A Review of Wood Dust Longitudinal Health Studies: Implications for an Occupational Limit Value

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Abstract

Numerous studies reporting on the health effects of wood dust have been published over many decades. For the clear majority of these studies, their use for setting a science-based occupational exposure level is problematic due generally to insufficient exposure measurement data, inadequate participant follow-up, and lack of control for confounding variables. However, there exists a robust data set from a large longitudinal lung function study that provides a scientifically sound basis for establishing an occupational limit of 5 mg/m^3 inhalable wood dust. The choice of this data set and its application for this purpose are presented in this review.

Introduction

The health effects of occupational exposure to wood dusts have been well studied over a period of 50 years or more. These studies have examined potential carcinogenic and noncarcinogenic effects in the upper and lower respiratory systems of humans. In the 1960s, researchers in Great Britain in a seminal study reported a large excess of adenocarcinomas of the nasal sinuses in furniture workers in the High Wycombe area.[1] A number of other predominantly European case–control studies also found elevations of this type of nasal tumor in wood industry workers. In 1995, the International Agency for Research on Cancer (IARC) listed wood dust in Group I, carcinogenic to humans, based on the reported evidence of this tumor end point.[2] (See also updated IARC wood dust monograph's review of case-control and cohort studies.[3]) Because of the retrospective design of these studies, and tumor latency periods upward of 25 years, contemporaneous wood dust exposure measurements for the study participants are lacking. Thus, establishing an occupational limit based on these studies is unachievable. What has long been suspected, however, is that these rare type tumors arose from very high wood dust exposure levels that preceded installation of adequate ventilation systems. This has been amply manifested in a recent follow-up study[4] of the High Wycombe wood workers, which demonstrated a dramatic decline in the incidence of nasal adenocarcinomas since improvements in working conditions

made during the 1960s and later. The follow-up cases obtained from hospital records were all exposed prior to 1970. Based on statistical analysis, and taking latency into account, the authors rule out that the declining incidence could solely be attributed to a reduction in workforce population. In addition, they note that the working condition improvements largely preceded the adoption of a 5 mg/m^3 inhalable exposure limit in 1988. Studies of nonmalignant respiratory effects of wood dust are also extensive in the published literature. Unusual wood species such as Western Red Cedar have known allergenic hazard and have been dealt with separately in terms of establishing a safe exposure level. For the more common species used in the manufacture of wood products, most of the studies conducted are cross-sectional in design. As noted in Glindmeyer et al[5] regarding these types of wood dust studies, "[L]imitations in the scope and design of previous studies have included small

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populations, single process exposures, exotic or allergenic wood species, variable and often sparse environmental sampling, and diverse response variables (sometimes only symptoms), external controls of dubious comparability, inadequate assessment of lung function, and unorthodox analytic strategies." Moreover, in 2 published articles,[6,7] researchers have provided a qualitative overview of studies that have examined nonmalignant effects of wood dust exposure, including both dry woods and green woods. With respect to the published cross-sectional studies, the authors expectedly note that, "When studying the effects of exposure on lung function, a cross-sectional design as used in most of the reviewed papers, is at best suboptimal." They further indicated the deficiencies of these study designs when attempting to assess associations between exposure and chronic diseases in light of latency periods. These and other limitations are well recognized for studies of this type, which are often conducted for purposes of hypothesis generation. Despite these recognized limitations, and without critical analyses of the individual studies, the authors conclude that their review supports wood dust being a risk factor for various nonmalignant effects. This conclusion is troublesome given the cited study limitations, questionable reliance on comparison of numbers of positive versus negative studies, and critically, lack of any exposure–response analysis.

In a later published study, researchers from this same group[8] investigated whether cross-shift changes in lung function might predict chronic lung function changes. Wood-dust exposed and reference workers were drawn from a previous study cohort, which had been studied both cross-sectionally and in a 6-year follow-up (see original cohort description and wood dust exposure measurement information under longitudinal studies below). They reported the absence of correlation between cross-shift changes and annual change in FEV_1 contrary to the results of some cross-sectional studies in several other industries as noted in their article. Thus, these longitudinal outcomes add clear caution to using cross-sectional studies for setting maximum acceptable exposure levels for wood dust.

Many governmental regulatory bodies have established occupational exposure limits for wood dust over the years based on assessments of nasal cancer and noncancer end points. Because of the lack of quantitative exposure–response data, however, the exposure limits that have been developed tend to be based on qualitative data assessments, and as a result are quite diverse in their numerical values. Well-conducted longitudinal studies of adequate size and quantitative exposure–response analysis can overcome the observed deficiencies of these studies, and our purpose here is to systematically examine the available published literature on these studies and assess their utility in serving as a basis for developing a science-based occupational exposure level for wood dust.

Methods

This article provides a review of the published literature on longitudinal studies of pulmonary function in woodworkers. Based on a systematic review of the published literature, we performed a Medline search using the search terms lung function, cross-sectional, longitudinal, FEV_1, and limit. Only 3 longitudinal studies were found to be available for review. More specifically, 2 large studies and 1 small study are included in the literature. The small study[9] composed of 31 wood dust exposed nonsmoker workers in furniture manufacturing. This study, with reported average exposures exceeding 5 mg/m^3, did not report any statistically significant longitudinal decreases in pulmonary function. Our collective experience and the data provided by Kalliny et al[10] indicate that furniture manufacturing includes the higher end of exposures in current wood operations. However, due to its small size, we have selected to remove it from further evaluation. Our focus is on the 2 largest reported studies.

Results

Jacobsen et al,[11] conducted a 6-year follow-up study based on a population that had been previously studied cross-sectionally. From that original cohort, 1112 woodworkers (927 males and 185 females) and 235 reference workers (104 males and 131 females) participated at follow-up. Exposure assessment utilized a job-exposure matrix developed from a questionnaire survey of study participants, and inhalable dust measurements (2217 at baseline and 1355 at follow-up). The inhalable wood dust measurements were performed using passive dust monitors. Using cumulative exposure, the median (range) inhalable wood dust exposure was 3.75 (0-7.55) mg-year·m^3. Regression analysis was performed between cumulative exposure and absolute changes in lung function stratified by sex. Adjustments were made for smoking, age, height, and weight gain during follow-up. There was no reported statistically significant association between exposure and lung function decline during follow-up in male workers. In female workers, regression analysis produced a dose–response relationship between decline in FEV_1 and cumulative exposure in smokers only. The authors provided some information that females may be more sensitive to dust exposures, citing studies on tobacco use and exposure to mineral and biological dusts. However, the results for females should be reviewed with some skepticism. There were small numbers of female participants in each of the closely spaced cumulative exposure categories, which make outcome variables highly sensitive to changes in intergroup cut points and to adjustments for confounders. For female workers in the exposure groups where an association was indicated (3.75-4.71 and $\geq$4.71 mg·year·m^{-3}), there were only 37 and 19 participants, respectively, compared with 233 and 230 males in the same exposure categories. Thus, the reported association in female workers could likely be an artifact of the small numbers in the female groupings.

Tulane University Study

The other longitudinal study was performed by researchers at Tulane University.[5] This study is the largest known longitudinal study examining the pulmonary function of workers across

the wood processing industry. The study was commissioned to address the unreliable nature inherent within cross-sectional studies, as well as correct for data gaps in prior studies. The study included 1164 participants (67% males, 33% females; white 82%, African American 18%) with a minimum of 3 pulmonary function tests (average 4.5) each within the follow-up study period (average 4.0 years per participant). The 10 facilities participating in the study were selected by the researchers after a survey of 447 US facilities to represent a broad spectrum of workplaces, although with a bias toward larger facilities that had complete exposure and smoking records for the exposed workers, and minimal confounding exposures. Facilities using softwood, hardwood, or a mixture of the 2 were included.

There were 2363 valid sets of personal dust exposure measurements over the course of the study for use in the exposure–response analysis. As reported in a separate publication,[10] the researchers employed state-of-the art sampling methods and reported on multiple size fractions for both wood solids and nonsolid wood residual particulate matter (RPM). With regard to sampling by wood type, 9% were mixed wood, 60% hardwood, 2.7% engineered wood, 27% softwood, and 1.5% plywood. As explained by Glindmeyer et al,[5] the RPM "represents the mass of nonwood derived particles [in the workplace] such as soil, engine exhaust, environmental tobacco smoke, spray finish aerosols, etc. plus the volatile components of the whole wood dust including the water fraction of the wood, terpenes, and essential oils." The wood solids "represent the combined mass of cellulose, hemicellulose, lignin, wood protein and other wood-derived biological macromolecules present in the collected particulate matter." The Respicon (Helmut Hund GmbH) personal particle sampler used excludes noninhalable particles and thus overcomes the potential oversampling artifact possibly generated in some previous studies based on inhalable sampling. These sampling artifacts lead to confounding when particles that are greater than the inhalable range fall into the sampler and are included in the mass of inhalable particles. The sampler provides simultaneous measurements of 3 particle-size fractions: respirable, tracheobronchial, and extrathoracic, the sum of which equals the inhalable dust level. Diffuse Reflectance Fourier Transform Infrared Spectroscopy was employed to determine the wood solids content of gravimetric samples for 527 sets of dust samples. The researchers were thus able to differentiate between wood solids and nonsolid wood dust-related material (ie, RPM). Both the wood solids and RPM fractions (individually and in combination) of each of the 3 size fractions were considered in the health effects regression modeling.

Results

As reported in their study, "[t]here were no adverse effects for the levels of any size fractions of wood solids dust encountered at any facility studied." The regression analysis was adjusted for demographics, baseline pulmonary function, and cigarette smoking. The study also controlled for potential volatile exposures such as paint, varnish, solvents etc. The study observed respiratory effects from respirable RPM at 2 facilities, one a milling facility, and the other a sawmill-planing-plywood facility. Analysis of the observed effects from the respirable RPM indicated the following: (1) obstructive effects were noted at the milling facility, although it was unclear if the effects may have been related to smoking. In this regard, the authors reported of having learned that "in 1999, just prior to the start of the study, increased health insurance premiums were implemented for the smokers, which could have led to under-reporting of cigarette use." Casting further doubt on a respirable RPM-related exposure effect, the respirable RPM level at the milling facility was the lowest of the 4 facility-type categories. Yet, at other locations with higher respirable RPM levels, no similar effects on lung function were reported; thus, a relevant concentration–response relationship was not observed. (2) Restrictive responses of the type corresponding with alveolar hypersensitivity reactions were observed at the sawmill planing-plywood facility. There were frequent observations of mold at this facility, and the authors concluded that airborne bacteria or fungi were potential causative agents of the observed effect at that facility, consistent with the significantly greater prevalence of pneumonia reported for this group. At each of these facilities, and irrespective of whether the reported effects were RPM exposure related, it is highly improbable that such effects would be related to any wood constituents. It can readily be shown from the data in the study, which give % wood solids and % RPM in the dust samples, and from known % constituent composition of wood, that the wood volatile organic material fraction of the respirable RPM is minute, in the order of 1% or less of the respirable dust *in toto*.

The researchers also examined whether a healthy worker effect might have influenced results. A comparison of data presented between the longitudinal cohort and those not followed longitudinally (less than at least 3 pulmonary function tests over at least 2.5 years, and incomplete exposure and smoking information) assist in shedding light on this matter. Both groups had similar average years of working within the wood-related industry (facilities within the study, and at other wood facilities); 12 to 17 years for the longitudinal and 11 to 16 years for the nonlongitudinal worker groups. At baseline at the studied facilities, nonlongitudinal workers had on average approximately 2-year shorter employment duration than those followed longitudinally, with the mean baseline employment for all workers greater than 7.5 years. It was noted that much of the recorded attrition during the course of the study was due to involuntary downsizing of the workforce. The 2-year shorter employment at baseline of the nonlongitudinal workers likely explains their subsequent loss to complete follow-up since they would have had lower job seniority resulting in layoff. Thus, the researchers conclude that attrition of these workers was not related to any respiratory effects of exposure, nor does the analysis support a healthy worker effect in the studied population.

Table I. Wood Dust Exposure Levels, Summary Statistics, and Number (n) of Study Participants by Exposure Segment.[a]

Inhalable Dust (mg/m^3)	Mean (mg/m^3)	SD	SE	Min.	Max.	n
<0.5	0.34	0.07	0.01	0.20	0.49	32
>0.5 to <1	0.78	0.12	0.01	0.50	0.99	171
>1 to <2	1.47	0.26	0.01	1.01	1.99	478
>2 to <3	2.40	0.26	0.02	2.00	2.99	305
>3 to <4	3.45	0.32	0.04	3.00	3.91	70
>5 to <10	6.33	1.08	0.17	5.04	9.99	42
>10	13.0	1.50	0.31	10.4	15.7	24

[a] Source: Dr. Roy Rando, Tulane University. (Personal Communication)

Table 2. Inhalable Dust Measurement Percent by Exposure Category.[a]

Inhalable Dust (mg/m^3)	Percentage of Samples	Inhalable Dust (mg/m^3)	Percentage of Samples
>0.5	86	0.5 – 1	21
>1	65	1 – 2	28
>2	37	2 – 3	14
>3	23	3 – 4	9
>4	14	4 – 5	4
>5	10	5 – 10	7.6

[a] Source: Kalliny et al.[10]

Table 3. Regression Analysis of the Tulane Study Cohort Adjusted for Baseline Lung Function, Age, Sex Cumulative Pack Years, Using Multiple Linear Regression Models.[a]

Regression Categorical Exposure Comparisons Inhalable Dust (mg/m^3)	Coefficient (P Value) FEV$_1$(ml/yr)	Coefficient (P Value) FVC(ml/yr)	Coefficient (P Value) FEV$_1$/FVC(%/yr)	Coefficient (P Value) FEF$_{25-75}$(ml/s/yr)
≥1 compared to <1	4.55 (0.40)	−2.79 (0.67)	14.04 (0.04)	22.32 (0.04)
≥2 compared to <2	−2.89 (0.49)	−5.09 (0.31)	2.10 (0.68)	4.41 (0.61)
≥ 3 compared to <3	3.41 (0.55)	7.93 (0.25)	−2.89 (0.68)	2.02 (0.86)
Interval ≥ 2 to < 5	1.92 (0.69)	1.14 (0.84)	7.38 (0.25)	6.53 (0.50)

[a] Source: Drs. John J. Lefante and Roy J. Rando, Tulane University.

Use of the Tulane University Study for Deriving an Occupational Limit for Wood Dust

The Tulane study is a scientifically rigorous industrial hygiene and epidemiologic study. A review of the body of literature on wood dust and pulmonary function demonstrates that this study provides a scientifically sound basis for establishing an occupational limit based on pulmonary function. Tables 1-3 represent information either in the Tulane study or new data generated by the original study authors. Table 1 gives the number of workers studied in each exposure category; Table 2, the categorical percentages of inhalable dust measurements; and Table 3, lung function regression analyses useful for establishing the confidence of a scientifically based protective value for wood dust. For example, there were 483 workers exposed to inhalable dust at levels of 2.0 mg/m^3 and higher without adverse pulmonary effects. At levels of 3.0 mg/m^3 and above, 178 workers were exposed without adverse effects. If one looks at just the exposure category of 2.0 to 4.9 mg/m^3, there were 417 workers studied, and 638 inhalable dust measurements. These latter data provide a statistically sound foundation for a health protective value, showing no adverse effects from inhalable dust within this exposure interval, or as previously noted, across the overall study exposure range. Based on the results of the previously discussed follow-up study of the High Wycombe wood furniture workers showing a major decline in nasal tumors even prior to adoption of a 5 mg/m^3 exposure limit, and on the foregoing Tulane study data, it appears that a 5 mg/m^3 inhalable dust concentration would serve as an adequate occupational limit for wood dust.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article. AF&PA members are regulated for wood dust exposure. S. Holm is affiliated with the American Forest & Paper Association (AF&PA) while J. Festa is a consultant who received financial support for this analysis from AF&PA.

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