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Factors Associated With Non-compliance of Asbestos Occupational Standards in Brake Repair Workers

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ABSTRACT

Asbestos and non-asbestos containing brake products are currently used in low- and middle-income countries like Colombia. Because brake products are distributed detached from their supports, they require manipulation before installation, which release fibers and expose workers. Previous studies of our research group have documented exposures in excess of the widely accepted 0.1 f/cm^3 exposure guideline. The aim of this study is to identify factors associated with non-compliance of the 8-h time weighted average (TWA) 0.1 f/cm^3 asbestos occupational limit among brake mechanics (i.e. riveters). Eighteen brake repair shops (BRS) located in Bogotá (Colombia) were sampled during 3 to 6 consecutive days for the entire work-shift. Personal and short-term personal samples were collected following NIOSH methods 7400 and 7402 Longitudinal based logistic regression models were used to determine the association between the odds of exceeding the 8-h TWA 0.1 f/cm^3 asbestos occupational limit and variables such as type of tasks performed by workers, workload (number of products manipulated daily), years of experience as riveters, and shop characteristics. These models can be used to estimate the odds of being currently or historically overexposed when sampling data do not exist. Since the information required to run the models can vary for both retrospective and current asbestos occupational exposure studies, three models were constructed with different information requirements. The first model evaluated the association between the odds of non-compliance with variables related to the workload, the second model evaluated the association between the odds of non-compliance with variables related to the manipulation tasks, and the third model evaluated the association between the odds of non-compliance with variables related with both the type of tasks performed by workers and the workload. Variables associated with the odds of non-compliance included conducting at least one manipulation activity with beveling and grinding of asbestos and non-asbestos containing brake products during the work shift, the location of the worker in the shop during non-manipulation activities, cleaning activities of the manipulation area, the years of experience working as riveters, and the number of asbestos and non-asbestos containing brake products manipulated daily. These models could be useful for current and retrospective occupational studies, in determining the odds of non-compliance of the asbestos occupational limit among brake mechanics.

KEYWORDS: asbestos exposures, brake mechanics, compliance, occupational standards

INTRODUCTION

Asbestos is comprised of a group of minerals that because of their physical and chemical characteristics, have been extensively used in different types of products including brake and transmission products (ATSDR, 2001; OMS, 2006). Asbestos is classified into two main groups: amphiboles and serpentines (ATSDR, 2001). Chrysotile is the only type of asbestos of the serpentine group, and is currently the type of asbestos with the most extended use worldwide (ATSDR, 2001). All types of asbestos are classified as carcinogenic to humans (IARC, 1998, 2012), and asbestos is one of the most important occupational carcinogens (OMS, 2006). Asbestos is related with both malignant and non-malignant diseases (ACCP, 2012; IARC, 2012).

The most important asbestos exposures occur in occupational environments (ACSH, 2007; Wagner and Lemen, 2008) where the manipulation of asbestos containing products may result in excessive asbestos exposures (OIT, 1986). Most of the legislation and control activities regarding asbestos exposures of brake mechanics and other occupational groups started in the 1970s (OSHA, 2013), and in 1994 the US Occupational Safety and Health Administration (OSHA) issued the current standards for personal asbestos exposure in workplaces: a personal exposure limit (US OSHA PEL) of 0.1 f/cm^3 for an 8-h time weighted average (TWA) based on phase contrast microscopy equivalent (PCM-Eq) asbestos concentration, and an excursion limit (US OSHA EL) of 1 f/cm^3 for a 30-min exposure period PCM-Eq asbestos concentration (OSHA, 1994a, 2013). In Colombia (i.e. an upper middle-income country), asbestos exposure standard is based on the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) of 0.1 f/cm^3 for a TWA of 8-h (MSPS, 2011).

Recent studies performed by our research group have shown that brake mechanics are exposed to high asbestos concentrations, exceeding in some cases the US OSHA PEL and the Colombian standards (Cely-García *et al.*, 2012; Cely-García *et al.*, 2015). These findings are in contrast with studies conducted in high-income countries (Hickish and Knight, 1970; Yeung *et al.*, 1999; Weir *et al.*, 2001; Blake *et al.*, 2003; Paustenbach *et al.*, 2003; Paustenbach *et al.*, 2004; Blake *et al.*, 2006; Madl *et al.*, 2009). One of the most important reasons for this difference is that in Colombia asbestos containing brake products are distributed by the manufacturer detached from their support, requiring manipulation in the shops before installation in the vehicles (Cely-García *et al.*, 2012; Cely-García *et al.*, 2015). Thus, brake products are drilled, countersinked, riveted, beveled, and grinded, and a specific group of mechanics, known as riveters, conducts these tasks (Cely-García *et al.*, 2012; Cely-García *et al.*, 2015). An additional manipulation task observed include bonding the brake linings or brake pads to the support in passenger vehicles. In this case, riveters have to grind and bevel the brake products in order to remove excess glue (Cely-García *et al.*, 2012). The same riveters that manipulate asbestos containing brake products may also manipulate non-asbestos containing brake products. It is important to clarify that blowing the brake drums with compressed air is not a common practice of brake mechanics in Colombia.

This study identifies factors associated with personal asbestos concentrations that exceed the 8-h TWA of 0.1 f/cm^3 asbestos occupational limit, among riveters that manipulate asbestos containing brake products.

METHODS

Since 2010, several sampling campaigns were conducted in 18 brake repair shops (BRS) located in

Bogotá, Colombia. Nine of these shops service passenger vehicles, and nine service heavy-duty vehicles. Results of these sampling campaigns were used to establish the factors associated with the odds of non-compliance of the 8-h TWA occupational standard. Ethics Committees from the Universidad de Los Andes and Fundación Neumológica Colombiana approved the sampling campaigns and the informed consent signed by the riveters that participated in this study.

Sampling campaigns

The identification of the shops sampled was initially done using the phone book, and in a subsequent stage of the project by walking through the zones of Bogotá where BRS are clustered to identify additional shops that could potentially participate in the project. This second strategy has been performed since 2012 and includes the application of a structured questionnaire adapted from the OSHA Medical Questionnaire (OSHA, 1994b) to characterize the working conditions of those riveters of the shops who agreed to voluntarily participate in the project. The information collected was used to identify and select BRS that currently perform manipulation activities of brake products. BRS were also classified according to their workload, based on the average number of sets of asbestos and non-asbestos containing products that they manipulate daily.

Sample collection and analysis was similar to those described in previous studies of our research group (Cely-García *et al.*, 2012; Cely-García *et al.*, 2015; Salazar *et al.*, 2014). Shops were sampled during 3 to 6 consecutive days for the entire work-shift. Personal samples were collected following NIOSH methods 7400 (NIOSH, 1994a) and 7402 (NIOSH, 1994b). Air samples were collected on 25-mm MCE filters, 0.45 μm pore size, mounted on 50 mm conducting extension cowls cassettes (SKC Preloaded Cassette, SKC), using AIRCheck XR5000 pumps (SKC, Eighty Four, PA, USA) that operated at a flow rate of ~2LPM. Standard procedures were applied to measure flow rates at the beginning and at the end of each sampling window, using Defender 510 High or 520 High BIOS International Calibrators (MesaLabs, Butler, NJ, USA).

Personal samples were collected on riveters during the entire work-shift. All workers sampled were instructed to keep their activities and working procedures as usual. Thirty minutes short-term personal samples were collected during manipulation activities and longer or shorter personal samples were collected during non-manipulation activities. Each sampling day had one blank sample, and each shop had one background sample collected during one night of the sampling days. Detailed activity diaries were filled with all the activities performed by workers sampled during the entire sampling campaigns. Shop's owners and workers sampled were informed of the results of the sampling campaigns.

Samples were analyzed by Forensic Analytical Laboratories, Inc (Forensic Analytical Laboratories, Hayward, CA, USA), an American Industrial Hygiene Association (AIHA) accredited laboratory. The analysis of the samples was performed on a Philips CM12 transmission electron microscopy (TEM) (Philips, Eindhoven, The Netherlands). Fibers with length >5 μm were counted at a magnification of ×2500. For fibers close to 5 μm in length, fiber dimension was determined by using a magnification of ×10 000. The accelerating voltage used was 100 keV, and an Energy Dispersive X-ray (EDXA) (Evex NanoAnalysis System IV, Princeton, NJ, USA) was also used (Forensic Analytical Laboratories, personal communication).

PCM-Equivalent (PCM-Eq) asbestos concentrations were calculated multiplying the phase contrast microscopy (PCM) fiber concentration by the fraction of asbestos fibers to total fibers determined by Transmission Electron Microscopy (TEM) (NIOSH, 1994a, 1994b). To determine regulatory compliance with the 8-h TWA of 0.1 f/cm^3 asbestos occupational limit, the 8-h TWA PCM-Eq personal asbestos concentration was estimated for each worker. When the work-shift exceeded 8-h, the worst partial-period sampling windows were used, according with the recommendations of the US OSHA Technical Manual (OSHA, 2008). When the work-shift was shorter than 8-h (i.e. due to overloaded samples, or because the work-shift ended early or the worker left the shop early), the 8-h TWA asbestos concentration was calculated assuming 0 f/cm^3 for the remaining time. Additionally, when the PCM concentration was below the limit of detection (LOD), one half of the LOD was used for calculation purposes. This last procedure was applied because of the results of a sensitivity analysis performed by our research group in a previous study, which showed no important differences in the TWA concentration estimated using 0 f/cm^3 or half the LOD, when samples are below the LOD (Cely-García *et al.*, 2015).

Additionally, bulk asbestos content of 18 duplicate linings, pads or blocks from 12 of the most common brake product's brands that have been used at the shops sampled was estimated following EPA 600/R-93-116 PLM method (EPA, 1993), by an AIHA accredited laboratory (Forensic Analytical Laboratories, Hayward, CA, USA).

Data analysis

Three longitudinal based logistic regression models were used to identify variables significantly associated with the odds of non-compliance of the 8-h TWA 0.1 f/cm^3 asbestos occupational limit, according with the type of information available to develop the models. Eight-hour TWA PCM-Eq personal asbestos concentrations below or equal to 0.1 f/cm^3 were classified as in compliance and 8-h TWA PCM-Eq personal asbestos concentrations exceeding 0.1 f/cm^3 were classified as non-compliant. The 8-h TWA PCM-Eq asbestos concentrations calculated for workers sampled were approximated to three decimals and compared against the 0.100 f/cm^3 value.

Samples collected during work-shifts with at least one manipulation activity or at least one dry cleaning activity of the manipulation area were analyzed by both PCM and TEM, allowing for the estimation of the PCM-Eq asbestos concentration, and this information was used for the analysis. Because a worker could have more than one 8-h TWA PCM-Eq personal asbestos concentration, observations within workers could not be considered independent (Stata, 2015). Thus, regression inference utilized robust estimates of standard errors to accommodate the within person correlation (UCLA, 2015c). This was accomplished clustering by riveter in the longitudinal logistic regression models, so that estimation of the regression coefficient standard errors are adjusted for the lack of independence between the 8-h TWA PCME personal asbestos concentrations collected on the same riveter on different days.

Regression covariates evaluated included the type of tasks performed by the workers, the workload defined as the number of asbestos or non-asbestos containing products manipulated daily disregarding the type of manipulation performed, the shop characteristics (i.e. ventilation, presence of control systems, and type of vehicle serviced), and the number of years of experience working as riveters. Based on observations and the detailed activity diaries, the type of activities performed during each sample collection, the location of the worker during non-manipulation activities, and the number of asbestos and non-asbestos containing products manipulated daily, could be identified.

Since information on all the covariates proposed are not always available, especially for retrospective exposure assessments, three models were evaluated according with the type of information that may be obtained and would be available for analysis. The first model (Model 1—Workload) assumes that the information available is related with the work load (i.e. how many brake products were manipulated), and some characteristics of the workers and shops. The second model (Model 2—Work tasks) assumed that the information available is related with the work tasks (i.e. type of manipulation performed), and some characteristics of the workers and shops. The third model (Model 3—Complete) was developed for those cases in which the information regarding both work tasks and workload was available.

The description of the covariates evaluated and the model in which they were used are detailed in Table 1.

Detailed descriptions of the covariates related with the work tasks (i.e. shown in Table 1) can be found in previous studies of our research group (Cely-García *et al.*, 2012; Cely-García *et al.*, 2015).

All models have the following logistic regression format for identifying variables significantly associated with the odds of non-compliance:

$$\ln\left(OR_{non-compliance}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_p X_p$$

Where OR denotes the odds ratio of non-compliance relative to compliance, $(X_1, \ldots, X_p)$ are the covariates available based on the model type (Table 1), and possible interactions, and $\beta's$ are their associated effects.

All covariates were evaluated and the model building process started with those predictors statistically significantly associated with the odds of non-compliance in univariate models (i.e. each variable separately one at a time). Model fit and multicollinearity were evaluated, and selection of models was performed according with the Akaike's Information Criterion (AIC), the individual and general results obtained, and personal judgment (UCLA, 2015b). Interactions were also analyzed in the models. The statistical analysis was conducted using the software Stata/SE 12.1 (StataCorp, College Station, TX, USA).

Table 1. Description of the covariates used in the three models evaluated to establish the odds of non-compliance of the 8-h TWA of 0.1 f/cm^3 asbestos occupational limit

Covariate	Type of covariate	Description of the covariate	Model that included the covariate
Number asbestos products manipulated daily	Integer variable	Represents the number of asbestos containing brake products (i.e. brake linings, brake pads, or brake blocks) manipulated daily, without considering the type of manipulation performed.	Model 1—Workload Model 3—Complete
Number non-asbestos products manipulated daily	Integer variable	Represents the number of non-asbestos containing brake products (i.e. brake linings, brake pads, or brake blocks) manipulated daily, without considering the type of manipulation performed.	Model 1—Workload Model 3—Complete
Manipulation w/o beveling and grinding of asbestos	Indicator variable	Represents at least one manipulation that included drilling, countersinking, riveting, and/or bonding asbestos containing brake products (one or more manipulations = 1, no manipulations = 0).	Model 2—Work tasks Model 3—Complete
Manipulation w/o beveling and grinding of non-asbestos	Indicator variable	Represents at least one manipulation that included drilling, countersinking, riveting, and/or bonding non-asbestos containing brake products (one or more manipulations = 1, no manipulations = 0).	Model 2—Work tasks Model 3—Complete
Manipulation w/ beveling and grinding of asbestos	Indicator variable	Represents at least one manipulation that included beveling, grinding, and/or cutting with electric saw asbestos containing brake products (one or more manipulations = 1, no manipulations = 0). These tasks release important amounts of fibers, and may also include drilling, countersinking, riveting, and/or bonding asbestos containing brake products.	Model 2—Work tasks Model 3—Complete

Table 1. *Continued*

Covariate	Type of covariate	Description of the covariate	Model that included the covariate
Manipulation w/ beveling and grinding of non-asbestos	Indicator variable	Represents at least one manipulation that included beveling, grinding, and/or cutting with electric saw non-asbestos containing brake products (one or more manipulations = 1, no manipulations = 0). These tasks release important amounts of fibers, and may also include drilling, countersinking, riveting, and/or bonding non-asbestos containing brake products.	Model 2—Work tasks Model 3—Complete
Dry cleaning activities of the manipulation area	Indicator variable	Represents at least one cleaning activity of the manipulation area performed under dry conditions (one or more cleaning activity = 1, no cleaning = 0).	Model 2—Work tasks Model 3—Complete
Location of worker during non-manipulation activities	Indicator variable	Incorporate the location of the worker during non-manipulation activities, either inside of the manipulation area ($X = 1$), or outside of the manipulation area ($X = 0$).	Model 1—Workload Model 2—Work tasks Model 3—Complete
Ventilation conditions of the shop	Indicator variable	Represents the ventilation condition of the shop; good ($X = 1$) or bad ($X = 0$). This classification was based on the 'near field' concept (Cherrie and Schneider, 1999; Tielemans *et al.*, 2008; Cherrie *et al.*, 2011). If manipulation equipment was within 1 m of a window or door, ventilation was considered good.	Model 1—Workload Model 2—Work tasks Model 3—Complete
Presence of control system	Indicator variable	Represents the presence of local control ventilation in the manipulation equipment, such as fans or extraction systems, disregarding their performance (presence of control system = 1, no control system = 0).	Model 1—Workload Model 2—Work tasks Model 3—Complete
Experience of worker	Continuous variable	Represents the number of years of experience working as riveter.	Model 1—Workload Model 2—Work tasks Model 3—Complete

Table 1. *Continued*

Covariate	Type of covariate	Description of the covariate	Model that included the covariate
Type of vehicle serviced in the shop	Indicator variable	Represents the type of shop sampled: passenger vehicles BRS ($X = 0$), or heavy duty vehicles BRS ($X = 1$). If a shop serviced both types of vehicles, it was classified based on the type of vehicle most commonly served during sampling campaigns.	Model 1—Workload Model 2—Work tasks Model 3—Complete

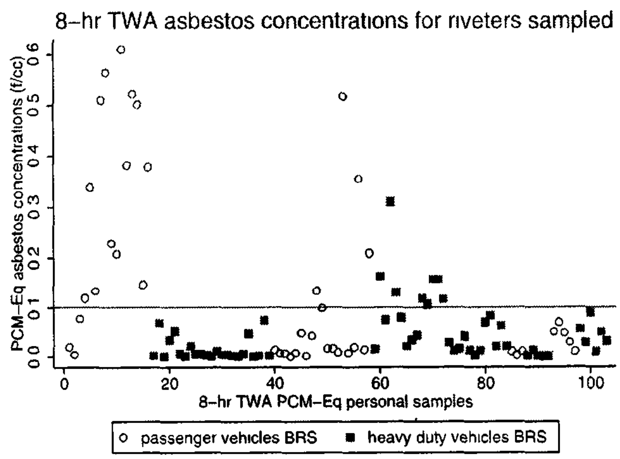

Figure 1 Eight-hour TWA PCM-Eq asbestos personal concentrations for workers sampled.

RESULTS

A total of 28 riveters were sampled. Thirteen out the twenty-eight riveters were from the nine passenger vehicles BRS sampled, and the remaining 15 were from the nine heavy-duty vehicles BRS sampled. Forty-three 8-h TWA PCM-Eq asbestos exposures were calculated for passenger vehicles riveters, and 60 were calculated for heavy-duty vehicles riveters, for a total of one hundred three 8-h TWA PCM-Eq personal asbestos concentrations. The number of riveters based on both the type of vehicle serviced and the number of repeated 8-h TWA PCME personal asbestos concentrations each riveter had, was: For passenger vehicles BRS (i.e. 13 riveters), one riveter had six repeated measurements, three riveters had five repeated measurements, two riveters had four repeated measurements, one riveter had three repeated measurements, five riveters had two repeated measurements, and one riveter had one measurement. For heavy-duty vehicles BRS (i.e. 15 riveters), three riveters had six repeated measurements, five riveters had five repeated measurements, five riveters had three repeated measurements, and two riveters had one measurement.

Twenty-five 8-h TWA PCM-Eq personal samples (24%) exceeded both the US OSHA PEL and the Colombian standard of 0.1 f/cm^3. Some of these concentrations were up to six times the standard, as can be observed in Figure 1. Seventeen out of the twenty-five 8-h TWA PCM-Eq asbestos concentrations above the occupational standard were collected on riveters from passenger vehicles BRS, and the remaining eight were collected on riveters from heavy-duty vehicles BRS. The only type of asbestos identified in personal samples was chrysotile. Owners and brake mechanics involved in the study were informed regarding the results of the sampling campaigns, and we also explained to them some preventive strategies they could implement to reduce or eliminate asbestos exposure.

The bulk asbestos analysis of 18 duplicate samples of linings, pads or blocks from 12 brands of brake products distributed in Bogotá is presented in Table 2. The

Table 2. Bulk asbestos content obtained for two linings, pads or blocks of 18 product's brands of brake products distributed in Bogotá.

Manufacturer	Brand	Type of brake product	Asbestos content (%)	
			Sample 1	Sample 2
1	1	Brake lining[a,b]	10	10
	2	Brake block[c]	15	15
2		Brake lining[c]	15	15
		Brake block[c]	10	10
		Brake block	ND	ND
	3	Brake lining	ND	ND
	4	Brake lining[c]	15	15
3	5	Brake lining[b]	10	10
		Brake block[b]	15	15
		Sheet (for brake pads)	ND	ND
4	6	Brake lining[c]	10	10
	7	Brake lining[a,b]	10	10
5	8	Brake lining[a,b]	15	15
		Brake lining[a,b]	10	10
	9	Brake lining[c]	10	10
6	10	Sheet (for brake pads)[b]	10	10
7	11	Roll (for brake lining)[b]	5	5
8	12	Brake lining[b]	15	15

ND, Non-detected
[a]Product distributed in Bogotá more than 20 years ago
[b]Label of the product does not specify that it contain asbestos
[c]Label of the product does not report the asbestos content following standard recommendations (EPA, 2011, OIT, 1984)

bulk asbestos analysis showed that only three brake products (one brake lining, one sheet that is cut into pads, and one brake block) from three different brands did not contain asbestos fibers (i.e. reported as non-detected—ND). For the other 15 brake products analyzed, the chrysotile asbestos content ranged between 5 and 15%. Asbestos content did not differ between duplicate samples. As shown in Table 2, four brake linings from brands 1, 7 and 8 that were used in the past but are no longer distributed, were also analyzed (i.e. purchased from old stocks of one of the BRS sampled).

Daily workload can be expressed in terms of the number of asbestos containing products manipulated daily ranging from 0 to 50, and the number of non-asbestos containing products manipulated daily ranging from 0 to 52. Workers experience ranged from 1 to 34 years.

Table 3 presents the results of the models evaluated, including the longitudinal based univariate logistic regression models for each covariate analyzed, and the three longitudinal based multivariate logistic regression models evaluated according with the type of information available.

Table 3. OR of the covariates included in the univariate and multivariate longitudinal based logistic regression models evaluated for workers sampled

Covariates	Longitudinal based univariate logistic regression models	Longitudinal based multivariate logistic regression models					
	OR (*P*-value)	Model 1—Workload		Model 2—Work tasks		Model 3—Complete	
		OR (*P*-value)[a]	95% CI	OR (*P*-value)[a]	95% CI	OR (*P*-value)[a]	95% CI
No asbestos products manipulated daily	1.12 (0.082)	1.1 (0.277)	0.93–1.29	NA	NA	1.00 (0.994)	0.92–1.09
No. non-asbestos products manipulated daily	1.07 (0.093)	1.08 (0.004)	1.02–1.14	NA	NA		
No. asbestos products manipulated (no beveling/grinding)							
≥1	2.15 (0.239)	NA	NA	2.94 (0.149)	0.68–12.65		
0	Ref	NA	NA	Ref			
No. non-asbestos products manipulated (no beveling/grinding)							
≥1	0.81 (0.736)	NA	NA				
0	Ref	NA	NA				
No. asbestos products manipulated (beveling/grinding)							
≥1	44.6 (0.000)	NA	NA	30.4 (0.001)	4.19–220.7	48.6 (0.000)	6.26–377.5
0	Ref	NA	NA	Ref		Ref	
No. non-asbestos products manipulated (beveling/grinding)							
≥1	6.71 (0.002)	NA	NA	3.92 (0.096)	0.78–19.7		
0	Ref	NA	NA	Ref			
Dry cleaning activities							
≥1	3.33 (0.063)	NA	NA	1.74 (0.522)	0.32–9.39	2.68 (0.249)	0.50–14.3
0	Ref	NA	NA	Ref		Ref	

Table 3. *Continued*

Covariates	Longitudinal based univariate logistic regression models	Longitudinal based multivariate logistic regression models					
	OR (*P*-value)	Model 1—Workload		Model 2—Work tasks		Model 3—Complete	
		OR (*P*-value)[a]	95% CI	OR (*P*-value)[a]	95% CI	OR (*P*-value)[a]	95% CI
Location of worker during non-manipulation activities							
Inside manipulation area	8.06 (0.039)	6.13 (0.059)	0.94–40.2	9.29 (0.040)	1.11–77.5	6.61 (0.058)	0.94–46.7
Outside manipulation area	Ref	Ref		Ref		Ref	
Ventilation conditions							
Good	0.40 (0.425)						
Bad	Ref						
Presence of control system							
Some	1.25 (0.854)						
None	Ref						
Experience of the worker (years)	1.04 (0.458)	1.04 (1.428)	0.94–1.15			1.02 (0.775)	0.93–1.13
Type of vehicle serviced							
Heavy duty	0.26 (0.102)						
Passenger	Ref						

CI, confidence interval
[a]The significance level for the longitudinal based multivariate logistic regression model is 0.05
NA Covariate not included in the model evaluated according with the type of information required in the model
Blank cells represent covariates evaluated but not included in the model selected due to lack of contribution

Based on the univariate regression analysis, the odds of non-compliance are 45 times higher with at least one manipulation with beveling and grinding of asbestos containing products than when this activity is not performed (P-value = 0.000), are seven times higher with at least one manipulation with beveling and grinding of non-asbestos containing products than when this activity is not performed (P-value = 0.002), and are three times higher with at least one dry cleaning activity of the manipulation area than when this activity is not performed (P-value = 0.063). The odds of non-compliance are eight times higher when the worker remains inside of the manipulation area than when the worker remains outside during non-manipulation activities (P-value = 0.039), are 1.1 times higher with each additional asbestos containing products manipulated daily (P-value = 0.082), are 1.1 times higher with each additional non-asbestos containing products manipulated daily (P-value = 0.093), and are 77 times lower in heavy duty vehicles BRS than in passenger vehicles BRS (P-value = 0.102).

Model 1, which was focused on the association between non-compliance of the asbestos occupational limit and the workload of the workers sampled, showed that the odds of non-compliance are 1.1 times higher with each additional non-asbestos containing product manipulated daily disregarding the type of manipulation performed, and this association is significant (P-value = 0.004). The odds of non-compliance increases six times if the worker remains inside of the manipulation area during non-manipulation activities than when he remains outside, and this association is marginally significant (P-value = 0.059). Although non-significant, the odds of non-compliance increases 1.1 times with each additional asbestos containing product manipulated daily disregarding the type of manipulation performed (P-value = 0.277), and increases 1.04 times per each additional year of experience working as riveter (P-value = 0.428).

Several interactions were tested and a potential effect modifier was identified in Model 1. Interactions were initially tested with models that only included two covariates and their interaction term. With these models, the presence of a control system and the effect of the number of non-asbestos containing products manipulated daily, disregarding the type of manipulation performed, was identified as a significant and meaningful interaction. However, when the interaction term and the two covariates were included in Model 1 (i.e. results not shown), the P-value of the interaction term was no longer significant, and the AIC coefficient indicated that the model was more parsimonious without it. Thus, this interaction was excluded from Model 1.

Model 2, which evaluated the association between non-compliance of the asbestos occupational limit and the work tasks performed by the workers sampled, showed that the odds of non-compliance are 30 times higher with at least one manipulation with beveling and grinding of asbestos containing products than when this activity is not performed (P-value = 0.001), and are nine times higher when the worker remains inside of the manipulation area during non-manipulation activities than when he remains outside (P-value = 0.040), and these two associations are statistically significant. The odds of non-compliance are four times higher with at least one manipulation with beveling and grinding of non-asbestos containing products than when this activity is not performed (P-value = 0.096), and this association is marginally significant. The odds of non-compliance are three times higher with at least one manipulation without beveling and grinding of asbestos containing products than when this activity is not performed (P-value = 0.149), and are two times higher with at least one dry cleaning activity of the manipulation area than when this activity is not performed (P-value = 0.522), although these two associations are not significant.

Several interactions were tested and a potential effect modifier was identified in Model 2. Similarly to Model 1, interactions were initially tested with models that only included two covariates and their interaction term. The presence of a control system and at least one manipulation without beveling and grinding of non-asbestos containing products was identified as a significant and meaningful interaction. Although the inclusion of the interaction term in Model 2 favored the AIC coefficient, it increased the robust standard errors, and the 95% confidence intervals were wider. For this reason the interaction term was excluded from Model 2.

Model 3, which evaluated the association between non-compliance of the asbestos occupational limit and both the workload and work tasks of the workers sampled, show that the odds of non-compliance are 49 times higher with at least one manipulation with beveling and grinding of asbestos containing products than when this activity is not performed (P-value = 0.000), and this association is statistically significant. The odds of non-compliance are seven times higher when the worker remains inside of the manipulation area during non-manipulation activities than when he remains outside (P-value = 0.058), and this association is marginally significant. Although non-significant, the odds of non-compliance are three times higher with at least one dry cleaning activity of the manipulation area than when this activity is not performed (P-value = 0.249), and increase with each additional asbestos containing product manipulated daily disregarding the type of manipulation performed (P-value = 0.994), and with each additional year of experience working as riveter (P-value = 0.775).

Both interaction terms previously identified in Model 1 and 2 were evaluated by separate in Model 3 (i.e. results not shown). In both cases the AIC coefficient favored the model with the interactions, but neither was included because they increased the robust standard errors, and the 95% confidence intervals were wider with the terms. Additionally, when the interactions were included the odds of non-compliance for the covariate 'number asbestos products' decreased (i.e. OR below 1) per each additional asbestos containing product manipulated daily disregarding the type of manipulation performed, which is a counter intuitive behavior.

DISCUSSION

This study analyzed factors that could be associated with the odds of non-compliance of the 8-h TWA 0.1 f/cm^3 asbestos occupational limit in riveters exposed to chrysotile asbestos that work in BRS in Bogotá. Among the variables tested, the most important ones that were associated with the odds of non-compliance were the types of tasks performed during the work-shift, and the location of the worker during non-manipulation activities. The number of products manipulated daily (i.e. workload) showed non-significant associations in the longitudinal based multivariate logistic regression models.

One of the potential uses of the models constructed in the current study is to determine the risk of non-compliance experienced by workers in countries or situations in which conducting sampling campaigns is not possible. Using the models presented in this study, compliance of the 8-h TWA 0.1 f/cm^3 asbestos occupational limit could be estimated by determining the type of manipulations performed on asbestos and non-asbestos containing brake products, and the number of asbestos and non-asbestos containing brake products manipulated daily. This information could be obtained using occupational questionnaires or observations during work-shifts.

Additional models for the odds of non-compliance were constructed (i.e. not shown) with detail information regarding the number of manipulations and the tasks involved in each manipulation. No significant associations were found. Considering that this level of detail information is difficult, and in retrospective studies almost impossible to obtain, the three models presented in the current study require information that is reasonable to obtain for both current and retrospective studies, which favors these models.

Three different models were constructed, offering different options depending on the information required to run the models. The results when analyzing the workload (Model 1) show that both the number of asbestos and non-asbestos containing products manipulated daily increase the odds of non-compliance. The results when analyzing the work tasks performed by workers (Model 2) suggest that tasks that can potentially release important amounts of fibers are highly associated with the odds of non-compliance (i.e. manipulation of brake products that include beveling, grinding, and/or cutting). Furthermore, this association was observed not only with asbestos containing products, but also when non-asbestos containing products were manipulated. This is something also found in Model 1 with the number of non-asbestos containing products, and is something we have reported in previous studies (Cely-García *et al.*, 2012; Cely-García *et al.*, 2015; Salazar *et al.*, 2014). Two probable reasons why the odds of non-compliance of the asbestos occupational limit could be associated with the manipulation of brake products that do not contain asbestos include poor hygiene of the manipulation equipment and lack of maintenance of the shops. Poor hygiene and lack of maintenance could result in the accumulation of asbestos fibers on different surfaces, and the subsequent resuspension of the fibers during other activities, such as the manipulation of brake products that do not contain asbestos. Another explanation could be that non-asbestos containing products were not labeled correctly, which may create a false sense of safety in the workers that manipulate these products.

The analysis of asbestos content of brake products confirmed the presence of chrysotile asbestos in a range between 5–15% in most of the brake products used in the shops sampled, and no other asbestos type was identified. As can be observed in Table 2, the asbestos content of brands distributed in the past does not differ from the asbestos content of some of the brands currently distributed. Most of the brands analyzed are manufactured in Colombia, except for Brand 11, which has the lowest asbestos content (5%). Furthermore, the asbestos content does not seem related with the type of brake product (lining, block or sheet for pads). It is important to highlight that brands 2 and 5 (i.e. manufacturer 2 and 3, respectively) have both asbestos and non-asbestos containing products. This seems to contradict one of the arguments of the asbestos industry against an asbestos ban, and is the lack of safer substitutes. Furthermore, since some of the brake industry is already manufacturing non-asbestos containing brake products, a transition to asbestos substitutes in a future asbestos ban seems to be feasible in the short term.

The results suggest that the manipulation equipment used and the type of manipulation performed (i.e. with or without grinding, beveling, and/or cutting tasks) have a stronger association with the risk of non-compliance than the number of asbestos containing products manipulated daily. Furthermore, the odds of non-compliance are higher when asbestos containing products are manipulated, compared to the manipulation of non-asbestos containing products, as expected.

For all three models (Model 1, 2, 3), the location of the worker during non-manipulation activities was marginally or significantly associated with the odds of non-compliance. This covariate was included because some personal samples collected during non-manipulation activities contained asbestos fibers, which could indicate that asbestos fibers could remain suspended in the air for long periods of time and migrate to other areas of the shop. Thus, workers that stay or work at the proximity of the manipulation equipment during non-manipulation activities could be also at risk of asbestos exposure. This is supported by inhalation exposure studies that evaluate both near- and far-field compartments (Cherrie and Schneider, 1999; Tielemans *et al.*, 2008; Cherrie *et al.*, 2011; De Vocht *et al.*, 2013).

Dry cleaning activities of the manipulation area, which can re-suspend fibers, had a significant association with the odds of non-compliance using a longitudinal based univariate logistic regression model (OR: 3.33, $P = 0.063$). The importance of dry cleaning activities in predicting the odds of non-compliance of the asbestos occupational limit was also observed in models 2 and 3.

One unexpected result was that as the years of experience of the mechanic increased, the odds of non-compliance increased (i.e. non-significantly). Since the models were adjusted for the workload, higher efficiency of experienced mechanics in performing the manipulations, which may result in higher exposures, is already considered in the analysis. Experienced mechanics having higher odds of non-compliance contradicts the findings of other occupational groups, where it has been observed that less years of experience can result in poor skills to perform the work tasks, which may result in higher occupational exposures (Andjelkovich *et al.*, 1977; Delzell *et al.*, 1982).

Several authors have recognized the importance of the workplace characteristics in the estimation of personal exposures (Cherrie and Schneider, 1999; Tielemans *et al.*, 2008; Cherrie *et al.*, 2011). Ventilation conditions of the shops are one of these characteristics. The longitudinal based univariate logistic regression model performed with the ventilation conditions of the shops showed a non-significant decrease of the odds of non-compliance in shops with good ventilation, compared to poorly ventilated shops (OR: 0.4, $P = 0.425$). However, the classification of the ventilation conditions was based on qualitative assessment of specific characteristics of the shops, such as the distance of the manipulation equipment to doors or windows, and not quantitative assessment of the air exchange rates. The AIC indicated that including this covariate did not contribute to the models.

Regarding other workplace characteristic, the results of the longitudinal based univariate logistic regression model suggest that the presence of control systems (i.e. that in most cases included a general extraction system) does not guarantee the protection of workers. Although the objectives of this study did not include an evaluation of the performance of the existing control systems, it was observed that in some occasions workers did not use them, and it seemed (i.e. just by observation) that in some instances the control system did not redirect and extract the fibers released during the manipulation processes. This was corroborated by the results of the longitudinal based univariate logistic regression model, which showed OR values above 1, although in this case the association was not statistically significant.

Additionally, the association between the odds of non-compliance and the type of vehicle serviced (i.e. passenger versus heavy duty), showed an OR of 0.235 in the longitudinal based univariate logistic regression model (P-value = 0.102). Thus, the type of vehicle serviced does not seem to have an influence on the odds of non-compliance. Moreover, the convergence of the models evaluated was bad when this covariate was included because it increased the robust standard errors and made the confidence intervals very wide.

To the best of our knowledge, a sampling campaign of this size to understand the risk of elevated asbestos exposures of brake mechanics has never been done in low- and middle-income countries. However, as authors we recognize that a larger sample could improve the results in the longitudinal based logistic regression models with the cluster analysis applied in this study (UCLA, 2015a).

As we have explained in previous studies (Cely-García *et al.*, 2012; Cely-García *et al.*, 2015; Salazar *et al.*, 2014), the results of the models evaluated confirm that the physical form some of these brake products are distributed (i.e. detached from the support) results in an unavoidable manipulation of asbestos containing brake products at the shops, making the 'controlled or safe use' difficult, if not impossible, to achieve.

Finally, it is also important to highlight once again the unacceptable working conditions of these workers. Out of the one hundred three 8-h TWA PCM-Eq personal asbestos concentrations estimated, 24% exceeded the Colombian standard and the US OSHA PEL of 0.1 f/cm^3 asbestos occupational limit. Furthermore, 15% of the samples were in compliance but above the USA OSHA PEL action level of 0.050 f/cm^3. The highest exposures were observed in three riveters that had high workloads and that worked in two poorly ventilated passenger vehicles BRS, who also bond and grind the brake products to remove excess glue, and in two riveters from another poorly ventilated passenger vehicle BRS with a medium-low workload. In this last shop, asbestos fibers accumulated over the floor and the manipulation equipment. Similarly to the conclusions of previous studies conducted by our research group with auto mechanics, these workers experience high asbestos occupational personal exposures, and because of this, they are at excessive risk of developing asbestos related diseases.

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