Ventilatory responses of normal subjects to flax dust inhalation: the protective effect of autoclaving the flax

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ABSTRACT A homogenous batch of dew retted hackled flax was divided into two portions. One was untreated and the other was steamed for 45 minutes at 125°C in three pressure/vacuum cycles in an autoclave. Dust was collected when the two flaxes were separately processed by industrial doubler and stapler machines. From untreated flax 7.2 g of dust was collected per kilogram of flax after two processing operations. From the steamed flax 4.4 g of flax was obtained per kilogram after four operations. A method was devised to disperse the dust in a room to produce dust levels similar to those encountered in a dusty mill (4.5-5.7 mg/m³). Twelve normal volunteers from the managerial staff of the linen industry of Northern Ireland inhaled the dust over six hour periods. With the untreated flax decreases were obtained in mean forced expiratory measurements of 7.6% in FEV₁ and 4.5% in FVC ($p < 0.01$). A double blind crossover comparison of similar levels of untreated and steamed flax dusts showed 30% less impairment of the forced expirations with steamed than with untreated flax ($p < 0.05$). If these responses reflect the long term airway effects of flax dust then the steaming of flax may help in reducing byssinosis.

Cotton byssinosis has been investigated more thoroughly than flax. There is still an extensive use of flax, and it would be useful to have more direct information on the pulmonary effects of flax dust and how they might be prevented. It has been clearly shown that the acute symptoms of byssinosis are associated with airway narrowing, which is initially reversible.¹ Normal people, whether subjects exposed for the first time or long term workers in the industry, also respond to the inhalation of textile dusts.¹ Merchant *et al* have used this effect to study steaming as a possible preventive measure for cotton byssinosis.² They found a beneficial effect in an experimental cardroom which was confirmed under factory production conditions.^{3,4} The steaming process also affected dust levels and this, in addition to the impracticability of carrying out a double blind crossover trial, made interpretation difficult.

We have set up an experimental chamber into which dust may be dispersed to give controlled levels. The bronchoconstrictor responses of normal subjects have been used as a model to compare dust from steamed and untreated flaxes. The amount of

dust liberated from these flaxes has also been measured.

Methods

SUBJECTS

The subjects were normal male volunteers aged 25-54 (mean 37) recruited from the managerial staff of the linen industry. One subject was a smoker but he did not smoke on trial days. Two volunteers were excluded from entry to the trial, one because of chronic bronchitis and one because of a history of asthma.

GENERATION OF DUST

Imported dew retted flax was obtained in sliver form after hackling in a local mill. Some of the slivers were steamed in a 1500 l autoclave (Andrew Engineering, Nottingham). Three cycles of steaming were carried out, one at 120°C for five minutes followed by two at 129°C for 20 minutes. The temperature in the centre of the bale was 5-10°C lower. A vacuum of 660 mm Hg below atmospheric was applied for five minutes before and between each steaming and for 10 minutes after steaming. The total steaming time was 45 minutes and the total

Fig 1 Dust dispersal in the experimental chamber.

treatment time 70 minutes. The steamed flax was then dried by keeping it for three weeks in the same environment as the untreated flax. Dusts from the untreated and steamed flaxes were collected by suction while each flax was passed through a doubler followed by a stapler. It was possible to clean these machines between the dusts, and mixing of the dusts was thereby avoided.

DISPERSAL OF THE DUST

A weighed quantity of dust was placed in an annular groove on a slowly revolving turntable (fig 1). The dust was lifted from the groove at a rate of 1 g/min using the Venturi effect of an air jet directed into the mouth of a tube (Brauer air mover). The air jet also served to propel the dust laden air along the tube to an input port in the ceiling of the dust room. The tube delivering the dust was directed upwards under an inverted hemisphere suspended over a funnel leading to an input impeller fan. In this way the dust was dispersed in the air entering the room to fairly uniform controlled levels. The room floor space was 4×3.5 m and its volume was 34 m³. Extractor vents were arranged at floor level. A lobby was provided to minimise fluctuation of dust levels by entry and exit of personnel during the experiment. Dust levels were recorded by two Rotheroe and Mitchell dust analysers situated at head height at either end of the room, sampling at 60 l/min for half hourly intervals.

Dust particle size distribution was recorded by a Batelle cascade impactor.

FORCED EXPIRATORY MEASUREMENTS

The subjects were trained to carry out forced expirations reproducibly. The forced expirations were made into a McDermott spirometer, digitalised, and recorded on magnetic tape. Flow/volume curves were later drawn and the flow rate at 50% of the vital capacity (MEF_{50}) calculated by microcomputer (Hewlett Packard 9825A).

SYMPTOMS

Symptoms were assessed by a questionnaire about nasal irritation, throat irritation, chest tightness, cough, breathlessness, nausea, sweating or shivering, or both, or other symptoms.

TRIAL PROCEDURE

The 12 subjects were randomly divided into two groups and each group was studied on alternate Mondays. Forced expiratory measurements were made on the group before they entered the dust chamber and after six hours in the chamber. The first group was exposed to untreated flax dust on the first Monday followed by steamed flax on the third Monday. The second group was exposed in the reverse order of steamed flax dust on the second Monday followed by untreated flax dust on the fourth Monday. The subjects and observers were unaware of the treatment given to the dust. This double blind crossover trial was repeated in a second trial in which the order of exposure of the two groups to the untreated and steamed flax dusts was reversed.

STATISTICAL ANALYSIS

Analysis of variance was used to compare means of the three forced expirations on the 12 subjects. The FEV_1 , FVC, and MEF_{50} were tested separately. The effect of untreated flax dust was tested by comparing the means obtained before and after inhaling the dust. The effect of steaming was tested by (a) comparing the means after steamed flax dust inhalation with the means after untreated flax dust inhalation;

Table 1 Means ($\pm$ SE) and mean decreases (l and l/s) of three forced expirations by 12 subjects before and after dust inhalation (trial 1)

		Untreated	Steamed
Before	FEV_1	3.92 (± 0.09)	3.97 (± 0.09)
	FVC	5.34 (± 0.11)	5.40 (± 0.11)
	MEF_{50}	4.04 (± 0.16)	4.14 (± 0.19)
After 6 h minus before	FEV_1	-0.29	-0.18
	FVC	-0.22	-0.15
	MEF_{50}	-0.57	-0.49

Table 2 Means and mean decreases (l and l/s) trial 2, three forced expirations per subject before and after

		Untreated	Steamed	No of subjects
Before	FEV ₁	4.05 (± 0.09)	4.03 (± 0.10)	} n = 12
	FVC	5.36 (± 0.12)	5.34 (± 0.13)	
	MEF ₅₀	4.36 (± 0.24)	4.33 (± 0.25)	
After 6 h minus before	FEV ₁	-0.32	-0.22	} n = 12
	FVC	-0.26	-0.16	
	MEF ₅₀	-0.62	-0.37	

(b) testing for interaction between (i) differences with steamed and untreated flax dusts (dust type) and (ii) after-before differences (dust effect). This latter test takes into account any difference between the means obtained before the untreated and steamed flax dusts were inhaled.

Results

DUST COLLECTION

The untreated dust was passed once through the doubler and once through the stapler; 7.2 g of dust was collected per kilogram of flax. The steamed flax was passed once through the doubler and three times through the stapler; 4.4 g/kg was collected.

PULMONARY EFFECT OF UNTREATED DUST

Appendix 1 shows the mean lung function changes for the individual subjects. Table 1 shows the combined means for the 12 subjects in the first trial. The FEV₁, FVC, and MEF₅₀ were reduced by 7.4%, 4.2%, and 14.1% respectively. These decreases were each statistically significant at the 1% probability level. The means before untreated flax dust was inhaled were similar to the means before steamed flax, the differences being less than 60 ml (1.2%) for volume and 100 ml/s (2.5%) for flow, and not statistically significant. Six subjects over a six hour period in the chamber with no dust present showed an increase in mean FEV₁ of 50 ml, which was not statistically significant. In this trial the absence of dust was visible to the subjects, but the observer who measured lung function was unaware whether or not there had been exposure to dust.

EFFECT OF STEAMING

Appendix 1 shows the individual subject mean

Table 3 Mean dust levels ($\pm$ SE) [range] (mg/m³), of half hourly duplicate measurements on two trial days for each dust

	Untreated	Steamed
Trial 1	5.0 (± 1.8) [1.5-8.6]	4.5 (± 1.0) [2.9-6.0]
Trial 2	5.7 (± 1.0) [4.0-7.5]	5.5 (± 0.8) [4.1-6.8]

changes with untreated flax dust inhalation compared with steamed flax dust in the first double blind crossover trial. Table 1 shows the mean decreases for all 12 subjects. Appendix 2 and table 2 show the individual and combined decreases in the second trial, in which the order of exposure of the two groups of subjects to the two types of dust was reversed. In the second trial flow data is available for only one group of six subjects because of a magnetic tape failure on one experimental day; otherwise the means are for all 12 subjects. The decreases were smaller and the absolute means higher after steamed compared with untreated for each of the three variables measured in both trials. The mean decreases for both trials combined were FEV₁ 7.6% and FVC

Table 4 Number of subjects with symptoms, by dust type

	Untreated	Steamed
Nasal irritation	4	2
Throat irritation	3	2
Chest tightness	3	1
Cough	5	3
Breathlessness	—	—
Nausea	—	—
Sweating or shivering, or both	—	—
Other	—	—

Fig 2 Particle size distribution by weight. Means of the two days for each dust in trial 2.

4.5% with untreated flax and FEV₁ 5.0% and FVC 2.9% with steamed flax. The MEF₅₀ decreased 14.1% with untreated and 11.8% with steamed flax in trial 1 and 14.2% with untreated and 8.5% with steamed in trial 2. Comparison of steamed and untreated flax dusts, by absolute means after dust inhalation and by interaction between dust type and the effect due to each dust, was statistically significant at the 5% probability level, except for the difference in flow rates in trial 1 which did not reach statistical significance.

DUST LEVELS AND PARTICLE SIZE DISTRIBUTION

Table 3 shows the means of the duplicated measurements of dust levels for each trial. The differences between steamed and untreated flax dust levels were not statistically significant.

The aerodynamic particle size distribution in trial 2 is shown in fig 2. One determination was carried out on each day. The means shown are of the two days for each dust. The differences between the steamed and untreated were small and could not be tested for statistical significance with the limited data available. The weight of dust less than 6 µm was over 60% for both dusts.

SYMPTOMS

Five subjects experienced symptoms with untreated flax but not with steamed flax. Two subjects had more symptoms with untreated than with steamed flax, giving a total of seven of the 12 subjects showing a preference for steamed flax. One subject showed a preference for the untreated flax, having three symptoms with untreated and four symptoms with steamed flax. The remaining four subjects had no symptoms with either flax; table 4 shows the frequency distribution of the symptoms.

Discussion

There were consistent falls in pulmonary function when normal subjects inhaled flax dust at levels similar to those found in a dusty mill. The decreases in FEV₁ are consistent with bronchoconstriction associated with textile dust inhalation.⁵ The fall in FEV₁ in these volunteers who had minimal previous exposure to flax dust is within the range of values reported for mill workers in the industry. Valic and Zuskin found a decrease of 0.42 l in flax workers exposed to a total dust concentration of 4.36 mg/m³.⁶ They also found a decrease of 0.18 l in seven non-byssinotic volunteer workers over a shift at a respirable dust concentration of 3.4 mg/m³.⁷

The decreases in MEF₅₀ were larger than the decreases in FEV₁, which corresponds to the findings of Valic and Zuskin.⁷ This may be due to

the greater sensitivity of this test,⁸ particularly if small airways are constricting. The measurements of airway resistance by McKerrrow *et al* would suggest that large airways may also respond.⁵ Some authors have divided subjects into "reactors" and "non-reactors" based on the size of the fall in FEV₁ when challenged with dust, and Bouhuys and van de Woestijne found differences between these groups in the sensitivity of MEF₅₀ and airway resistance measurements.⁹

Insufficient data are available to enable direct comparison of these acute responses to flax dust with cotton, but the falls in FEV₁ do appear similar. Edwards *et al* found a mean decrease of 0.38 l at a mean cotton dust level of 4.8 mg/m³ in 21 volunteers from outside the industry^{10,11}; and in a survey of mill workers Imbus and Suh found decreases of 0.14 in reactors and 0.022 l in non-reactors over six hour periods of exposure to cotton dust at 1.7 mg/m³.⁴ Further comparison of cotton and flax has been reviewed by the British Occupational Hygiene Society.¹¹

Steaming the flax in an autoclave was found to have the combined useful effects of reducing both the quantity of dust liberated and its byssinotic quality. The reduction in dust liberated is consistent with the lower dust levels after steaming when cotton was used in an experimental cardroom by Merchant *et al*,² who also reported lower dust levels in the early stages of processing steamed cotton in a spinning mill but higher levels in the later stages.³ Imbus and Suh reported lower levels with steamed cotton in all work areas in a spinning mill, though with greatest effect in the early stages.⁴ There have been no studies on steaming in flax mills.

The effect of steaming on the bronchoconstrictor responses is more clearly shown in this study on flax than in previous studies on cotton, because those trials compared responses at different levels of steamed and untreated dust and a double blind crossover comparison was not available.²⁻⁴ The shape and steepness of the dose-response curve for cotton dust level/fall in FEV₁ has been the subject of several studies. Combining the data from different papers suggests that the curve rises steeply initially, 0.3 l/mg/m³ from 0 to 1 mg/m³ (derived from data by Merchant *et al*²), and then less steeply, 0.023 l/mg/m³ from 1 to 8 mg/m³ (derived from data by Edwards *et al*¹¹). If these figures apply to flax, in the dose range used in the present experiments, it would not be possible to account for the differences between steamed and untreated flax dust responses by the small differences in dust levels.

This steaming effect suggests that a byssinotic agent in flax dust is water soluble or thermolabile or both. Washing by condensed water vapour was

probably a component of our steaming process. We found lower endotoxin levels in dust from the steamed flax. As endotoxin is water soluble but not thermolabile this observation does confirm that washing of the flax did occur. The association between reduction of endotoxin levels in the dust and protection against bronchoconstriction does not prove a causative role for the endotoxin. Challenge of these same subjects with a purified endotoxin extract from flax dust produced no bronchoconstriction (RC Lowry and JP Jamison, unpublished data). Washing alone has been found to be effective in reducing the bronchoconstrictor effect of cotton, whereas oven-heating was not.² Edwards found that a combination of washing with some bacteriostatic agent such as ethanol was more effective than washing alone.¹² The dual action of steaming may be acting in a similar way. Differences in the particle size distribution between steamed and untreated flax dusts could not be excluded, but the measurements in the dustroom did not suggest that this was the cause of differences in the pulmonary effects of the dusts.

The degree of steaming carried out in this study produced some weakening of the yarn. The balance between the additional cost of production and the beneficial effect of steaming therefore needs further assessment before the process could be introduced

commercially. Steaming is preferable to washing from an industrial point of view because evacuation of the steam is a useful drying process and because washing may damage the fibre. The duration of steaming required may be less than in the present trial. Merchant *et al* achieved a useful effect for cotton with only five minutes of steaming which, if effective for flax, would be less costly and less likely to damage the fibre.²

The validity of experimental exposure of normal subjects for predicting the incidence of byssinosis can be assessed directly only by long term prospective trials. In support of its validity some correlation between lung function changes and symptoms was found in this trial. Merchant *et al* found a correlation between lung function changes and symptoms during challenge equally in normal and byssinotic subjects.² Monday fall in FEV₁ was also found to correlate with the development of symptoms of byssinosis in the prospective survey of Berry *et al*.¹³

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Appendix 1 Changes in individual subject means, after minus before (1 and l/s), trial 1

	Untreated			Steamed		
	FEV ₁	FVC	MEF ₅₀	FEV ₁	FVC	MEF ₅₀
And	+0.014	+0.073	-0.200	-0.227	-0.210	-0.998
Bai	-0.170	-0.060	-0.213	-0.120	+0.110	-0.814
Bin	-0.067	+0.050	-0.050	-0.090	-0.117	-0.200
Cla	-0.913	-0.493	-2.158	-0.130	-0.078	-0.433
Mcc	-0.427	-0.164	-0.807	-0.104	-0.190	-0.031
Mck	-0.173	-0.097	-0.336	-0.130	-0.044	+0.357
Pau	-0.603	-0.607	-0.760	-0.494	-0.407	-0.687
Ran	-0.380	-0.543	-0.427	-0.296	-0.330	-0.360
Ros	-0.202	-0.226	-0.467	-0.358	-0.408	-0.563
San	-0.110	-0.063	-0.654	+0.060	+0.103	-0.570
Sco	-0.254	-0.382	-0.276	-0.056	+0.013	-0.147
Ste	-0.241	-0.166	-0.520	-0.255	-0.228	-1.460

Appendix 2 Changes in individual subject means, after minus before (1 and l/s), in trial 2

	Untreated			Steamed		
	FEV ₁	FVC	MEF ₅₀	FEV ₁	FVC	MEF ₅₀
And	+0.026	-0.040	+0.053	+0.003	-0.070	
Bai	-0.293	-0.020	-0.473	-0.207	-0.270	-0.053
Bin	-0.037	+0.140	-0.223	-0.094	+0.020	
Cla	-0.523	-0.227	-1.737	-0.473	-0.307	
Mcc	-0.416	-0.297	-0.713	-0.357	-0.263	-0.597
Mck	-0.230	-0.127	-0.367	-0.100	-0.126	-0.017
Pau	-0.613	-0.547	-0.987	-0.486	-0.460	
Ran	-0.300	-0.470	-0.024	-0.126	+0.053	
Ros	-0.270	-0.114	-0.754	-0.056	+0.010	
San	-0.127	-0.223	-0.380	-0.146	-0.206	-0.270
Sco	-0.313	-0.280	-0.637	-0.237	-0.196	-0.648
Ste	-0.777	-0.903	-1.143	-0.320	-0.103	-0.660

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