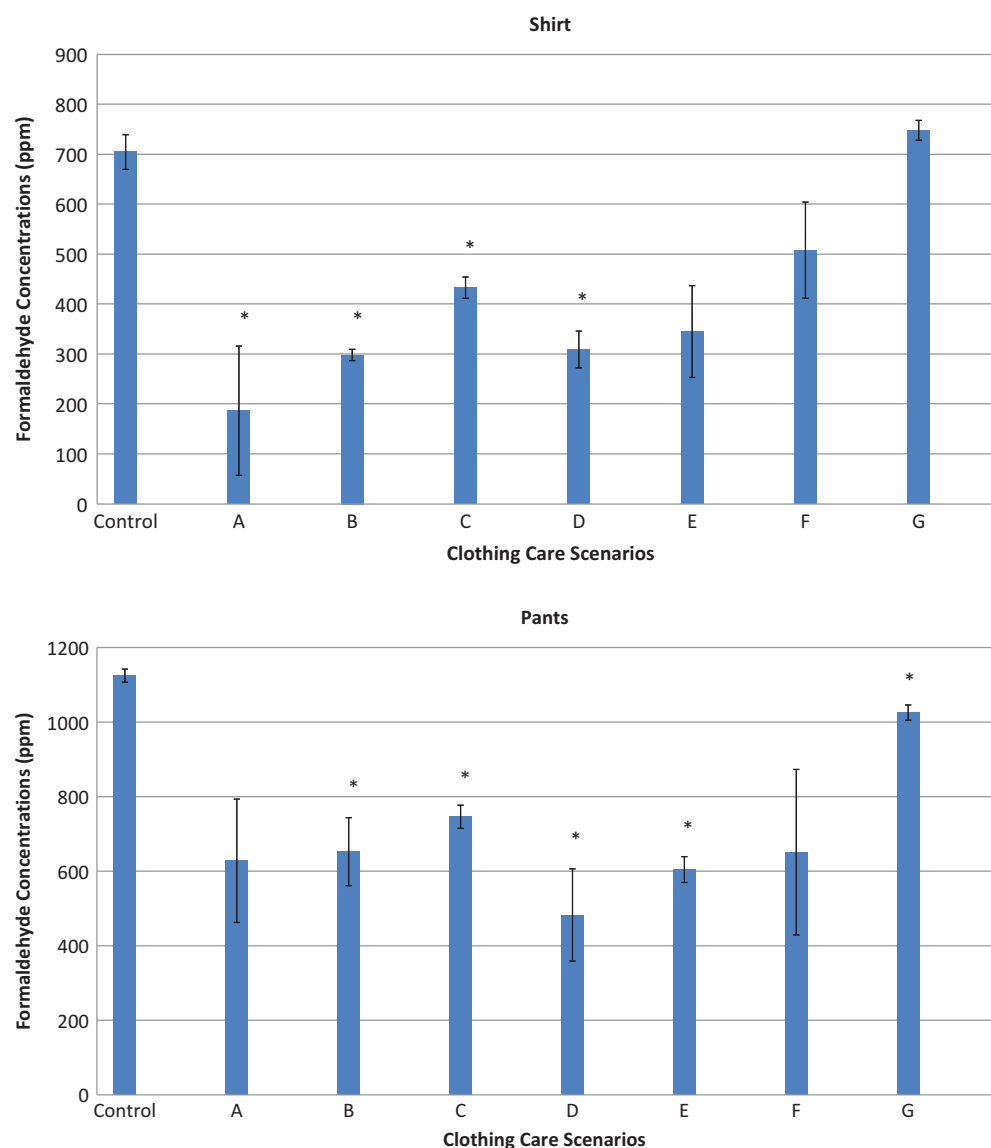


FIGURE 1. Changes in formaldehyde levels in textiles after clothing care activities. Formaldehyde was measured by Japanese Law 112 method to simulate skin exposure. Asterisk indicates significant at $p < .05$ (color figure available online).

formaldehyde (Table 1). In those instances in which formaldehyde was detected, the reported levels are usually in the range of 100–200 ppm or less. Brookstein et al. (2009) reported that several young men's khaki pants and dress shirts exhibited <136 ppm and <126 ppm formaldehyde, respectively. In a study conducted by the U.S. GAO in 2010, 180 textiles were tested; all samples contained <206 ppm formaldehyde (U.S. GAO, 2010). The magnitude of formaldehyde levels detected in the pants and shirt in this study

(1391 ppm and 3172, respectively) have not been reported in the literature since the 1960s and 1970s, which was before most countries began to pass legislation to limit formaldehyde levels in finished textile products. It is possible that high levels were found as this study focused on 100% cotton wrinkle free items that undergo a more severe finishing process. It is also postulated that items ordered online have less opportunity to off-gas than those purchased in a store, which may contribute to the observed higher levels.

The results of this study are consistent with previous reports describing reduced formaldehyde levels in textiles as a result of washing and drying activities (Andrews and Harper, 1980; Voncina et al., 2002). As shown in Figure 1, data showed that formaldehyde reduction was significant for most combinations of washing and drying scenarios, for both the shirt and the pants. In particular, hand-washing with hot water followed by machine drying (treatment D) resulted in significant formaldehyde decreases for both the shirt and the pants (44 and 42% of control, respectively). A significant reduction in formaldehyde was not observed with shirt or pants treatment F, which was a machine wash with cold water, followed by machine drying.

Because heat is believed to increase the rate of hydrolysis of formaldehyde resins (Rao et al., 2004), it was anticipated that hot water treatments and/or machine drying would consistently yield much greater formaldehyde concentration reductions than would room-temperature or cold water use, or ambient air-drying scenarios. However, temperature may have influenced formaldehyde reduction only under certain conditions. Specifically, no marked difference was found in mean formaldehyde levels following hand washing with room-temperature versus hot water followed by ambient-air drying (treatments A vs. B). Similarly, the degree of heat involved in drying (ambient air dry vs. machine dry) did not exert any influence on the amount of formaldehyde reduction following hand washing at room temperature (treatments A vs. C) or hot water (B vs. D). In contrast, for both the shirt and the pants, the mean formaldehyde levels following hand washing with hot water were significantly lower than those following room-temperature water wash and machine drying (treatments C vs. D).

Interestingly, formaldehyde levels in the shirt and pants samples decreased during the approximately 30-day period between the initial screening test and the time of the washing experiments (Table 3 and Figure 1). Specifically, shirt 5 exhibited a formaldehyde concentration of 3172 ppm during the initial screening, but

only 704 ppm when used as a control during the washing treatments. A smaller decrease from 1391 to 1124 ppm was observed with the pants sample. These findings are unlikely to be a result of method or analytical variability, as there was reliable reproducibility in the values used to calculate the means presented in Figure 1. The most plausible explanation, then, is that because of formaldehyde's volatile nature, some amount of the chemical off-gassed from the clothing during the storage period. This phenomenon has been discussed in the literature (Cronin, 1980).

Some countries have chosen to regulate formaldehyde concentrations in clothing to prevent against the risk of ACD (Table 4). The first of these laws was enacted in 1975 by the Japanese government (Sugai and Yamamoto, 1980). As can be seen in Table 4, most regulations distinguish between clothing for adults and clothing for children (lower allowable levels for children), and between clothing with and without direct contact with skin (higher allowable levels for the latter). Generally, acceptable formaldehyde levels were limited to 75 ppm for adult clothing articles in direct contact with the skin, while infant clothes were required to contain <20 ppm formaldehyde (the typical limit of detection). To our knowledge, the United States has not established specific regulations regarding free formaldehyde in clothing, although there are several apparel trade organizations that provide guidance values. The International Association for Research and Testing in the Field of Textile Ecology (OEKO-TEX) and the American Apparel and Footwear Association (AAFA) suggest formaldehyde limit values of 75 ppm for fabrics intended to have direct contact with skin, 300 ppm for fabrics not intended to have contact with skin, and nondetect levels for baby apparel (<20 ppm). These recommendations are similar, if not identical, to many of the regulations summarized in Table 4.

As noted earlier, the two clothing articles examined in this analysis contained formaldehyde levels that were much higher than those typically reported over the last 30 years; these levels (1391 and 3172 ppm) also exceeded the maximally acceptable

TABLE 4. International Regulations of Formaldehyde Levels in Textiles

Country	Regulations/requirements	Regulations for textile products	References
Japan	Japanese Law 112	For children under 36 months old: ≤ 20 ppm Direct skin contact: ≤ 75 ppm Without direct skin contact: ≤ 300 ppm	ADDIN EN.CITE.DATA (AAFA, 2012; Brookstein et al., 2009; ACCC, 2013)
China	Limits of Formaldehyde Content in Textiles GB18401-2001	For children under 36 months old: ≤ 20 ppm In direct contact with skin: ≤ 75 ppm Without direct contact with skin: ≤ 300 ppm	ADDIN EN.CITE.DATA (AAFA, 2012; Brookstein et al., 2009; ACCC, 2013)
Finland	Decree on Maximum Amounts of Formaldehyde in Certain Textiles Products (Decree 210/1988)	For children under 24 months old: ≤ 30 ppm In direct contact with skin: ≤ 100 ppm Without direct contact with skin: ≤ 300 ppm	ADDIN EN.CITE.DATA (AAFA, 2012; Brookstein et al., 2009; ACCC, 2013)
Norway	Regulations Governing the Use of a Number of Chemicals in Textiles (April 1999)	For children under 36 months old : ≤ 30 ppm In direct contact with skin: ≤ 100 ppm Without direct contact with skin: ≤ 300 ppm	ADDIN EN.CITE.DATA (AAFA, 2012; Brookstein et al., 2009; ACCC, 2013)
France	Official Gazette of the French Republic, Notification 97/0141/F	For infants: ≤ 20 ppm In direct contact with skin: ≤ 100 ppm Without direct contact with skin: ≤ 400 ppm	(Brookstein et al., 2009; ACCC, 2013)
Netherlands	The Dutch (Commodities Act) Regulations on Formaldehyde in Textiles (July 2000)	Any textiles containing more than 120 ppm formaldehyde must be labeled "Wash before first use" After washing, these products must not contain more than 120 ppm	(Brookstein et al., 2009; ACCC, 2013)
Austria	Formaldehydverordnung BGBl Nr. 194/1990	Textiles that contain 1500 ppm or above must be labeled	(Brookstein et al., 2009; ACCC, 2013)
Germany	Gefahrstoffverordnung (Hazardous Substances Ordinance) Annex III, No. 9, 26.10.1993	In direct contact with skin and more than 1500 ppm of formaldehyde must have a label stating: "Contains formaldehyde." Washing this garment is recommended prior to first time use in order to avoid irritation of the skin."	(Brookstein et al., 2009; ACCC, 2013)
New Zealand	Nonregulatory policy	For ages under 24 months: ≤ 30 ppm Specifically designed for sensitive skin: ≤ 30 ppm In direct contact with skin: ≤ 100 ppm or ≤ 100 ppm after wash if there is a label or instruction recommending to wash before first use	(Brookstein et al., 2009; ACCC, 2013)
Vietnam	Circular 32/2009/TT-BCT	Not in direct contact with skin: ≤ 300 ppm. For children under 36 months old: ≤ 30 ppm In direct contact with skin: ≤ 75 ppm Without direct contact with skin: ≤ 300 ppm	(Socialist Republic of Vietnam, 2010)
Australia	Interim, nonregulatory reference limits from the ACCC	Infant clothing: ≤ 30 ppm Marketed for those with sensitive skin: ≤ 30 ppm In direct contact with skin: ≤ 100 ppm Other garments: 300 ppm	(ACCC, 2013)

levels in almost every country that regulates formaldehyde levels in finished textiles. However, both of these clothing articles were from China and continued to exceed the acceptable limits in China (and those of most other countries) even after washing and

drying. It is possible that some of the post-washing/drying levels measured in this analysis (which ranged from approximately 187 to 746 ppm) would be capable of inducing ACD in a sensitized individual. The formaldehyde textile concentration threshold for eliciting a

reaction in sensitized individuals is unknown, but was estimated to be around 200 ppm de Groot and Maibach, (2010).

Although our sample size was small, our findings warrant additional research into the formaldehyde content of durable press clothing articles, both pre- and post-washing/drying. First, there are clearly clothing articles that may contain high levels of formaldehyde available for purchase online. All of the clothing articles that contained detectable formaldehyde in this analysis originated in China. An expanded market survey that focuses on Chinese textiles sold to the general population (particularly clothing for infants) is thus warranted. Second, while only one washing and drying cycle was assessed, determination of how many cycles would be required to reduce elevated levels (such as those observed here) to quantities that comply with international standards and suggested guidelines would be useful. Further studies on the effects of various storage conditions on formaldehyde levels in textiles would also be informative.

CONCLUSIONS

Formaldehyde has been used for several decades in the textile industry. Although formulations and manufacturing techniques seem to have improved, further developments to reduce formaldehyde levels in certain textiles before the product reaches the consumer would be beneficial. Better characterization of the time frame and storage conditions in which formaldehyde concentrations decrease is warranted. Finally, washing clothing known to contain formaldehyde decreased concentrations by approximately 28 to 74% regardless of washing technique. Individuals with a known or suspected susceptibility to formaldehyde should wash clothing with stated durable press characteristics before first use.

REFERENCES

- American Apparel & Footwear Association. 2012. Restricted substances list, 11th edition. October. Arlington, VA: American Apparel & Footwear Association. <https://www.wewear.org/industry-resources/restricted-substances-list/english> (accessed February 5, 2013).
- Australian Competition & Consumer Commission. 2013. Are formaldehyde levels in clothing regulated in other countries? <http://www.productsafety.gov.au/content/index.phtml/itemId/975834> (accessed February 5, 2013).
- Andrews, B. A. K., and Harper, R. J., Jr. 1980. Formaldehyde release—Are current test methods realistic? *Textile Res. J.* March:177–184.
- Berrens, L., Young, E., and Jansen, L. H. 1964. Free formaldehyde in textiles in relation to formalin contact sensitivity. *Br. J. Dermatol.* 76: 110–115.
- Best-Gobdon, H. W. 1953. A survey of the quality of crease-resist treatment on fabrics supplied to the retail trade. *J. Soc. Dyers Colourists* 69: 41–50.
- Boukham, M. P., and Maibach, H. I. 2001. Thresholds in contact sensitization: Immunologic mechanisms and experimental evidence in humans—An overview. *Food Chem Toxicol* 39: 1125–1134.
- Brookstein, D., Barndt, H., and Pierantozzi, J. 2009. On current research associated with textile and apparel product safety. In *86th Textile Institute World Conference 2008, Hong Kong, 1821 November 2008*, vol. 1 of 4, ed. Textile Institute, pp. 1975–1986. West Chester, OH: Curran Associates, Inc.
- Brookstein, D. S. 2009. Factors associated with textile pattern dermatitis caused by contact allergy to dyes, finishes, foams, and preservatives. *Dermatol. Clin.* 27: 309–322.
- Centers for Disease Control and Prevention. 2012. Skin exposures & effects. <http://www.cdc.gov/niosh/topics/skin> (accessed February 7, 2013).
- Cronin, E. 1980. Clothing and textiles. In *Contact dermatitis*, pp. 58–59. New York, NY: Churchill Livingstone.
- de Groot, A. C., Flyvholm, M. A., Lensen, G., Menne, T., and Coenraads, P. J. 2009. Formaldehyde-releasers: Relationship to formaldehyde contact allergy. *Contact*

- allergy to formaldehyde and inventory of formaldehyde-releasers. *Contact Dermatitis* 61: 63–85.
- de Groot, A. C., and Maibach, H. I. 2010. Does allergic contact dermatitis from formaldehyde in clothes treated with durable-press chemical finishes exist in the USA? *Contact Dermatitis* 62: 127–136.
- Espada, B. 1993. Recent developments in non-formaldehyde resin finishing. In *Total quality control in fabric finishing: 33rd Annual conference*, ed. American Association for Textile Technology, pp. 1–11. Gastonia, NC: American Association for Textile Technology.
- Fisher, A. A., Kanof, N. B., and Biondi, E. M. 1962. Free formaldehyde in textiles and paper. Clinical significance. *Arch. Dermatol.* 86: 753–756.
- Hovding, G. 1959. Free formaldehyde in textiles. A cause of contact eczema. *Acta Derm. Venereol.* 39: 357–368.
- Kimber, I., Basketter, D. A., Gerberick, G. F., and Dearman, R. J. 2002. Allergic contact dermatitis. *Int. Immunopharmacol.* 2: 201–211.
- Marcussen, P. V. 1959. Contact dermatitis due to formaldehyde in textiles 1934–1958. Preliminary report. *Acta Derm. Venereol.* 39: 348–356.
- Rao, S., Shenoy, S. D., Davis, S., and Nayak, S. 2004. Detection of formaldehyde in textiles by chromotropic acid method. *Indian J. Dermatol. Venereol. Leprol.* 70: 342–344.
- Scheman, A. J., Carroll, P. A., Brown, K. H., and Osburn, A. H. 1998. Formaldehyde-related textile allergy: An update. *Contact Dermatitis* 38: 332–336.
- Schorr, W. F., Keran, E., and Plotka, E. 1974. Formaldehyde allergy. The quantitative analysis of American clothing for free formaldehyde and its relevance in clinical practice. *Arch. Dermatol.* 110: 73–76.
- Socialist Republic of Vietnam. 2010. National Technical Regulation on Content of Formaldehyde and Azo Colorants in Textile Products. QCVN 1: 2010/BCT. Hanoi: Socialist Republic of Vietnam. http://members.wto.org/crnattachments/2010/tbt/VNM/10_3718_00_et.pdf (accessed February 5, 2013).
- Sugai, T., and Yamamoto, S. 1980. Decrease in the incidence of contact sensitivity to formaldehyde. *Contact Dermatitis* 6:154.
- U.S. Government Accountability Office. 2010. Formaldehyde in textiles while levels in clothing generally appear to be low, allergic contact dermatitis is a health issue for some people: Report to Congressional committees. August. GAO-10-875. Washington, DC: U.S. Government Accountability Office.
- Vail, S., and Reinhardt, R. M. 1981. What do formaldehyde test measure? *Textile Chem. Colorist* 13: 13–17.
- Voncina, B., Bezek, D., and le Marechal, A. M. 2002. Eco-friendly durable press finishing of textile interlinings. *Fibers Textiles Eastern Eur.* July/September: 68–71.