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Immunological Reactions and Respiratory Function in Wool Textile Workers

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Immunological status and respiratory function were studied in a group of 64 wool textile workers (52 women and 12 men). A group of 46 workers not exposed to wool dust served as a control for the respiratory symptoms and immunologic testing. Skin testing was performed with different wool allergens (domestic and Australian) as well as with common allergens. Ventilatory capacity was measured in wool workers on Mondays before and after the work shift. The prevalence of positive skin tests to all allergens was higher in wool than in control workers, although the difference was statistically significant only for washed domestic wool (wool workers: 42.2%; control workers: 19.6%; $p < 0.05$). Increased serum IgE levels were more frequent in wool (26.6%) than in control workers (3.1%) ($p<0.01$). In wool textile workers there was a high prevalence of acute and chronic respiratory symptoms. Significant across-shift reductions in ventilatory capacity tests, as well as abnormal baseline lung function, were recorded in wool textile workers. Individual data demonstrated that many of the wool workers had FEF_{25} lower than 70% of predicted. In general, the prevalence of symptoms and the lung function abnormalities did not correlate with the results of specific (wool) skin tests. Our data indicate that exposure to wool dust in some workers may be associated with the development of acute and chronic respiratory symptoms and impairment of lung function. Immunologic abnormalities, although frequent in this group, do not appear to be associated with the severity of these changes.

Key words: wool textile workers, immunological reactions, respiratory symptoms, lung function

INTRODUCTION

Previous studies suggest that wool dust has deleterious effects on the respiratory system of texile workers [Moll, 1933; Zuskin et al., 1976; Ozesmi et al., 1987; Brown and Donaldson, 1991]. Few studies, however, have examined immunologic findings in wool workers. Ozesmi et al. [1987] performed intracutaneous skin testing in 61 wool workers and demonstrated a prevalence of 49% positive reactions to wool

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antigen. In another study, Love et al. [1991] showed positive intracutaneous prick tests to common allergens including sheep wool in 24% of wool textile workers. Love et al. [1988] reported that allergic symptoms were more frequent in wool workers exposed to higher than to lower concentrations of wool dust. Moreover, some of the symptoms were related to the number of years worked in such jobs. Our recent study with a wool dust extract using guinea pig trachea has shown a direct constrictor effect of this material on tracheal smooth muscle [Schachter et al., 1992].

In the present study we correlated the prevalence of respiratory symptoms and lung function changes to immunological reactions in wool textile workers in one textile mill in Croatia.

MATERIALS AND METHODS

Subjects

Sixty-four wool workers (52 women and 12 men) from a cohort of 216 who participated in a previous study characterizing respiratory function in wool workers [Zuskin et al., 1995] volunteered for immunologic testing. All 64 workers had participated in the original study. The mean age of the female workers was 39 years (range: 21–54 years), their mean height was 160 cm (range: 151–170 cm) and the mean duration of their work exposure was 18 years (range: 5–31 years). The mean age of the male workers was 38 years (range: 25–52 years), their mean height was 172 cm (range: 166–181 cm), and the mean duration of their work exposure was 16 years (range: 4–35 years). Ten (19.2%) of the women and 4 (33.3%) of men were regular smokers, smoking an average of 15 cigarettes daily. Textile wool workers were employed in the opening of bales and the operating of carding, spinning, and weaving machines. All processes were performed in different areas, which were only partially separated. Workers frequently changed jobs from one area to the other. Potential bias in the selection of such a subgroup may, of course, occur. Self-selection could be postulated for a number of health related reasons; however, the most frequently voiced reason for nonparticipation was fear of needle sticks. It should be noted nonetheless that the demographic parameters of this subgroup as well as the prevalences of chronic respiratory symptoms were similar to those of the original cohort.

A group of 46 workers (29 women and 17 men) of similar ages and smoking habits, employed as transport workers not exposed to wool or other dusts or fumes were studied as the control for immunological testing. These workers were employed loading trucks and were not exposed to dust or fumes.

Immunological Studies

Skin prick tests with specific occupational, as well as with common, allergens were performed in the 64 wool and in 46 control workers. Wool dust extracts were prepared using a standard immunological technique [Sheldon et al., 1967] employing the dust collected from the work areas where workers were examined. Skin prick testing was performed with domestic and Australian wool extracts (fatty and washed) in a concentration 1:10 v/w. In addition, workers were skin tested with histamine base (1 mg/ml), with *Dermatophagoides pteronyssinus* (0.2%), mold and bacterial extracts as well as with a buffer solution used as a control. Bacterial antigen was prepared using *H. influenzae, S. pneumoniae, S. viridans, S. pyogenes,* and *Staph. aureus*

killed in a suspension of 3×10^6 organisms per ml. Mold antigen was prepared from a mixture of *Alternaria, Penicillium, Mucor, Cladosporium, Aspergillus niger,* and *Aspergillus fumigatus* in 0.2% solution. Skin prick reactions were read after 20 minutes. A skin test was considered positive if the diameter of the observed wheal was >3 mm.

Serum levels of total IgE antibody were measured by the method PRIST, reference laboratory (Pharmacia Diagnostics, AB, Upsala, Sweden) using a direct radioimmunological "sandwich" technique based on paper disc as a solid phase. Levels of IgE below 125 kU/L were considered normal [Johansson, 1968].

Respiratory Symptoms

Chronic respiratory symptoms were recorded by using a modification of the Medical Research Council Committee [1960] questionnaire with additional questions on occupational asthma [WHO, 1986] and on byssinosis [Schilling et al., 1963]. Additionally, the workers were asked about "acute," work-related symptoms, such as cough, dyspnea, irritation or dryness of the throat, eye irritation, bleeding, secretion or dryness of the nose, and headache. These were specifically noted to occur in the workplace alone. In all workers, a detailed occupational history, as well as the data on smoking habits, was taken. The following definitions were used:

Chronic cough/phlegm. Cough or phlegm production or both on most days for at least 3 months in the past year.

Chronic bronchitis. Cough and phlegm for a minimum of 3 months in a year and for not less than 2 successive years.

Dyspnea grades. Grade 3—shortness of breath when walking with others of the same age on level ground; grade 4—shortness of breath when walking at one's own pace on level ground.

Occupational asthma. Chest tightness, cough, wheezing, shortness of breath, and acute decreases in ventilatory capacity (>15% of FEV_1), consistently associated with or following the work shift. The diagnosis was confirmed by medical records from the employee health service.

Byssinosis grades. Grade 0—no symptoms on Mondays; grade 1/2—occassional chest tightness on Mondays; grade 1—chest tightness and/or difficulty in breathing on every Monday only; grade 2—chest tightness and/or difficulty in breathing on Mondays and other workdays; grade 3—grade 2 symptoms accompanied by evidence of permanent incapacity from reduced ventilatory capacity.

Ventilatory capacity measurements

Ventilatory capacity was measured by recording maximum expiratory flow volume (MEFV) curves on which forced vital capacity (FVC), 1-second forced expiratory volume (FEV_1), and flow rates at 50% and the last 25% of the vital capacity (FEF_{50}, FEF_{25}) were determined. Ventilatory capacity measurements were performed using a portable Pneumotach-spirometer (Autospiror Hi-498, Chest Co., Tokyo, Japan). The acute effect of exposure to wool dust on ventilatory capacity was studied by recording MEFV curves on a Monday before and after a work shift. The measured preshift values were compared with the expected normal values of Quanjer [1983]. The spirometer was callibrated for volume on a daily basis. Both measurements and callibration were performed in accordance with the ATS standards for spirometric measurements [Ferris, 1978].

Bronchial Provocation Testing

Bronchial inhalation challenge was performed in 21 female wool workers who volunteered for the study. These volunteers were selected among those workers with across-shift reductions of ventilatory capacity of at least 15% in FEV_1, and who complained of respiratory symptoms. The age of these workers ranged from 27–50 years and the duration of their employment in the wool industry ranged from 2–27 years. The demographic features of this group did not differ from those of the other studied wool workers. In all subjects tested, baseline lung function values were normal. Nonspecific and specific challenge tests were performed using the five breath cumulative method of Chai et al. [1975] following inhalation of saline, histamine, or wool dust extract separately on different days. Aerosol was dispersed by DeVilbis nebulizer (Rosenthal-French dosimeter). Measurements of bronchial response were performed by recording MEFV curves on a spirometer Pneumoscreen (Jaeger, Wurzburg, Germany).

Nonspecific bronchial provocation testing was performed with histamine diphosphate solution in concentrations of 0.125–32.000 mg/ml. The bronchial response was measured 30 sec and 90 sec after each histamine inhalation. The $PC20FEV_1$ was read from the dose-response curve by interpolation. Specific bronchial provocation was performed with an aqueous wool extract in a concentration 1:100 w/v prepared from the wool dust collected in the workroom. Wool dust extract was prepared by the method of Sheldon et al. [1967]. The bronchial response was measured every 3 min up to 60 min after allergen inhalation. A positive response was defined as a 20% decrease in FEV_1.

Statistical Analysis

The results of ventilatory capacity measurements were analyzed using the Student's *t*-test for differences of paired measurements including across-shift changes and the comparison of baseline values to predicted values. The chi-square test (or Fisher's exact test when appropriate) was used for testing differences in the prevalence of respiratory symptoms. The value $p < 0.05$ was considered as statistically significant.

RESULTS

Immunological Studies

The data on immunological testing in wool and control workers are presented in Figure 1. The results were similar in female and male workers and therefore the data are presented together. The highest prevalence of positive skin prick tests in wool workers was obtained for domestic washed wool and Australian fatty wool (27; 42.2%) followed by domestic fatty wool (26; 40.6%) and Australian washed wool (15; 23.4%). Relatively high prevalences of positive skin prick tests were also recorded for standard antigens, including *Dermatophagoides pteronyssinus* (18; 23.1%), molds (17; 26.6%) and bacteria (9; 14.1%). Only one wool worker demonstrated a late positive skin reaction to domestic washed wool. Lower prevalences of positive skin tests to wool allergens were found in control workers compared to wool workers; the difference, however, in the prevalence of positive skin prick tests be-

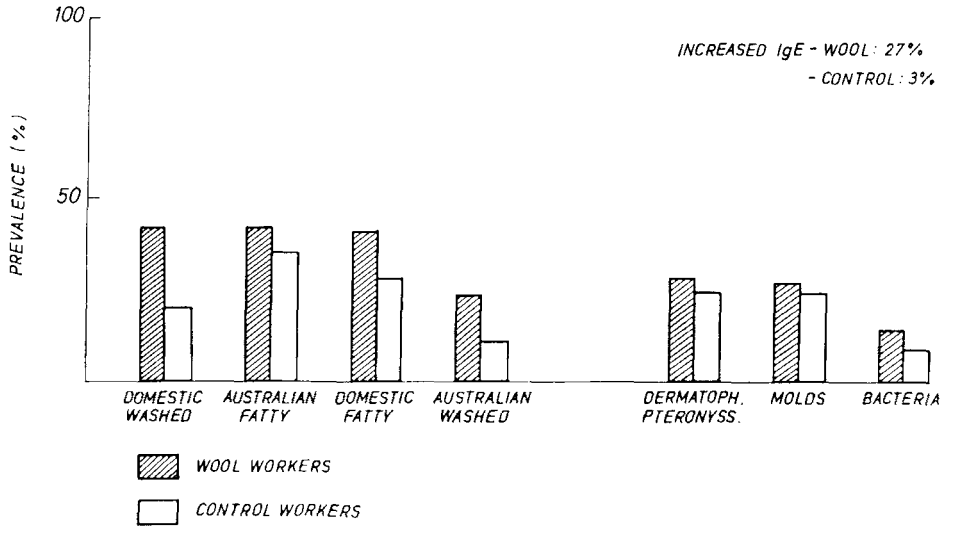

Fig. 1. Prevalence of positive skin tests to specific wool extracts and to common allergens in 64 wool textile and in 46 control workers.

tween these two groups of workers was statistically significant only for domestic washed wool (wool workers: 42.2%; control workers: 19.6%; $p < 0.05$).

Results of immunoglobulin testing demonstrated increased IgE serum levels in 17 of 64 (26.6%) wool workers and in 2 (3.1%) of 46 control workers ($p < 0.01$). Fifteen of the 17 wool workers (88.2%) with an increased serum IgE levels had positive skin prick reactions to one of the wool allergens. The two control workers with increased serum IgE levels had negative skin prick tests to the tested wool allergens.

Respiratory Symptoms

Prevalences of chronic respiratory symptoms in wool textile workers by skin reactivity is presented in Table I. There was a trend of more frequent chronic respiratory symptoms among skin test positive workers, but these differences were not statistically significant. The highest symptom prevalences for women and men were recorded for dyspnea and hoarseness.

Table II presents the prevalence of acute symptoms in wool workers by skin reactivity to wool allergen. Women with positive skin tests in general had higher prevalences than women with negative skin tests, but the differences were not statistically significant (NS).

Ventilatory capacity measurements

Table III presents ventilatory capacity data in female wool workers for the group as a whole and separately for workers with positive and negative skin reactions to wool dust allergens. There were statistically significant across-shift reductions in ventilatory capacity tests for the combined group of women wool workers. In a separate analysis by skin reactivity to wool allergens, across-shift changes were greater for skin test positive workers than for skin test negative workers. These

TABLE I. Prevalence of Chronic Respiratory Symptoms in Wool Textile Workers by Skin Reactivity to Wool Dust Allergens

Sex	Skin test	Mean age (yrs)	Mean exposure (yrs)	Chronic cough	Chronic phlegm	Chronic bronchitis	Dyspnea grade 3 or 4	Occupational asthma	Nasal catarrh	Sinusitis	Hoarseness
	Positive	39	18	9	8	8	24	6	14	20	18
	N=39	±8.9	±8.3	23.1%	20.5%	20.5%	61.5%	15.4%	35.9%	51.3%	46.1%
Female				NS	NS	NS	NS	NS	NS	NS	NS
	Negative	38	18	0	0	0	7	0	4	3	8
	N=13	±8.7	±8.8	0%	0%	0%	53.8%	0%	30.8%	23.1%	61.5%
	Positive	38	17	4	4	4	5	3	4	4	5
	N=9	±4.5	±9.1	44.4%	44.4%	44.4%	55.6%	33.3%	44.4%	44.4%	55.6%
Male				NS	NS	NS	NS	NS	NS	NS	NS
	Negative	38	14	2	2	2	2	1	3	2	3
	N=3	±6.7	±9.1	66.7%	66.7%	66.7%	66.7%	33.3%	100.0%	66.7%	100.0%

NS = difference statistically not significant ($p>0.05$).

TABLE II. Prevalence of Acute Symptoms in Wool Textile Workers by Skin Reactivity to Wool Dust Allergens

				Throat		Eye	Nose			
Sex	Skin test	Cough	Dyspnea	irritation	dryness	irritation	secretion	dryness	bleeding	Headache
	Positive	11	17	21	25	19	4	18	8	17
	N=39	28.2%	43.6%	53.8%	64.1%	48.7%	10.3%	46.1%	20.5%	43.6%
Female		NS	<0.05	NS	NS	NS	NS	NS	NS	NS
	Negative	2	2	5	7	5	0	6	1	5
	N=13	15.4%	15.4%	38.5%	53.8%	38.5%	0%	46.2%	7.7%	38.5%
	Positive	2	2	6	5	3	0	7	4	6
	N=9	22.2%	22.2%	66.7%	11.1%	33.3%	0%	77.8%	44.4%	66.7%
Male		NS	NS	NS	NS	<0.01	NS	NS	NS	NS
	Negative	2	1	1	2	3	0	2	0	2
	N=3	66.7%	33.3%	33.3%	66.7%	100.0%	0%	66.7%	0%	66.7%

NS = difference statistically not significant ($p>0.05$).

differences were significant for all ventilatory capacity tests except for FVC in those with negative skin tests ($p<0.05$ to $p<0.01$). Comparison of preshift data with predicted normal values demonstrated decreased baseline FEF_{50} and FEF_{25} ($p<0.01$) in women workers with positive skin tests, and FEF_{25} ($p<0.01$) in women workers with negative skin tests. Measured mean values were generally > 80% of predicted except for FEF_{25}, which was lower than 80% (total group average: 76.8%; positive skin test: 79.8%; negative skin test: 66.3%). Analyzing individual data in women wool textile workers, the measured values were found lower than 70% of predicted in 3 (5.8%) for FEV_1, in 14 (26.9%) for FEF_{50} and in 23 (44.2%) for FEF_{25}.

Ventilatory capacity data in male wool workers are presented separately in Table IV for the group as a whole and separately for workers with positive and negative skin reactions to wool allergen. Only three male workers were skin test negative. For the group as a whole, statistically significant mean across-shift reductions were recorded for FEF_{25} (−7.4%; $p<0.01$). Workers with positive skin tests had smaller across-shift FEF_{25} reductions (−3.8%) than those with negative skin tests (−16.2%). In comparison to predicted normal values, mean measured preshift data

TABLE III. Ventilatory Capacity in Female Wool Textile Workers by Skin Reactivity to Wool Dust Allergens*

Group	FVC			FEV_1			FEF_{50}			FEF_{25}		
	Before shift	Difference before/after shift		Before shift	Difference before/after shift		Before shift	Difference before/after shift		Before shift	Difference before/after shift	
	L	%	P	L	%	P	L/s	%	P	L/s	%	P
Total N = 52												
	3.19 ± 0.35	−3.4	<0.01	2.61 ± 0.43	−6.9	<0.01	3.61 ± 0.98	−9.7	<0.01	1.42 ± 0.67	−9.2	<0.01
	NS			NS			<0.01			<0.01		
	3.23[a] ± 0.54			2.80[a] ± 0.43			4.10[a] ± 0.29			1.85[a] ± 0.31		
Positive skin test N = 39												
	3.21 ± 0.57	−3.6	<0.01	2.64 ± 0.45	−4.9	<0.01	3.53 ± 0.86	−11.0	<0.01	1.46 ± 0.72	−9.6	<0.01
	NS			NS			<0.01			<0.01		
	3.29[a] ± 0.51			2.82[a] ± 0.47			4.10[a] ± 0.31			1.83[a] ± 0.24		
Negative skin test N = 13												
	3.05 ± 0.57	−2.3	NS	2.50 ± 0.49	−4.0	<0.01	3.84 ± 1.30	−6.0	<0.01	1.28 ± 0.57	−7.0	<0.05
	NS			NS			NS			<0.01		
	3.14[a] ± 0.34			2.73[a] ± 0.32			4.08[a] ± 0.26			1.93[a] ± 0.48		

*Data are presented as mean ± SD.

[a]Predicted values.

NS = difference statistically not significant ($p>0.05$).

were greater than 80% of predicted. Analysis of the individual data demonstrated that among men the measured values were below 70% of predicted in two (16.7%) for FEF_{50} and in two (16.7%) for FEF_{25}.

Women and men wool workers with increased serum IgE levels had across-shift reductions similar to those of women workers with normal IgE. Preshift data in lung function values also did not differ between those with increased and normal serum IgE level.

Bronchoprovocation Testing

Nonspecific bronchial hyperreactivity ($PC20FEV_1 < 16$ mg/ml histamine) was confirmed in 5 of the 21 workers (23.8%) tested. None reacted to saline. None of the 21 tested wool workers demonstrated specific airway hyperreactivity following inhalation of wool dust extract. Two of 21 tested workers (9.5%) had positive skin prick reaction to the wool dust extract. One of them had a late skin test reaction to wool. These data suggest that specific bronchial hyperresponsiveness to wool dust seems not to be associated with skin test reactivity in these workers.

DISCUSSION

Our data demonstrate that wool dust allergens may cause positive immediate skin reactions in a large number of wool workers. Similarly, increased IgE levels were noted more frequently among wool workers than among controls. Love et al. [1991] noted that 24% of wool textile workers responded to intracutaneous application of one or more common allergens. In their study, atopic subjects did not appear to have an increased susceptibility to the effects of wool dust on lung function. In our previous immunological study in cotton and hemp workers [Zuskin et al., 1992, 1992a], we found 33% of cotton workers and 20–48% of hemp workers had positive skin reactions to at least one of the textile allergens tested. There was also a high prevalence of elevated IgE among these textile workers. Schachter et al. [1985] reported that cotton bract extract injected intradermally in three naive subjects induced a wheal-and-flare reaction, suggesting that textile dust causes a nonspecific inflammatory reaction initiated by mast cell-derived mediators unrelated to prior sensitization. Petronio and Bovenzi [1983] reported no correlation between total serum IgE concentration and byssinosis in cotton workers. Taken together, these studies suggest that whereas atopic manifestations to textile dust may be seen in wool and other textile workers, acute and chronic responses to textile dusts and extracts are not associated with skin sensitization or an IgE-mediated mechanism.

In the present study there was no significant difference in the prevalence of chronic respiratory symptoms between the exposed wool workers with positive and negative skin tests (NS). In a previous study [Zuskin et al., 1976], a significantly higher prevalence of chronic respiratory symptoms was recorded in wool workers compared to control workers. In that study, workers exposed for > 10 years demonstrated a higher prevalence of chronic respiratory symptoms and lower ventilatory capacity than those with shorter exposures. Moll [1933] described occupational asthma in 18.4% subjects as a consequence of sensitivity to sheep wool. In a cohort of wool workers studied in Bogota, Sanchez-Medina (1969) reported respiratory allergy (allergic rhinopathies and/or asthma) to wool in 16% of patients. Love et al. [1987, 1987a] reported a relationship between respiratory symptoms and exposure to

TABLE IV. Ventilatory Capacity in Male Wool Textile Workers by Skin Reactivity to Wool Dust Allergens*

Group	FVC			FEV_1			FEF_{50}			FEF_{25}		
	Before shift	Difference before/after shift		Before shift	Difference before/after shift		Before shift	Difference before/after shift		Before shift	Difference before/after shift	
	L	%	P	L	%	P	L/s	%	P	L/s	%	P
Total N = 12												
	4.51 ± 0.50	−1.6	NS	3.66 ± 0.47	−1.4	NS	4.87 ± 1.54	−1.2	NS	2.16 ± 0.76	−7.4	<0.05
	NS			NS			NS			NS		
	4.59[a] ± 0.32			3.82[a] ± 0.31			5.01[a] ± 0.32			2.17[a] ± 0.25		
Positive skin test N = 9												
	4.53 ± 0.55	−2.0	<0.05	3.70 ± 0.47	−3.2	NS	4.67 ± 1.75	−1.1	NS	2.13 ± 0.74	−3.8	NS
	NS			NS			NS			NS		
	4.58[a] ± 0.31			3.80[a] ± 0.31			5.01[a] ± 0.34			2.16[a] ± 0.26		
Negative skin test N = 3												
	4.48 ± 0.43	−0.4		3.53 ± 0.16	−4.5		5.03 ± 0.34	−1.6		2.20 ± 0.26	−16.2	
	NS			NS			NS			NS		
	4.63[a] ± 0.42			3.87[a] ± 0.35			5.47[a] ± 0.34			2.22[a] ± 0.26		

*Data are presented as mean ± SD.

[a]Predicted values.

NS = difference statistically not significant ($p>0.05$).

inspirable wool dust in workers manufacturing woolen and carpet yarns. Love et al. [1988] described that allergic symptoms, such as persistent cough and phlegm, wheeze, breathlessness, persistent rhinitis, conjuctivitis, chills, and nosebleeds, in wool workers may be associated with functional impairment of the lungs.

Ozesmi et a. [1987] described symptoms compatible with byssinosis in 22% of carpet weavers exposed to wool contaminated with endotoxin. The authors suggested that "byssinosis" in these workers is due to bacterial endotoxin rather than the wool per se. The airborne dust and endotoxin concentrations in this study were high. Petsonk et al. [1986] demonstrated that water washing of cotton results in reduced airborne endotoxin and less induced bronchoconstriction. Rylander [1987] suggested that after cotton dust exposure, symptoms such as airway hypersensitivity and chronic inflammation are related to endotoxin exposure.

In the current study, of a subgroup of workers with across-shift decrements to wool, 25% had documented airway hyperreactivity, as measured by histamine PC20 FEV_1. This suggests that $PC20FEV_1$ is less sensitive to dust reactivity than the actual measurement of across-shift changes. Furthermore, challenge testing with wool dust extract in this group failed to elicit significant bronchoconstriction. This may suggest that wool dust extract was either not specific or insufficiently potent. Alternatively, tachyphylaxis may have occurred accounting for this finding.

Increased responsiveness to various stimuli may be induced by several mechanisms such as increased mucosal permeability, enhanced exposure of irritant receptors, or increased local reflex activity [Pauwels et al., 1990]. Brown and Donaldson [1991] found no direct effect of wool dust extract on epithelial cells in an in vitro experiment, although they suggest that injurious effects of wool dust on the bronchial epithelium of textile workers could be important in causing inflammation and irritation. After they artificially contaminated cotton and wool by *Staph. aureus*, no staphylococci could be found on cotton after several days, whereas they could be isolated from wool after 30 days. Topping et al. [1989] noted that wool workers may have work-related respiratory symptoms associated with exposure to reactive dyes used in the wool industry. There was an association between symptoms to a particular dye and specific IgE to an albumin conjugate of that dye. In the same study, specific IgG was found in exposed subjects, irrespective of the presence of allergic symptoms, indicating that specific IgG reflects exposure rather than clinical sensitization. In our worker cohort, the workers were exposed to fatty and washed wool that was not treated with any dye.

In the studied wool workers, we recorded acute and chronic lung function changes of the obstructive type. Such changes were most pronounced in the measurement of flows at low lung volumes, particularly FEF_{50} and FEF_{25}. The acute as well as the chronic changes in lung function found in our wool workers were smaller than those reported in cotton, flax, or hemp workers [Valic and Zuskin, 1971, 1972; Zuskin et al., 1990]. Sigsaard et al. [1992] reported that the mean change in FEV_1% and FVC was greater among atopic textile workers in both the cotton and wool industries.

We have found a high prevalence of elevated IgE levels and skin reactivity both specific (wool extracts) and nonspecific among workers in the wool industry. Our study, however, fails to demonstrate convincing relationships between measurements of immediate sensitivity (skin test reactions, IgE) and the effects of wool and dust exposure on respiratory symptoms and function. These studies suggest that a non-

specific inflammatory mechanism is responsible for these effects and that immunologic testing may not have significant predictive value for this occupational problem.

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