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Case Report

Exposure Assessment Suggests Exposure to Lung Cancer Carcinogens in a Painter Working in an Automobile Bumper Shop

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A B S T R A C T

A 46-year-old man who had worked as a bumper spray painter in an automobile body shop for 15 years developed lung cancer. The patient was a nonsmoker with no family history of lung cancer. To determine whether the cancer was related to his work environment, we assessed the level of exposure to carcinogens during spray painting, sanding, and heat treatment. The results showed that spray painting with yellow paint increased the concentration of hexavalent chromium in the air to as much as 118.33 $\mu g/m^3$. Analysis of the paint bulk materials showed that hexavalent chromium was mostly found in the form of lead chromate. Interestingly, strontium chromate was also detected, and the concentration of strontium chromate increased in line with the brightness of the yellow color. Some paints contained about 1% crystalline silica in the form of quartz.

1. Introduction

Painting the bumpers of automobiles involves coating metal with paint using either a brush or spray gun. In the case of spray painting, the paint disperses in the air and painters are exposed to, and may inhale, paint. Automobile paint contains various chemicals, including pigments, solvents, fillers (extenders), binders (resins), and other additives. It is thought that these chemicals can cause lung cancer. The Occupational Lung Disease Institute, the Korea Workers' Compensation and Welfare Service [1] reported a case of lung cancer in a painter who had painted car bumpers for 15 years and provided the results of an exposure analysis conducted to determine the lung cancer carcinogen. This case study was conducted following a request from the patient and a representative of their employer for an epidemiological investigation.

2. Materials and methods

We reviewed industrial hygiene assessment reports for the working environment, and conducted an interview with the patient and a workplace walk-through survey in order to determine potential occupational factors associated with the disease.

2.1. Workforce information

The patient was a man who had been diagnosed with lung cancer at the age of 44 years; he had filed a claim for occupational accident benefits from the government for rehabilitation. The patient's lung cancer was not detected in the health screening provided by the company, but was revealed by a computed tomography scan that had been performed to investigate a condition of the shoulder.

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The patient had worked as a car bumper painter for 15 years, beginning at the age of 30 years in 1996 and continuing in the role until 2011. Prior to moving into the role, the patient had held a managerial position and did not work in an environment that was potentially related to lung cancer. He was a nonsmoker with no family history of lung cancer.

2.2. Workplace information

The patient worked from Monday to Saturday for 10 hours each day, excluding a 1-hour lunch break. His work broadly consisted of surface sanding and spray painting. For a single car bumper, 5 minutes of sanding and 15 minutes of painting is required (Figs. 1, 2). On average, he worked on 15–20 bumpers per day and worked continuously, except for his lunch break. The order in which his work was performed was as follows: sanding the bumper surface, painting the bumper, and then drying the paint by heat treatment. Bumpers were classified as new or damaged, and damaged bumpers were repaired by first applying putty and then sanding. The painting booth had a ventilation system that consisted of a ceiling panel with an exhaust filter on the lower side. The paint particles that were aerosolized during spray painting caused turbulence in the air and were exhausted through the lower side filter. The exhaust filter was replaced regularly once a year and a visual assessment showed that the ventilation appeared to be in good condition. However, for the first several years that the patient worked there, work was done in a temporary booth made of plywood rather than in a booth set up exclusively for painting, and this booth offered only a small space without any appropriate ventilation equipment. Heat treatment was done at 60 °C for 30 minutes, and the workers collected the dried product. During the 15 years he spent working as a painter, the patient wore a normal cotton facemask for the first 10 years and a certified dust respirator for the next 5 years.

2.3. Exposure assessment and bulk materials analysis

Paints vary greatly depending on the type of car, and the exposure assessment in this study was conducted with silver, the most frequently used color, and yellow, which is suspected to contain the highest content of heavy metals such as hexavalent chromium. We determined the exposure to lung carcinogens, namely hexavalent chromium, metal, and crystalline silica, during spray painting and sanding. During heat treatment, polycyclic aromatic hydrocarbons (PAHs) can be formed; therefore, the PAH levels in front of the heat treatment room were also measured using a real-time instrument (particulate PAH monitor, PAS2000; Ecochem Inc., League City, TX, USA). Hexavalent chromium samples were collected on polyvinyl chloride filters (SKC Inc., Eighty Four, PA, USA; 5.0 μm, 37 mm) as sampling heads with a sampling pump (AirChek XR5000; SKC Inc., Eighty Four, PA, USA) at a flow of 4 L/min. Analysis of hexavalent chromium was performed by ion chromatography (ICS3000; Thermo Scientific Dionex Inc., Sunnyvale, CA, USA) according to the approved National Institute for Occupational Safety and Health (NIOSH) method 7605 [2]. The heavy metal samples were collected on mixed cellulose ester filters (SKC Inc., Eighty Four, PA, USA; 0.8 μm, 37 mm) as sampling heads with a sampling pump at a flow of 4 L/min. Analysis of heavy metals was performed by inductively coupled plasma mass spectrometry (ICP/MS, Elan DRC-e; Perkin-Elmer SCIEX Inc., Waltham, MA, USA) according to the NIOSH method 7300 [2]. Crystalline silica samples were collected on polyvinyl chloride filters (SKC Inc., Eighty Four, PA, USA; 5.0 μm, 37 mm) using high volume cyclones (GK2.69; BGI Inc., Waltham, MA, USA) as sampling heads with a sampling pump at a flow of 4.2 L/min. GK2.69 cyclones were used to collect the respirable dust fraction, which is relevant in determining exposure to respirable quartz. The analysis of quartz was performed by X-ray diffraction (XRD, D8 Advance; Bruker Inc., Karlsruhe, Germany) according to the NIOSH method 7500 [2]. To facilitate the detection of low concentrations, a rate of sampling of 4 L/min was used, and ICP/MS was used to analyze the metals. Our laboratory provides internal quality-control

Fig. 2. The sanding process. For a single car bumper, 5 minutes of sanding and 15 minutes of painting is required.

Fig. 1. The spray painting process. (A) Gray paint. (B) Yellow paint.

Table 1
Airborne concentrations of heavy metals detected during spray painting and sanding (unit: mg/m^3)*

Process		Sampling type	Sampling time	Hexavalent chromium	Total chromium	Lead	Aluminum	Iron	Manganese	Strontium	Silica	PAHs
Painting	Gray	Personal	195	ND	—	—	—	—	—	—	—	—
		Area	195	ND	ND	ND	0.882	0.024	ND	ND	ND	—
	Yellow	Personal	7.5	0.118	—	—	—	—	—	—	—	—
		Area	7.5	0.116	0.608	2.824	ND	0.986	0.011	0.001	ND	—
Sanding		Personal	5	ND	—	—	—	—	—	—	—	—
		Area	5	ND	ND	ND	ND	0.187	ND	ND	ND	—
Heat treatment		Pre	20	—	—	—	—	—	—	—	—	4.3
		Post	20	—	—	—	—	—	—	—	—	4.3

ND, not detected; PAH, polycyclic aromatic hydrocarbon.
* The PAHs were measured by the PAS 2000 particulate PAH monitor (unit: ng/m^3).

programs for hexavalent chromium and heavy metals and has passed the Proficiency Analytical Testing of the American Industrial Hygiene Association assessment for silica after many years of participating in their programs, which are external quality-control programs. Hexavalent chromium was measured using personal sampling and the other chemicals by area sampling. Hexavalent chromium and metal levels during spray painting were measured during 195 minutes of paint spraying with gray paint and 7 minutes 30 seconds of spray painting with yellow paint.

Bulk materials, including individual paint color and putty, were also analyzed. There were two types of paint: one type was classified as “normal paint” and the other was eco-friendly paint. Content analysis was performed for hexavalent chromium, heavy metals, and silica, with an additional asbestos analysis for putty (according to NIOSH 9000) [2]. Individual paints of each color and putty were ground using a Spex Mixer/Mill (8000D; Spex Industry, Edison, NJ, USA) after drying in a muffle furnace for 2 hours at 500 °C, in order to achieve a similar particle size as standard crystalline silica. The crystalline silica content of the samples was analyzed by XRD according to a standard material calibration method. We also calculated the probability of exposure and the level of exposure according to the length of time the patient had worked there in order to estimate the patient’s past exposure [3].

3. Results

3.1. Description of cancer

A computed tomography scan performed on 2011 showed that the patient had a 5.0 cm × 3.4 cm mass. The results of percutaneous needle aspiration led to the diagnosis of non-small cell lung cancer. Subsequently, the results of brain nuclear magnetic resonance imaging, positron emission tomography, and whole-body bone scan showed that there were no metastases.

3.2. Exposure assessment

In previous industrial hygiene assessment reports conducted annually by the employer in compliance with legal requirements, exposure tests were conducted only for organic solvents, without including any assessments for hexavalent chromium, silica, and PAHs (which may cause lung cancer). In the gray spray paint, no hexavalent chromium was detected, but the personal sample found 0.118 mg/m^3 of hexavalent chromium and the area sample found 0.116 mg/m^3 of hexavalent chromium in the yellow spray paint. Other metals were detected at the following concentrations: total chromium, 0.608 mg/m^3; lead, 2.824 mg/m^3; iron, 0.986 mg/m^3; manganese, 0.011 mg/m^3; and strontium, 0.001 mg/m^3 (Table 1). During the sanding process, hexavalent chromium was not detected, and only iron and manganese were detected. The average PAH concentration was very low (4.3 ng/m^3) and did not increase during heat treatment. No quartz was detected during either the painting or sanding processes. Table 2 shows the exposure to hexavalent chromium by the duration of employment of the patient. The results indicate that the patient was exposed to a high concentration of hexavalent chromium (0.024 mg/m^3), which exceeds the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) of 0.010 mg/m^3 of 9.5 years.

3.3. Bulk material analysis

In the yellow paint (normal paint), the hexavalent concentration was, on average, 14,438 parts per million (ppm), and considering that total chromium and lead concentrations were both high, the chromium probably existed in the form of lead chromate ($PbCrO_4$). Strontium was also detected, and given that strontium content increases with the brightness of the yellow color, it is probable that strontium chromate ($SrCrO_4$) was added to the paint to create the bright yellow color [4] (Table 3). The orange-yellow paint had 9 ppm of cadmium, and quartz (a type of crystalline silica) was

Table 2
Patient exposure to hexavalent chromium according to task

Duration (y) *	Job type	Job characteristics (in order of performance)	Exposure probability	Exposure level
4.8	Sanding	Damaged bumpers are repaired by applying putty and then sanding	Unlikely†	No exposure
9.5	Spraying	Spraying paint on the bumper	Certainly	ND–0.118 mg/m^3 (0.024 mg/m^3‡)
0.8	Heat treatment	Heating bumper for drying paints	Very unlikely	No exposure

ND, not detected.
* Estimated job-specific work period of 15 years (1997–2012).
† In this report, no hexavalent chromium was detected, but was likely to have been present when repairing damaged bumpers (containing Cr^+) in the past.
‡ Approximately 20 painting job units were completed per day, of which 1% were yellow; therefore, the number of yellow paint job units completed per day was 0.2. The concentration of hexavalent chromium for each yellow paint job unit is 0.118 mg/m^3 (Table 1), and the total concentration of hexavalent chromium exposure per day was therefore estimated to be 0.024 mg/m^3.

Table 3
Heavy metal and silica contents in the paints (units: metals, ppm; silica, percentage)

Paint type	Color	Hexavalent chromium	Total chromium	Lead	Strontium	Cadmium	Silica
Normal paint	Orange yellow	18,295	43,416	173,568	46	9	0.9
	Normal yellow	14,085	14,085	78,105	141	ND	1.2
	Bright yellow	10,935	36,302	186,437	267	ND	1.0
Eco-friendly paint	Yellow	0.43	8	46	4	ND	1.1
	Red	ND	2	12	2	ND	ND
	Green	0.04	3	ND	1	ND	0.7
	Silver	ND	3	9	2	ND	ND

ND, not detected; ppm, parts per million.

detected in the yellow and green paints at a rate of about 1%. In the eco-friendly paint, hexavalent chromium and metals were analyzed and the yellow and green paints had 0.43 ppm and 0.04 ppm concentrations of hexavalent chromium, respectively. Total chromium, lead, copper, aluminum, iron, manganese, strontium, and zinc were detected, but metals linked to lung cancer, including nickel, arsenic, beryllium, and cadmium, were not detected. The analyzed putty did not contain asbestos or quartz.

4. Discussion

In 1989, a systemic review based on five census studies and three cohort studies conducted by the International Agency for Research on Cancer (IARC) showed that the standardized mortality ratio for lung cancer in professional painters was 1.41; this confirmed that professional painting is an occupation with a high risk of lung cancer, even when the effect of smoking is taken into account [5]. Subsequently, in 2010, an analysis of 17 cohort and data-linked studies, as well as 29 case–control studies conducted before October 2007, showed that painters have an elevated risk of lung cancer [6,7].

Preference for yellow automobiles is uncommon in South Korea, although such automobiles are used for child-carrying vehicles, heavy construction-equipment vehicles, and as taxies in some of the country's cities. The number of automobile painters working in South Korea's five major vehicle producers is estimated to be approximately 4,000 (this estimate was obtained from an interview with a labor official at the automobile company). However, this number increases if we also include those working in small automobile body shops. Because the country's industrial accident statistics does not separately classify the automotive industry and the painters, the incidents of lung cancer in automotive painters cannot be measured. However, cases of lung cancer in painters have occasionally been reported.

According to Sabty-Daily et al [8], 71.8% of hexavalent chromium inhaled during spray painting accumulates in the upper respiratory system, whereas 1.4% and 2% accumulate in the bronchus and alveoli, respectively. Hexavalent chromium is a Group 1 lung cancer carcinogen, as declared by the IARC. The occupational exposure limit for hexavalent chromium is set at 1 $\mu g/m^3$ by NIOSH Recommended Exposure Limit (REL). The ACGIH set strict occupational exposure limits for insoluble hexavalent chromium at 10 $\mu g/m^3$, lead chromate at 12 $\mu g/m^3$, and strontium chromate at 0.5 $\mu g/m^3$.

According to a study conducted in the US Air Force [9], 88% of measured strontium chromate time-weighted average exposures exceed the TLV during sanding, whereas 100% of exposures exceed the TLV during spray painting. Moreover, the upper confidence limit of 492.2 $\mu g/m^3$ during spray painting is 988 times the TLV. In addition, the average exposure during the processes of spraying, sanding, and clean up involving a paint containing 1–30% chromates was 16 $\mu g/m^3$ (range: 3.8–55 $\mu g/m^3$) [10].

Spray painting expels paint at a very high pressure, and the paint is aerosolized and dispersed. Putty is used to fill in the dents in the bumper and is 60% talc, which has contained asbestos as a contaminant in the past. In this study, silica was not detected in the air samples. This is due to the low silica content in the paint and the short sampling time. According to a study conducted in the United States [11], the exposure rates of silica for a paint with 6% silica content were 8.8 $\mu g/m^3$ per hour during painting and 10.1 $\mu g/m^3$ per hour during sanding.

The patient painted, sanded, and heat-treated car bumpers for 15 years, painting 20 vehicles for approximately 6.3 hours every working day. The lung cancer seems to have been caused by yellow paint, which had a usage frequency of about 1% (green paint may also contain hexavalent chromium, but it is used less frequently). Hexavalent chromium is almost nonexistent in eco-friendly paint, but the employees in this workshop started using this paint only recently. Work using yellow paint containing high amounts of hexavalent chromium is performed infrequently. However, even considering the intermittent frequency, the work is believed to have had sufficient harmful effects owing to the fact that the concentration of hexavalent chromium, a powerful carcinogen, is high in this paint. The patient was exposed to 0.024 mg/m^3 of hexavalent chromium daily (Table 2). This concentration is rather high, according to the quantitative risk assessment (45-year exposure) performed by Park et al [12] (2004) who showed that this concentration causes 66 cases of additional deaths from lung cancer per 1,000 people.

The lead concentration in the yellow paint was also high (2.824 mg/m^3). This is because most of the hexavalent chromium in the paint exists as lead chromate ($PbCrO_4$). Although this particular worker did not exhibit symptoms of lead poisoning, a medical examination for lead poisoning should be performed for workers involved in similar jobs [13]. As a part of researching lung cancer cases, our laboratory has performed a mask fit test for workers who mixed pigments and talc for paint manufacturing in the past 20 years. The overall fit factor was 15 with a half-face Grade 2 (equivalent to European Nations P2) mask and 25 with a half-face Grade 1 (equivalent to European Nations P1) mask; these values were far lower than the pass value of 100. The masks currently available in the domestic market are all of the same size rather than different sizes to fit different workers, and workers are not trained to wear the masks correctly. Furthermore, the patient would not have benefited from the effects of wearing a mask for this particular case, as he wore a cotton mask for the first 10 years instead of a dust mask. In addition, as he was working in a temporary plywood booth for the first several years, and not in the current paint-job booth, the concentrations would have been higher than the values reported in this survey.

Conflict of interest

This manuscript has not been published or presented elsewhere in part or in entirety, and is not under consideration by another journal. A study participant provided informed consent, and the study design was approved by the appropriate ethics review boards. All the authors have approved the manuscript and agree with submission to your esteemed journal. There are no conflicts of interest to declare.

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