Airborne endotoxin in woodworking (joinery) shops†‡

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Symptoms such as shortness of breath and cough have been noted in woodworking facilities even where wood dust itself is well-controlled. Suspicion has fallen on other possible contaminants in the workplace atmosphere, including bacterial endotoxin. A few studies have indicated potentially high endotoxin exposure with exposure to fresh wood in sawmills and in the production of fiberboard and chipboard, but fewer studies have been carried out on exposure to endotoxin in dry wood work, for example in joineries. A study of the endotoxin content of airborne wood dust samples from US woodworking facilities is presented, from the re-analysis of samples which previously had been taken to establish mass collection relationships between the IOM sampler, the closed-face 37 mm plastic cassette (CFC) sampler and the Button sampler. Endotoxin was strongly correlated with total dust, but the endotoxin content of a few fresh wood samples was found to be up to ten times higher per unit of wood dust than for dried-wood samples, and this difference was significant. No long-term time-weighted average sample exceeded the recommended limit value of 50 EU m^{-3} (EU, endotoxin units)used in the Netherlands, although a number of the IOM samples came close (seven samples or 44% exceeded 20 EU m^{-3}) and one short-term (48 minute) sample registered a high value of 73 EU m^{-3}. The geometric mean concentration from the IOM samples (11 EU m^{-3}) is within the range of geometric means found from Australian joineries (3.7–60, combined: 24 EU m^{-3}). In contrast, the corresponding values from the CFC (3.6 EU m^{-3}), and the Button sampler (2.1 EU m^{-3}) were much lower and no samples exceeded 20 EU m^{-3}. Endotoxin is likely only to be a significant problem in working with dried woods when associated with very high dust levels, where the wood dust itself is likely to be a cause for concern. The results from the few samples in this study where fresh wood was being worked were similar to results from other studies involving fresh woods. The agreement between these studies is encouraging given the difficulties of endotoxin analysis and the wide variation often expected between different laboratories.

Introduction

Goldsmith[1] assessed the available literature with respect to the clinical and epidemiologic literature of nonmalignant respiratory diseases related to exposure to wood dust, in particular woodworker's asthma. While it was noted that most epidemiologic research has concentrated on estimating the prevalence of respiratory symptoms and describing changes in pulmonary function among workers exposed to western red cedar (*Thuja plicata*), case studies were summarized from exposures to other common woods, many of which are used in furniture manufacture. Other studies showed a higher than normal prevalence of symptoms (including in some cases declines in $FEV_{1.0}$ (forced expiratory volume in 1 second))

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among workers exposed to a variety of woods. Studies of sinonasal effects in furniture makers, who typically are exposed to a wide variety of woods, suggests rhinitis and nasal dysplasia are common among veterans of this profession. Enarson and Chang-Yeung[2] reviewed studies carried out by the Occupational Diseases Research Unit of the University of British Columbia on Canadian workers exposed to wood dust. The most common conditions linked to exposure were simple chronic bronchitis (probably exacerbated by smoking) and non-asthmatic chronic airflow obstruction, although occupational asthma was also observed. They observed that commonly used woods produce pulmonary effects that are less well-described than the asthmatic responses to western red cedar. These symptoms include bronchitis, loss of pulmonary function during the workday or when exposed, and nasal mucociliary stasis.

Hedenstierna *et al.*[3] noted that a lung-function study of wood-workers carried out by Lindberg in 1977 indicated a certain degree of impairment suggestive of airways obstruction. It was also noted that there had been an increased frequency of complaints of airways irritation among sawmill workers in most recent years, despite significant reductions in dust exposure levels. Two sawmills therefore were studied in northern Sweden. Despite dust concentrations that were well-controlled and exceeded the Swedish TLV (threshold limit value) of 1 mg m^{-3} in only a few measurements, exposed subjects showed a significantly higher frequency of symptoms involving the mouth and throat as well as a feeling of chest oppression and self-reported excess coughing. On Monday morning even non-smokers had an FEV_1 0.3 l below reference, a co-efficient of variation 1.1 percentage units above expected, and an alveolar plateau steeper than reference. The conclusion was of an airways obstruction that causes an uneven distribution of inspired gas and impedes forced expiration. In the light of symptoms occurring even with good overall dust control, exposure to other hazards has been suspected, including possible exposures to formaldehyde, terpenes, micro-organisms (bacteria, fungi) and their products (endotoxin, glucans).

Endotoxin is the name for lipopolysaccharides produced in the external cell membrane of Gram-negative bacteria, and it has been implicated in other occupational respiratory diseases, such as byssinosis[4] from inhalation of dust from cotton, flax, or hemp, and which is characterized by shortness of breath, coughing and wheezing. Primary colonization by bacteria may occur when logs are stored in the forest and in lumber yards, and apparently undecayed timber may contain a high level of microflora.[5] Secondary colonization can occur on chips and planks that are stored in conditions favorable to microbial growth. Some species of trees may be affected by a specific bacterial infestation known as ''wetwood'', and this has been implicated as a cause of elevated endotoxin levels.[6] Air drying apparently kills the bacteria which cause this condition, but does not affect endotoxin levels. It is not known what effect kiln drying has on endotoxin levels, but the elevated temperature is probably more destructive, and might be expected to lower overall endotoxin levels. Endotoxin is typically measured in endotoxin units (EU), because of the nature of the assay.[7] Converting this to a mass quantity varies with the specific assay used, but typically is reported as 10 EU equal to 1 ng. Suggested exposure limits for airborne endotoxin have included 1000 EU m^{-3} and 200 EU m^{-3}, but following the report by Castellan *et al.*[8] of 90 EU m^{-3} as the threshold value causing decreased lung function in exposed men, a value of 50 EU m^{-3} was recommended by the Dutch Expert Committee on Occupational Standards[9] and has been widely quoted, although no country has an officially recognized legal limit for endotoxin exposure. Airborne endotoxin is associated with wood dust particles which are captured on filters housed in samplers. The samplers do not all have the same collection efficiency for large particles, and so it may be difficult to compare endotoxin levels in environments where different samplers are used, and difficult to compare endotoxin levels to a standard where a sampler is used that is different from that intended in the standard. Many researchers have adopted the principle of sampling wood dust in accordance with the International Organization for Standardization (ISO) standard for ''inhalable'' sampling, that is to say a collection efficiency meant to mimic that of the human mouth and nose. Samplers frequently used include the IOM (Institute for Occupational Medicine sampler; SKC Ltd, Blandford Forum, UK), the GSP (Gesamtstaubprobenahme; Gesellschaft für Schadstoffmesstechnik GmbH, Germany), and the 7-hole sampler (SKC Ltd, UK). These samplers have been compared to the inhalable convention under laboratory conditions.[10]

A few, recent, studies have examined exposures of wood-workers using fresh wood to endotoxin. Dutkiewicz *et al.*[11] examined the exposure of workers in fiberboard and chipboard factories processing European alder (*Alnus glutiosa*), silver fir (*Abies alder*) and Scots pine (*Pinus sylvestris*) to endotoxin by means of a Polish sampler (AS-50) and found high levels (66–1974 EU m^{-3}) when the process involved chipping and shredding, and storage of wood chips, but minimal amounts in the processes of forming, trimming and sanding. The highest endotoxin concentrations were associated with the highest samples for wood dust. A survey of four sawmills in British Columbia[12] processing Engelmann spruce (*Picea engelmanii*), white spruce (*Picea glauca*), lodgepole pine (*Pinus contorta*), sub-alpine fir (*Abies lasciocarpa*) and Western hemlock (*Tsuga heterophylla*) using GSP inhalable samplers gave results up to about 350 EU m^{-3} (10 EU = 1 ng). A significant association between endotoxin concentration and the inhalable wood dust concentration was noted. In a survey of plywood workers in New Zealand[13] processing radiata pine (*Pinus radiata*), 35% of samples exceeded 50 EU m^{-3}, even though none of the inhalable (IOM sampler) samples exceeded the 5 mg m^{-3} wood dust standard, and the group of workers with the highest mean endotoxin concentration also had the highest mean inhalable dust concentration. A large survey in Australia examined sawmills[14] processing eucalyptus (*Eucalyptus*) with ''inhalable'' (7-hole sampler) samples recording up to 784 EU m^{-3} (10 EU = 1 ng) in some sawmills, but much lower concentrations of both bacteria and endotoxin where kiln drying was used. Again endotoxin concentration was correlated with inhalable wood dust concentration. In the United Kingdom,[15] levels up to 2660 EU m^{-3} (10 EU = 1 ng) were observed from IOM inhalable

samples in sawmills, even though maximum inhalable wood dust levels rarely exceeded 10 mg m^{-3}. Clearly, there is a cause for concern with respect to endotoxin exposure in the processing of fresh wood, most especially where high levels of wood dust are encountered. However, lower levels might be expected where kiln-dried woods are used in carpentry shops (joineries). Abdel Hameed *et al.*,[16] for example, noted low concentrations of gram-negative bacteria in Egyptian woodworking shops. The Australian survey referred to above[14] is the only one where joinery shops were also included for endotoxin determination, and endotoxin levels were generally much lower than in sawmills studied, except for one location which was associated with very high wood dust concentrations (up to 50 mg m^{-3}). A very recent survey of joineries in Tanzania[17] indicated both high inhalable dust levels (Dutch PAS-6 sampling head) and high endotoxin levels, but with only a weak correlation between the two, possibly as a result of extreme seasonal differences. The current authors are unaware of any survey for endotoxin in US carpentry (joinery) shops.

The objective of this study is to examine personal samples taken in three US carpentry (joinery) shops for endotoxin content. The samples were taken primarily to determine whether three different samplers had similar or different collection characteristics for wood dust. It was hypothesized that endotoxin is probably present on or in the wood particles, and that the quantity of endotoxin per unit of wood dust does not change with particle size, so that the samplers would have the same ratios of endotoxin one to another as wood dust. Given that this is so, then it is possible to compare the endotoxin concentrations of wood dust between the different types of wood used. However, to rule out the possibility of any bias resulting from different relative proportions of sampler types between wood type we have adjusted for sampler type in comparisons between wood types. Finally, it is possible to take the absolute endotoxin values from these samples and, provided coverage is sufficient, calculate time-weighted average (TWA) values that can be compared to other studies and proposed standards.

Methods and materials

Personal air samples for wood dust had been taken at three carpentry shops (joineries) in the south-eastern US in order to observe the differences in mass collection of side-by-side personal samples by different sampler designs.[18] Three different samplers were used: the 37 mm closed face plastic cassette (CFC, Omega Specialty Instruments, Chelmsford, MA, USA), the IOM inhalable sampler, and the Button sampler developed by the University of Cincinnati (SKC Inc, Eighty Four, PA, USA). All samples were collected on 5.0 μm nominal pore diameter PVC filters (the CFC uses 37 mm diameter filters; the IOM and Button samplers use 25 mm diameter filters), and all samplers were operated at their recommended flow-rates (CFC and IOM at 2 l min^{-1}; Button at 4 l min^{-1}). A total of 51 pairs of samples were collected, although each sampler was not equally represented in the total, as more pairs of CFC and Button samplers were taken in order to attempt to differentiate them. There were 16 IOM/CFC pairs, 12 IOM/Button pairs and 23 CFC/Button pairs, for a total of 28 IOM samples, 39 CFC samples and 35 Button samples. The results of that study, including a detailed description of the environments where the samples were collected and the job-types sampled, descriptions of the samplers and procedures for sample collection have been published.[18]

The three carpentry shops included one with approximately 50 employees that made antique reproduction furniture from dried Honduran (also known as American) mahogany (*Swietenia macrophylla*) with some maple (*Acer saccharum*), a shutter-blind manufacturer employing about a dozen individuals that used western red cedar and basswood (*Tilia Americana*), also dried, and a large (>1000 employees) company that made kitchen cabinets from various hardwoods. Only the latter company received, stored, cut and kiln-dried its own wood supplies. It is not known whether all wood types were received in fresh, but samples were taken from persons involved in the working of fresh oak (*Quercus* sp.), poplar (*Liriodendendron tulipifera*), sweet-gum (*Liquidamber styraciflua*) and hickory (*Carya* sp.) during one day's operations, and these are referred to as "fresh woods". On the main factory floor some workers were fitted with samplers when working with dried poplar and sweet-gum, and another group was sampled working with hickory, cherry (*Prunus serotina*), maple and oak, collectively referred to as "mixed hardwoods".

After the filters (or filter and cassette in the case of the IOM samples) were reweighed in the laboratory, the filters plus sample (but not the cassettes) were carefully transferred to 50 ml polypropylene centrifuge vials, tightly capped and stored in the dark at room temperature until analysis. Although the period of storage was approximately three years, endotoxin is considered relatively stable under these conditions.[19] The samples were submitted to the NIOSH contract laboratory (Datachem Laboratories, Salt Lake City, UT, USA) together with the field blanks and ten of each size of filter as media blanks.

Endotoxin was determined in this study using the kinetic limulus amoebocyte lysate (LAL) test. The specific assay used was the BioWhittaker Kinetic QCL assay (BioWhittaker, Inc., Walkersville, MD, USA), as described.[7] The procedure used was the laboratory's standard operating procedure MC-AN-007, which involves adding 10 ml of room temperature pyrogen-free water (PFW) to extract the samples in the tubes containing the samples, and placing them first in a vortex mixer for 30–60 seconds, and then on a rocker for one hour. Extracts were removed and centrifuged at 2200 rpm for 10 minutes at 4 °C. Serial dilutions (typically 5-fold) were prepared in polypropylene tubes and then samples were placed in 96-well plates and incubated at 37 °C for 10 minutes before the addition of the LAL reagent. Time required to develop color at 340 nm wavelength was compared to a series of standard dilutions. Results were reported in endotoxin units (EU) per sample. Twenty-nine samples were reported with results between the limit of detection (0.005 EU ml^{-1} or 0.05 EU per sample) and the limit of quantitation (0.05 EU ml^{-1} or 0.5 EU per sample). Field blank samples ranged from non-detected to 1.5 EU, the median of 13 37 mm filters being 0.076, while the median of 11 25 mm filters was 0.102 EU. Samples were not corrected for field blanks. Four heavily overloaded wood dust samples were not included in the linear regression analysis

described below, but were included in the comparison of data with other studies.

Linear regression analysis was applied to quantify the relationship between wood dust levels and endotoxin levels. In order to meet the requirements of approximate normality for regression analysis and for *t* statistics used in comparing these data to that from previous studies, wood dust and endotoxin concentrations were log transformed (log base 10). After transforming the data, approximate normality was verified by means of normal probability plots (data not shown). As would be expected for two normally distributed variables, regression residuals were also confirmed to closely follow a normal distribution. Regression residuals were also plotted to confirm constant variance across the range of the independent variable and also to confirm approximate linearity. Variances across wood group types were nearly equal (data not shown) further meeting the assumptions of the regression model used here. In order to explain the observed variability in the relationship between endotoxin and wood dust levels, subgroup regressions were performed to compare the regressions for log endotoxin and log wood dust concentrations. Comparisons between regression lines for several wood type subgroups were performed using indicator variables to parameterize differences in slope and intercept from the reference wood group.[20] The reference wood type group was set to fresh woods in the cabinet shop (oak, poplar, sweetgum and hickory) with other groupings as follows: mahogany–maple, mixed hardwoods and basswood–cedar. For subgroup regression comparisons the independent variable (log of wood dust concentration) was centered at its estimated grand mean, across all subgroups, in order to provide for estimation and comparison of subgroup regression intercepts at the middle of the wood dust log concentration distribution, rather than at the lower end of the wood dust range. This is a more meaningful comparison since otherwise the arbitrary convention for linear regression models would estimate the intercept at the zero value for the independent variable (wood dust). The transformation has no effect on slope comparisons but serves to provide estimates of the differences in location (intercepts) between subgroup regression lines. All regression models comparing wood types were adjusted for sampler type by including zero/one indicator variables for sampler type. This adjustment rules out the possibility that our results are a reflection of confounding by different distributions of sampler type across wood type sub-group.

Comparisons of concentration levels between these data and data from other studies were performed by using *t* tests on the log concentration data. Since some of the variances for these studies are significantly different we used the approximate *t* statistic for unequal variance and Satterthwaite's method[21] to calculate approximate degrees of freedom. This is a simple parametric approach that is analogous to comparing the medians between groups in the original concentration scale. This approach was made possible because the existing studies reported geometric means and geometric standard deviations which can be transformed back to the log scale directly.[14,17] These two statistics provide the mean and standard deviation of the original log scale data by definition. All significance tests were performed at the 0.05 significance level.

Results

Most samples covered rather short periods of time, so that single samples were not normally good estimates of a full-shift (8 hour) TWA (time-weighted average). One short-term (48 minutes) sample on an IOM sampler was found to have an endotoxin concentration as high as 73 EU m^{-3}. No other samples from any sampler exceeded 50 EU m^{-3}. Long-term TWA results were calculated when individual samples or combinations of samples exceeded about 160 minutes duration (most of these TWA samples or combinations of samples exceeded 300 minutes duration). The numbers of TWA samples derived in this fashion were 16 IOM, 31 CFC, and 24 Button. The highest TWA result (40 EU m^{-3}) was again found on an IOM sampler. Seven samples, or 44%, of the IOM TWA samples exceeded 20 EU m^{-3}, while none of the CFC or Button sampler TWA samples exceeded this value. Conversely, 55% of the CFC TWA samples and 83% of the Button TWA samples were below 5 EU m^{-3}, with geometric mean TWA concentrations of 3.6 EU m^{-3} and 2.1 EU m^{-3}, respectively. In the estimation of TWA values, all results were used including those between the limits of detection and quantitation.

In the gravimetric study of wood-dust study, median wood dust concentrations were found to differ according to sampler[18] because of their differences in sampling efficiency over the range of aerosol sizes encountered in the workplace, and this was confirmed by microscopic evaluation.[22] The ratios of the median TWA values for endotoxin between these samplers had a ranking similar to the ratios found for wood dust. For example the median IOM/CFC wood dust ratio was 3.35, while the IOM/CFC endotoxin ratio was 2.84, and the median CFC/Button wood dust ratio was 1.2, while the CFC/Button endotoxin ratio was 1.95. This is taken to be an indication that there is no gross effect of size distribution on endotoxin content per unit of wood dust, and that endotoxin concentration increases with wood dust concentration similarly for all samplers studied, so that the results from all samplers could be combined.

The regression plot for individual (not TWA) sample data above the LOQ for both wood dust and endotoxin (minus four very heavily loaded wood dust samples) is shown in Fig. 1. The association between endotoxin concentration and wood dust concentration was studied by means of linear regression

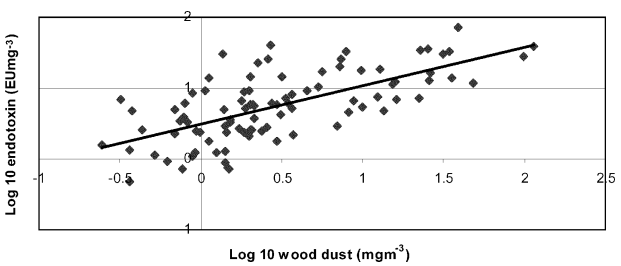

Fig. 1 Regression of log-transformed endotoxin concentration values and their associated wood dust concentrations for results where both values are above their respective limits of quantitation. Units given are for the untransformed data. Four heavily overloaded wood dust samples were omitted. $r^2 = 0.62$, $p < 0.0001$.

Table 1 Estimated regression coefficients for log endotoxin as a linear function log wood dust for data from the present study. All regressions are adjusted for sampler type. SE = Standard Error

	n	Intercept (SE)	Slope (SE)[a]
Mahogany–maple	16	0.50 (0.11)	0.43 (0.23)
Basswood–cedar	20	0.85 (0.15)	0.80 (0.19)
Mixed hardwoods	28	0.54 (0.05)	0.64 (0.08)
Fresh woods	10	1.31 (0.26)	0.85 (0.33)

[a] All slopes were not found to be different from each other ($p > 0.05$) all individual intercepts were significantly different from others ($p < 0.05$) except for mahogany–maple *vs.* mixed hardwoods ($p = 0.64$)

Table 2 Summary data for comparison of joinery studies

		Wood dust			Endotoxin		
Study	*N*	GM TWA/ mg m^{-3}	GSD	Range	GM TWA/ EU m^{-3}	GSD	Range
Tanzanian all seasons[17]	281	3.32	2.47	0.45–67	91	3.74	9–4915
Australian combined[14]	66	3.68	3.67	0.21–51	24	3.66	1–279
This study	17	5.08	4.95	0.59–131	11	2.46	2.2–40

analysis for wood type subgroups as defined in the methods section. These results are presented in Table 1. The linear relationship between log wood dust, centered at its grand mean, and log endotoxin produced similar slopes ($p > 0.05$) for all wood type subgroups but generally different intercepts ($p < 0.05$). One exception to this was the intercept for the mahogany–maple group from the furniture shop (intercept = 0.50) and the mixed hardwoods group from the cabinet shop (intercept = 0.54), which were not found to be significantly different from each other ($p = 0.22$). The western red cedar–basswood sample group from the shutter-blind shop had higher levels of endotoxin than the hardwoods noted above, possibly because these woods are subjected to less drying to preserve their resin contents. The fresh woods (oak, poplar, sweet-gum and hickory) sample group from the cabinet shop saw-mill had the highest endotoxin levels. Samples taken after these woods had been dried had lower endotoxin levels, bridging the range between the fresh wood data and the mixed hardwood data. These results are not included in the table.

The fresh wood samples analyzed at the sawmill of the cabinet shop had an endotoxin content of approximately 10 EU per mg of wood dust, about an order of magnitude higher than that found for the dried mixed hardwoods. This high endotoxin content resulted in higher airborne concentrations, but because of the good dust controls applied throughout this particular shop, the highest observed concentration did not exceed the recommended maximum value of 50 EU m^{-3}. It should also be noted that the fresh woods at the cabinet shop are treated on arrival for storage, but the nature of the treatment is unknown.

Discussion

The most problematic issue of endotoxin analysis is the analytical procedure. A recent large round-robin endotoxin assay of cotton dust had very high inter-laboratory variation when each laboratory followed its own in-house procedure.[7] When the extraction step was standardized, this variation was reduced, indicating that further standardization could make it possible to compare results from different laboratories. More recent results, where laboratories used the same assay kit from the same production lot, still produced large difference between laboratories, although most of the laboratories could discern the differences between samples with different levels of endotoxin.[7] Therefore, comparisons of results between this study and others should be interpreted with some caution.

In line with previous research on general wood dust sampling,[18] the IOM inhalable sampler gave higher results for endotoxin concentration in all workplaces in this study than either the closed-face 37 mm cassette or the Button sampler. The TWA concentrations given by the individual or combination IOM samples can be compared to equivalent inhalable samples from the Australian and Tanzanian studies of joineries (Table 2). The geometric mean (11 EU m^{-3}) is within the range of geometric means found from the four individual Australian joineries[14] (range 3.7–60 EU m^{-3}) and the difference between this study and the combined results for the Australian joineries is not significant for wood dust ($p = 0.34$), but is significant for endotoxin ($p = 0.007$). The recent study of joineries in Tanzania[17] gave significantly higher endotoxin concentrations ($p < 0.0001$) than either this study or the Australian study, even though again there was no significant differences in wood dust concentration ($p > 0.05$). This difference for endotoxin may be due to the type of wood, or to the climate, but may also be due to differences in drying practice; for example, the Tanzanian woods may be air-dried, since the study does not mention a particular drying practice. The endotoxin content of woods used in carpentry does vary according to wood type, as was noted by Dutkiewicz *et al.*[5] in stored timber, but likely also varies as a result of the extent of drying. Kiln-drying for extended periods at elevated temperatures may destroy the endotoxin molecules.

The geometric mean concentration (9.8 EU m^{-3}) of ten endotoxin results from fresh wood encountered in the sawmill of the cabinet shop is higher than that found in the rest of that shop or in the other shops where only dried woods were found. Half of the fresh wood results are from inhalable IOM samplers, and the TWA results ranged from 8.3 to 40 EU m^{-3}, and this included two of the seven samples in this study that exceeded 20 EU m^{-3}. Insufficient sample numbers preclude statistical comparisons, but these results are within the range of those found where fresh wood was encountered in other studies including Canadian sawmills[12] where a geometric mean concentration ($n = 216$ GSP samplers) of 8.3 EU m^{-3} was found with a high of 350 EU m^{-3}, and plywood factories in New Zealand[13] which reported a geometric mean concentration ($n = 20$ IOM samples) of 23 EU m^{-3}. The large Australian study included sawmills as well as joineries, and the green eucalyptus sawmills reported a higher geometric mean of 66 EU m^{-3} ($n = 83$, 7-hole head samples).[14] 9% of the Canadian study samples and 35% of the New Zealand study samples were also above 50 EU m^{-3}.

While it is possible that the higher endotoxin exposures noted in sawmills using fresh wood is due to the presence of airborne bark and outer layers of wood containing greater bacterial colonization than the wood found in carpentry (joinery) shops, Dutkiewicz *et al.*[5] found generally equivalent quantities of endotoxin per gram in heartwood, sapwood and bark for a range of stored lumbers, including many of the woods in this study. Stored basswood was found to have much greater levels of endotoxin in heartwood and sapwood than oak or cherry (typically 1000 to 10 000 times more), but differences of this magnitude were not seen among the dried woods in this study, again suggesting the likely cause of the difference in endotoxin levels between sawmills and carpentry shops is due to a reduction of the organic molecules during kiln-drying.

As demonstrated in other studies, the high endotoxin content of fresh wood can result in exposures above recommended limits, even though this was not seen in this study. However, the low endotoxin content of dried woods appears to result in generally low exposures to workers, unless accompanied by wood dust concentrations that are above generally accepted limit values for wood dust (which range from 1 mg m^{-3} to 15 mg m^{-3}, depending on the country or agency), where the wood dust itself may be the greater cause for concern. In the Australian study,[14] the joinery with the highest endotoxin results (geometric mean 60 EU m^{-3}, range 6–279 EU m^{-3}) also had the highest wood dust results (geometric mean 11.5 mg m^{-3}, range 5–51 mg m^{-3}). In this study, IOM inhalable TWAs for wood dust ranged up to 131 mg m^{-3}, but only a few values exceeded 5 mg m^{-3}. Eight of ten IOM dried-wood samples with endotoxin concentration values greater than 25 EU m^{-3} were associated with wood dust concentrations greater than 20 mg m^{-3}. None of the CFC TWA samples exceeded the US permissible exposure limit (PEL) for wood dust of 15 mg m^{-3}, and none of the endotoxin TWA results using the CFC sampler exceeded 20 EU m^{-3}.

Conclusions

Endotoxin levels in dried wood dusts were found to be low, and correlated with dust levels, such that endotoxin exposure in joineries is likely only to be a cause for concern when associated with levels of wood dust that would themselves be considered problematic. Therefore, effective control of dust levels provides control of endotoxin levels. There has been a perception of difficulty in endotoxin analysis on the part of some, but not all researchers, and at least one intra-laboratory study reported large variation even when protocols were standardized. Therefore, it has not generally been thought possible to directly compare results of different studies that may have used different protocols and analysts of differing capabilities. However, the general agreement in endotoxin concentrations between this and other studies insofar as green woods are concerned, suggests that comparison may indeed be possible and is encouraging for the development of endotoxin standards.

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