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Original Article

Controlling Painters' Exposure to Volatile Organic Solvents in the Automotive Sector of Southern Colombia

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ABSTRACT

Background: Painters in the automotive sector are routinely exposed to volatile organic solvents, and the levels vary depending on the occupational health and safety controls enforced at the companies. This study investigates the levels of exposure to organic vapors and the existence of controls in the formal economy sector in southern Colombia.

Methods: This is an exploratory study of an observational and descriptive character. An analysis of solvents is conducted via the personal sampling of painters and the analysis of samples using the National Institute for Occupational Safety and Health 1501 method. The amount of solvents analyzed varied according to the budget allocated by the companies. The person in charge of the occupational safety and health management system was interviewed to learn about the exposure controls implemented at the companies.

Results: A medium exposure risk for toluene was found in one company. Another presented medium risk for carbon tetrachloride, xylene, ethylbenzene, and n-butanol. The others showed low risk of exposure and that the controls implemented were not sufficient or efficient.

Conclusion: These results shed light on the working conditions of these tradespeople. The permissible limits established by Colombian regulations for the evaluated chemical contaminants were not exceeded. However, there were contaminants that exceeded the limits of action. The analysis of findings made it possible to propose improvements in occupational safety and health management systems to allow the optimization of working conditions for painters, prevent the occurrence of occupational diseases, and reduce costs to the country's health system.

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1. Introduction

The occupational exposure of painters to organic solvents has been widely studied in industrialized countries, such as Canada, Korea, New Zealand, and Spain, and in emerging economies such as Iran, Pakistan, Thailand, Argentina, Mexico, and Colombia [1–10]. In addition, the acute effects of organic solvents on the health of workers have also been demonstrated. However, in recent decades, the study of long-term effects (e.g., problems with the nervous system, cognition, memory, motor performance, hematological characteristics, renal status, hepatic symptoms, ototoxicity systems, and cancer risks) on the health of workers exposed to low concentrations of these substances is of interest [6,9,11,12]. Other

studies in industrialized countries have analyzed the health risks of paint to auto workers considering occupational, nonoccupational, and environmental exposure as well as the total daily intake and the health risk over the population [6,10,13–16]. Based on the results of these studies, some authors proposed adopting stricter exposure limits, improving industrial hygiene conditions (e.g., ventilation systems), providing personal protective equipment (PPE), and training workers [7,15,11]. Palma et al [10] conducted a study in 2015 on car painters belonging to the informal economy in Colombia. The study showed a very high exposure to organic solvents and precarious working conditions. The research group carried out the investigation with the objective of understanding the level of exposure to organic vapors and the existence of controls to

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diminish exposure in automotive painters in companies of the formal economy of southern Colombia. They took into account the variability of working conditions, based on whether the firms were assemblers of motor vehicles with legally hired workers and occupational safety and health management systems (OSHMSs) working in an organized manner, small- or medium-sized enterprises, dealerships, workshops, or a paint-shop yard. Some firms were found to engage in precarious contracting and with low resources allocated to the OSHMS.

2. Materials and methods

The present study represents an exploratory, observational, and descriptive study, whose main objective is to research the level of exposure to organic vapors and the existence of controls to diminish such exposure in companies of the formal economy located in southern Colombia, with diverse characteristics in relation to the size and resources allocated to their respective OSHMS.

2.1. Sample design

The sampling was nonprobabilistic for convenience, assuming the characteristics of the companies studied were different. Their participation in the study was voluntary, and a confidentiality clause was included. The researchers provided scientific technical advice to companies to ensure the validity of the hygienic evaluation methodology, without intervention in other variables, such as the number of solvents to be quantified and control methods available to reduce the level of exposure.

2.2. Sample

The sample studied corresponds to six legal corporations of the automotive sector located in southern Colombia. Owing to our confidential treatment of companies, we call them ESA₁, ESA₂, ESA₃, ESA₄, ESA₅S₁, ESA₅S₂, and ESA₆. The economic activities of these companies are described in the following section.

ESA₁, ESA₅, and ESA₆ are companies that sell and repair automotive vehicles.

ESA₂ is a company that manufactures metal parts.

ESA₃ is a company that sells and manufactures motorcycles.

ESA₄ is a company that repairs and paints industrial engines.

2.3. Analytical methodology

The National Institute for Occupational Safety and Health 1501 method, "Determination of aromatic hydrocarbons," was used for flame-ionization detector gas chromatography. Both the laboratory and the analytical technique were internationally certified. The parameters of determination are described in the following section:

The technique used was gas chromatography with flame-ionization detector as the detector. Analyte: aromatic hydrocarbons Desorption: 1 mL CS₂, stand 30 min with agitation. The injection volume was 1 µL (Group A: split 5:1; Group B: split 1:1). The injection temperature was set at 250 °C. The temperature of the detector was set at 300 °C. The temperature of the column was as follows: Group A: 40 °C (10 min) to 230 °C (10 °C/min) Group B: 35 °C (8 min) to 225 °C (10 °C/min). The carrier gas used was He at the rate of 2.6 mL/min.).

All samples were collected in activated carbon tubes and analyzed in the Maxxam laboratory (22345 Roethel Dr, Novi, MI 48375, EE. UU) located in Novi (Laboratory ID: 100967). The laboratory was accredited by the American Industrial Hygiene Association.

2.4. Sampling strategy

Companies carried out personal sampling of painters during the application of spray paints. Sample times varied between 280 and 360 min and corresponded in all cases to 80% of the painter's workday. A sample pump was used to collect samples. It was a Buck brand Libra series model S/N L405221 (7101 Presidents Dr. Suite 110 Orlando, Fl. 32809), and it was calibrated before each sampling using a Buck serial 30470 digital calibrator (7101 Presidents Dr. Suite 110 Orlando, Fl. 32809). The sample flow rate was 0.20 L/min. Glass tubes with double-fraction adsorbent solids, activated carbon (100/50 mg), were used. The sampling pump was calibrated before and after sampling to verify the flow as recommended by the National Institute for Occupational Safety and Health 1501 method.

For the sampling strategy, we chose the positions that had the highest exposure to organic vapors and the longest handling time of chemical substances. For this, we accounted for the workers and supervisors at each of the companies, and sampling was sought for the worst exposure conditions to understand the level of risk.

2.5. Interview with the OSHMS manager

During the interview with the occupational health and safety officer, questions about source controls and the type of paint to be applied were asked. The type of engineering control that the company had implemented was also queried. In addition, questions were asked about the types of PPE provided by the company, training that the company provides, and existence of standardized work procedures. Related to administrative controls, we inquired about the implementation of epidemiological surveillance systems and the performance of occupational medical examinations with an emphasis on respiratory and neurological systems, tests of liver and renal function, and biological indices of exposure.

2.6. Ethical considerations

Both the participation of companies and the results were provided freely and voluntarily by the companies. The research group neither did carry out any surveys nor did it sample the workers. For that reason, the study does not present any ethical implications for humans. This project was cataloged by the Ethical Committee of Fundacion Universitaria Tecnologico Comfenalco as a risk-free investigation according to the resolution N° 008430 de 1993, emanated by the Colombian Ministry of Health. (see [Table 1](#))

2.7. Characterization (determination) of the level of exposure

To classify the level of risk, the division of the time-weighted average (TWA) found in the measurement of the adjusted time limit value (TLV) was carried out using the following criterion:

$$\text{Risk Level} = \text{TWA/adjusted TLV}$$

3. Results

Regarding environmental measurements of organic solvents, companies ESA₂ and ESA₃ covered the analysis of 21 solvents, whereas the others only requested analysis of benzene, toluene, and xylene. [Table 2](#) presents the results of the environmental measurements of solvents. It contains the results of those yielding positive results for each company with the degree of risk of exposure, calculated from the TLV of each solvent established by the American Conference of Governmental Industrial Hygienist [17] and corrected according to the working day.

Table 1
Risk level classification

TWA/adjusted TLV ≤ 0.5	$0.5 \geq$ TWA/adjusted TLV ≤ 1.0	TWA/adjusted TLV > 1.0
Low risk	Medium risk	High risk

TLV, time limit value; TWA, time-weighted average.

The limits of detection for contaminants by gas chromatography technique are shown in Table 3.

The control methods used by the six companies are described in Table 4.

We compared the control method results to the requirements established by Resolution 2,400 of 1979 issued by the Ministry of Labor and Social Security of Colombia [18] and Law 55 of 1993, by which Convention number 170 was approved with Recommendation No. 177 on Safety in the Use of Chemical Products in the Workplace of the International Labor Organization [19]. The following noncompliance aspects were found.

Regarding source control, Article 15 of Law 55 of 1993 established that the employer must choose chemical products to eliminate or reduce health risks. However, owing to firm characteristics, just one firm can choose the type of paint to be used, whereas the others must apply the paint specified by the client.

In relation to engineering measures for environmental control, Article 74 of Resolution 2,400 of 1979 requires the elimination of toxic vapors from the work area and specifies that the air must be purified before being emitted into the atmosphere. This assertion was not met by ESA₂ and ESA₄. Article 77 established that for these type of activities, exhaustive ventilation systems must be installed. Furthermore, Article 78 established that these systems must function perfectly, unfulfilled at ESA₅ Site 2.

Table 2
Organic levels of volatile solvents per company

Company	Solvent	TWA mg/m ³	Adjusted TLV mg/m ³	Risk level = TWA/adjusted TLV
ESA ₁	Benzene	0.093	1.18	0.08
	Toluene	5.915	70	0.08
	Xylene	2.676	320.00	0.01
ESA ₂	Benzene	Not detected	1.18	Not detected
	Toluene	—	70	—
	Carbon tetrachloride	14.83	24.49	0.61
	m-Xylene	216.67	407	0.53
	Ethylbenzene	66.67	81.4	0.82
	Acetone	0.83	1.49	Not detected
	Cyclohexanone	0.717	75.28	0.01
	Isopropyl alcohol	0.38	460	Not detected
	Methyl amyl ketone	0.08	218	Not detected
	Methyl isoamyl ketone	0.48	87.6	0.01
	Methyl isobutyl ketone	7.67	76.8	0.10
	n-butanol	216.67	407	0.53
n-butyl acetate	11.50	667.5	0.02	
ESA ₃	Benzene	Not detected	1.20	Not detected
	Toluene	0.053	59	Not detected
	Xylene	4.722	344	0.01
	Ethylbenzene	0.875	68.8	0.01
	n-butyl acetate	3.19	564	0.01
ESA ₄	Benzene	Not detected	1.14	Not detected
	Toluene	1.375	59.00	0.02
	Xylene	15.000	54.00	0.28
ESA ₅ Site 1	Benzene	Not detected	1.17	Not detected
	Toluene	0.290	55.10	0.0053
	Xylene	1.804	339.00	0.0053
ESA ₅ Site 2	Benzene	0.100	1.50	0.0667
	Toluene	58.333	70.65	0.8257
	Xylene	25.833	434.00	0.0595
ESA ₆	Benzene	0.078	1.50	0.05
	Toluene	7.799	70.65	0.11
	Xylene	18.868	407.06	0.05

TLV, time limit value; TWA, time-weighted average.

Table 3
LOD for contaminants

Analyte	LOD (ug)
Benzene	1
Toluene	2
Xylenes	4
Ethylbenzene	2
Carbon tetrachloride	4
Cyclohexanone	4
Isopropyl alcohol	4
Methyl amyl ketone	3
Methyl isoamyl ketone	3
Methyl isobutyl ketone	3
n-Butanol	5
n-Butyl acetate	3

LOD, limit of detection.

Regarding work clothes, companies ESA₁ and ESA₄ supplied cotton suits, which facilitate the dermal absorption of solvents in breach of Article 170 of Resolution 2,400 of 1979.

None of the companies had established work procedures to perform painting tasks to minimize the risk of exposure. Thus, Article 15 of Law 55 of 1993 was not fulfilled.

Article 18 of Law 55 of 1993 requires the employer to perform medical evaluations when handling chemical substances. Although companies performed medical examinations, only one company performed specific tests to assess kidney and liver function. More seriously, specific examinations are not requested for the workers during their entrance examinations. Therefore, they are certainly capable of hiring painters suffering from prior health afflictions that may not be noticed until they are on the job.

Table 4
Control methods used by companies.

Company	Control in source	Control in the environment	Control in individual	Administrative control
ESA ₁	The company cannot perform any source control because the type of paint to be used is determined by the product according to the customer's specifications.	The company has a closed cabin for painting with exhaustive local ventilation and filters on the ceiling and floor for the vapors.	Workers wear respirators with an organic vapor cartridge, nitrile gloves, chemical splash goggles, and overalls. However, they neither receive training nor work procedures that help reduce the risks of exposure.	The company does not have an epidemiological surveillance system for organic vapors. Nor does it contract for the performance of liver or kidney function tests for workers.
ESA ₂	The company cannot perform any source control because the type of paint to be used is determined by the product according to the customer's specifications.	The company does not have mechanical ventilation, but has only natural ventilation.	Workers wear respirators with an organic vapor cartridge, nitrile gloves, chemical splash goggles, and a Tyvek suit. However, they neither receive training nor work procedures that help reduce the risk of exposure.	The company does not have an epidemiological surveillance system for organic vapors. Nor does it contract for the performance of liver or kidney function tests for its workers. However, it has applied the questionnaire of neurological symptoms Q16.
ESA ₃	The company requests paints with very low benzene content from its suppliers.	The company has a paint booth with a water curtain.	Workers wear a respirator with an organic vapor cartridge, nitrile gloves, chemical splash goggles, and a Tyvek jumpsuit. However, they neither receive training nor work procedures that help reduce the risk of exposure.	The company has an epidemiological surveillance system. Therefore, employees are given medical tests for spirometry and liver and kidney function tests.
ESA ₄	The company cannot perform any source control because the type of paint to be used is determined by the product according to the customer's specifications.	The company has a small craft booth for painting without filters to retain steam with a small axial fan located on the outside.	The workers wear nitrile gloves, chemical splash goggles, and work overalls in cotton. However, they neither receive training nor work procedures that help reduce the risk of exposure.	The company does not have an epidemiological surveillance system for organic vapors. Nor does it contract for the performance of liver or kidney function tests for its workers.
ESA ₅ S1 y S2	The company cannot perform any source control because the type of paint to be used is determined by the product according to the customer's specifications.	The company has an extraction system inside the paint booth, equipped with two filters, one on the ceiling and the other on the floor.	Workers wear a respirator with activated 3M 6001 filters, a Tyvek jumpsuit, and nitrile gloves. However, they neither receive training nor work procedures that help reduce the risk of exposure.	The company does not have an epidemiological surveillance system for organic vapors. Nor does it contract for the performance of liver or kidney function tests for its workers. It only performs annual spirometry.
ESA ₆	The company cannot perform any source control because the type of paint to be used is determined by the product according to the customer's specifications.	The company has an extraction system inside the paint booth, equipped with two filters, one on the ceiling and the other on the floor.	Workers wear a half-face respirator with an activated carbon cartridge, a Tyvek jumpsuit, and nitrile gloves. However, they neither receive training nor work procedures that help reduce the risk of exposure.	The company does not have an epidemiological surveillance system for organic vapors. Nor does it contract for the performance of liver or kidney function tests for its workers.

Data obtained in this study were compared with those obtained in studies conducted in a similar population in Argentina, Canada, Colombia, Spain, Iran, and Thailand (see Table 5 and Fig. 1).

Fig. 2. Levels of VOCs in mg/m^3 found in industries of different countries and companies included in this study.

4. Discussion

The selection of work controls for any hazard must be made in the order of priority, where the first choice includes controls that directly intervene with the source of danger. With reference to organic solvents, the best international control corresponds to the use of water-based paints without the presence of solvents, especially no or very low levels of benzene [20]. This intervention is consistent with the results found in this and other studies, with the exception of Harati et al. [6], who found levels above the internationally established TLV in car painters in Iran. However, this measure can be applied in factories or assemblers that can choose the type of paint to be used [21]. In this sense, it is very difficult to comply with those companies where the type of paint to be used does not depend on the organization but on the client's needs. Such is the case with auto repair and painting workshops, which constitute most of the companies of this study.

A review of exposure levels to benzene in Korean industries was carried out by Park et al [3] in 2015, affirming that there had been a substantial reduction in the amount of benzene in industrial products mainly because of internationally binding conventions and regulations. These findings supported those found in this study and at an international level. However, it remains important to continue monitoring the levels of this pollutant, given the dangerous nature of the substance and the fact that some levels in the companies studied were above the established limits.

In terms of engineering controls to reduce pollutants in the environment, thorough installations of efficient systems of exhaustive local ventilation were not implemented by all the companies in this study, such as ESA₂. In addition to having such systems, it is important to maintain them to prevent poor performance and generation of a false perception of protection, as with ESA₅ Site 2, where the action limit for toluene is exceeded, despite having a cabin of paint with an exhaustive local extraction system. These ventilation systems are referenced in studies conducted in Pakistan and Spain [1,5], inferring their lack of maintenance. They were installed to comply with the international law but did not offer real protection to workers.

Table 5

Levels of VOCs in painters worldwide.

Company	VOC concentration (mg/m^3)			
	Benzene	Toluene	Xylene	Ethylbenzene
ESA 1	0.093	6	3	—
ESA 2	Not detected	Not detected	217	67
ESA 3	Not detected	0.053	5	0.875
ESA 4	Not detected	1	15	—
ESA 5S ₁	Not detected	0.29	1.804	—
ESA 5S ₂	0.1	58.333	25.833	—
ESA 6	0.078	7.799	18.868	—
Iran [6]	0.2426	0.3184	9.79	10.55
Colombia [10]	450	27.220	150.150	—
Thailand [7]	Not detected	14.59	Not detected	Not detected
Argentina [8]	0.02888	0.6015	1.80	0.3849
Canada [2]	0.023	1	0.323	0.065
Spain [5]	0.015	19	21	4

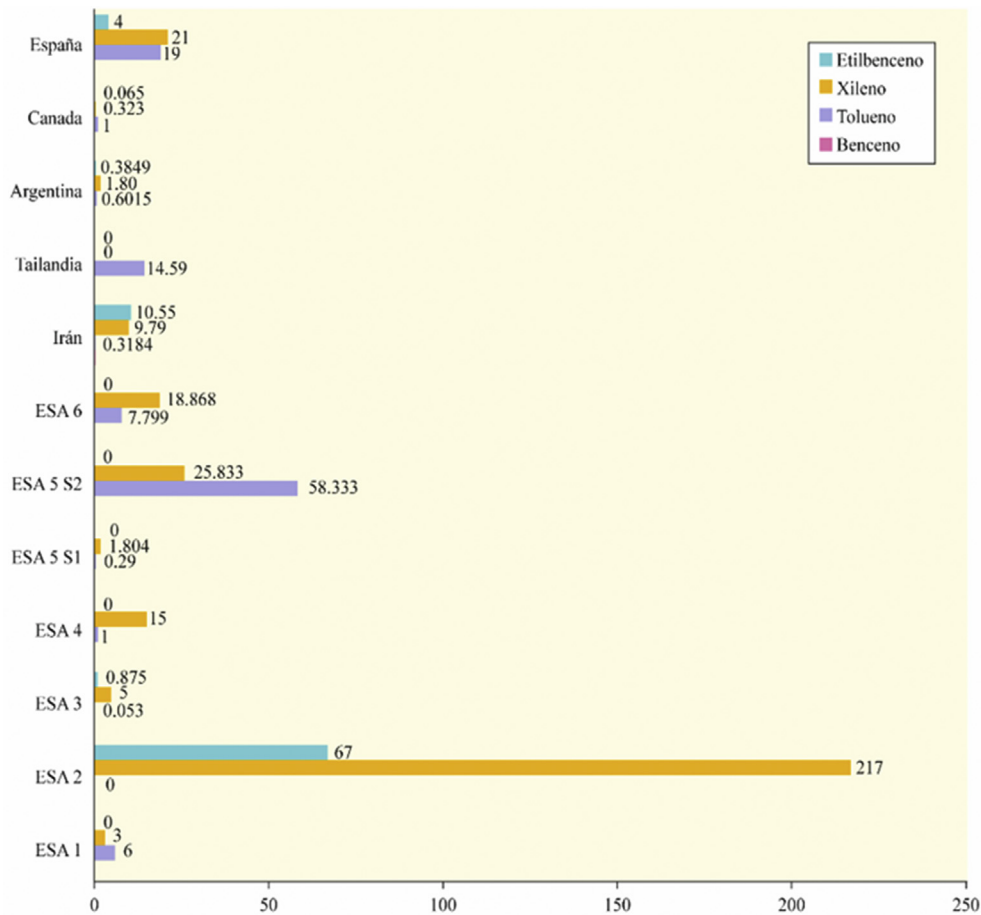


Fig. 1. Sampling train worn by the worker.

In relation to the control of the exposure to solvents through the supply of PPE, it is important to document 100% adherence to its use. Decharat [7], Caro and Gallego [5], and Palma et al [10] reported an adherence of $\sim 77\%$ in their studies. In the companies studied, there were no observations aimed at verifying the use of PPE by workers. Therefore, the actual percentage of adherence could not be corroborated. The companies dedicated to these tasks must have adequate programs of respiratory protection and strict controls on the use and replacement of equipment of personal respiratory and body protection.

Other measures that must be implemented in any industry where workers are exposed to chemical substances are training and the existence of standardized procedures for handling these substances. According to Kamal and Rashid [1], in the company evaluated in Pakistan, the workers did not use any type of PPE. They were not trained nor did they have standardized procedures for the safe handling of chemicals in the workplace. This could generate the absorption of solvents by dermal routes. This finding also confirms the need for industries to provide Tyvek-type attire and to adapt facilities for changing clothes at the end of the working day. It was found that the workers at the companies of the study received training. However, there were no documented procedures to determine if the tasks and equipment were being used appropriately.

The companies studied reported spirometry for painters. In addition, only ESA₂ performed liver tests, and ESA₃ applied Questionnaire Q16 to investigate neurological symptoms. Neither was tested for biological indicators of exposure. In this regard, Decharat (2014) used hippuric acid as a biological indicator, and Palma et al [10] used hippuric acid, ortho-methylhippuric acid, para-methylhippuric acid, and phenylmercapturic acid as biological markers commonly recommended by other authors.



Source: Own elaboration

Fig. 2. Levels of VOCs in mg/m³. Source: own elaboration

Occupational exposure to solvents in car painters continues to present itself both nationally and internationally, which is why it continues to be an area of interest for epidemiological surveillance in both developed and developing countries at both formal and informal companies.

Given the complexity of the solvent mixtures present in this type of work, it is recommended that officials extend the mandatory monitoring of benzene, toluene, and xylene and include solvents, such as ethylbenzene, n-butyl acetate, n-hexane, acetone, methyl ethyl ketone, and methyl isobutyl ketone; and chlorinated compounds, such as chloroform and trichlorethylene, given that they can be present in the work environment. However, the risks of other solvents were not evaluated [4,5,8]. According to the results found, companies engaged in activities related to vehicle painting should promote biological analysis in exposed workers, such as urine testing of hippuric acid and methylhippuric acid, to verify the degree of potential health impact. Furthermore, the health effects on organs, such as the kidney and liver, should be studied in workers exposed to volatile organic compounds (VOCs), even at doses below the maximum limits allowed in the workplace. According to the findings of other authors [11], all assessments must be framed within the epidemiological surveillance system for organic solvents within organizations.

5. Conclusions

This study investigated the level of exposure to organic vapors and the existence of controls to reduce said exposure in

companies belonging to the formal economy located in southern Colombia. It is concluded that the use of paints, which do not use organic solvents, should be promoted to control hazard source, as it has been established in other countries. There should also be a more vigilant monitoring of the controls implemented in all companies to ensure that they cover all aspects required by the Colombian legislation.

Furthermore, it is necessary to demand the implementation of epidemiological surveillance systems that encompass the performance of activities, such as environmental monitoring, expanding the number of solvents to be monitored in a compulsory manner because as complex mixtures, there is the possibility of the presence of other volatile compounds.

It is also necessary to implement engineering controls or exhaustive local ventilation systems in a mandatory manner, to prohibit the use of natural ventilation systems, and to check the effectiveness of the controls, to reach very low VOC concentrations.

Biological monitoring and medical examinations should be carried out in accordance with the health effects that these substances can cause to workers to avoid not only occupational diseases but also the appearance of subclinical symptoms.

It is necessary to train workers in standardized work procedures, the use and maintenance of PPE, and the safe handling of dangerous chemical substances. However, in Colombia, trade unions and insurers must promote policies so that the work of a painter is qualified as high risk (Group 1), according to the recommendations of the International Agency for Research on Cancer because this type of mixture can produce mesothelioma and bladder and lung

cancer [22]. The objective is reducing exposure and preventing premature labor pension for workers.

The workers of the companies studied did not understand the relationship between occupational cancer and exposure to aromatic hydrocarbons. They also did not know that they held high-risk jobs with different retirement characteristics. In addition, Colombia must establish intervention guidelines for mandatory compliance of the prevention of occupational cancer for these companies.

Finally, it is recommended to continue with investigations that expand the geographic zones studied to understand the real exposure of these workers throughout the country. Similarly, health risk tests should be included to measure occupational, nonoccupational, and environmental exposure to determine the daily dose to which said workers are exposed, accounting for the methodology used in the study by Badjagbo et al [2], given that these pollutants are present in our factories.

Conflict of interests

The authors declare that they do not have any conflict of interests.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.shaw.2019.06.001>.

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