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Exposure Assessment of Hexavalent Chromium for a Powder Coating Spray Painter Associated with the Development of Lung Cancer

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ABSTRACT

A 63-year-old man who diagnosed with lung cancer had worked for 13.5 years (1999–2013) as a spray painter. The Occupational Lung Diseases Institute conducted retrospective exposure assessment to examine whether a spray painter job he had performed could be associated with the development of lung cancer. We investigated lung cancer carcinogens in his work environment. The safety data sheet of six powder coating products showed that powder coatings contained 1–10% of hexavalent chromium. In addition, our quantitative analysis of powder coating samples also showed that the hexavalent chromium contents quantified in the yellow-green and red powder coating samples were 0.27% and 0.95%, respectively. In order to estimate his exposure level of hexavalent chromium, we measured a personal exposure level of hexavalent chromium for a spray painter in accordance with the National Institute for Occupational Safety and Health #7605 method. The results showed that the spray painter was exposed to the high level of hexavalent chromium (216.9 $\mu g\ m^{-3}$). Furthermore, we estimated that he was likely exposed to several lung cancer carcinogens such as crystalline silica or asbestos over the approximately 24 years at various construction sites prior to assuming a job as a spray painter. Therefore, we concluded that his lung cancer was caused by substantial exposure to several lung cancer carcinogens over approximately 37.5 years. Particularly, exposure characteristic to hexavalent chromium could substantially contribute to the development of lung cancer, despite of the sole case of exposure assessment.

Keywords: Lung cancer; Exposure assessment; Powder coatings; Spray painter; Hexavalent chromium.

INTRODUCTION

Powder coatings are types of advanced paint products composed of solid contents, including synthetic resins, pigments and other additives without a solvent or water. They have been widely applied in various manufacturing industries from the 1980s due to convenience, environmental concerns and economics (Steigleder *et al*., 2002). Hexavalent chromium, classified as a lung cancer carcinogen by the International Agency for Research on Cancer (IARC), has been widely used in pigments for paints, including powder coatings (IARC, 1990; OSHA, 2009). Powder coatings are reported to contain 0.1 to 25% hexavalent chromium compounds in the form of lead chromate, depending on the powder coating product (Lee *et al*., 2004). Lung cancer developed among spray painters who have applied powder coatings can likely be associated with exposure to hexavalent chromium.

A 63-year-old man who diagnosed with lung cancer had worked for 13.5 years (1999–2013) as a spray painter. Prior to working as a spray painter, he had performed work cementing tiles on bathroom floors at construction sites for about 24 years (1975–1999). He had smoked for about 40 years prior to his diagnosis with lung cancer. He claimed that the lung cancer he suffered was caused by work as a spray painter and merited public compensation for rehabilitation. The Occupational Lung Diseases Institute (OLDI) under the Korea Workers' Compensation and Welfare Service (KCOMWEL) conducted retrospective exposure assessment to examine whether the job he performed as a spray painter could be associated with the development of lung cancer and then reported on this first occupational assessment of lung cancer in a spray painter who applied powder coatings.

MATERIALS AND METHODS

A Brief Description of the Process and Job

Fig. 1 shows that spray painting with powder coatings is typically performed in four steps: objects are washed, cleaned for dust removal, sprayed with powder coating, and finally coated. Figs. 2(A) and 2(B) show that residual dust or water on the product's surface, which can interfere

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Table 1. The job history of the patient.

Work duration	Job title	The process	Potential lung carcinogens
1975–1999	Construction tiler	Cementing tiles at construction sites	Crystalline silica Hexavalent chromium Asbestos
1999–2013	Spray painter	Spray painting with powder coating	Crystalline silica (quartz) Hexavalent chromium (lead chromates)

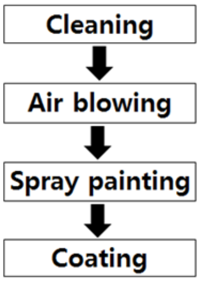


Fig. 1. A process diagram of the spray painting with powder coatings.

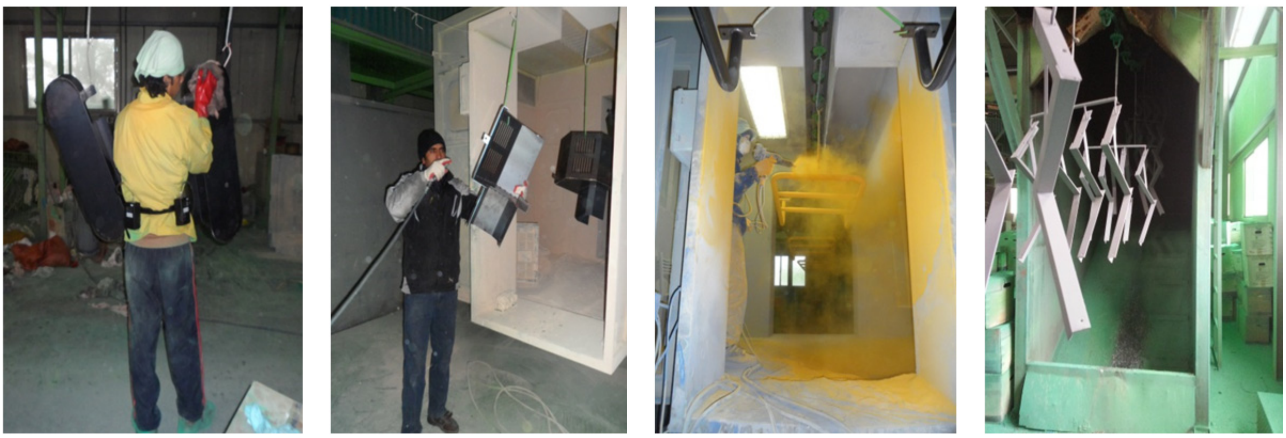
with painting adhesion, is generally wiped away using a cloth wetted with thinner, and then finally eliminated with an air gun. Fig. 2(C) shows that powder coatings are sprayed on by a painter using a spray gun in a spray booth. Lastly, Fig. 2(D) shows that powder coatings are adhered to the surface by melting at 150°C or higher in a heating furnace. The patient in question had only performed spray painting with powder coatings.

During his 13.5 years of spray painting, the patient normally worked from Monday to Saturday for 10 hours including a one-hour lunch break, and often performed an overtime shift of five additional hours. Products having been cleaned and air blown automatically entered the spray booth hanging from a conveyor and were promptly painted. Both side doors of the spray booth were of an open type and a local exhaust ventilation system was installed inside. Although the ventilation system was operated during working hours, a large amount of powder coating was aerosolized in the air and some of it was even emitted outside the spray booth. In addition, Fig. 3(A) shows that he swept and collected the powder coating that piled up on the bottom of the spray booth for recycling. Powder coating may also be aerosolized during this recycling process. Fig. 3(B) shows that he only wore a common cotton mask and gloves, which were unfit for the prevention of inhalation of aerosolized powder coatings.

Exposure Assessment

According to the safety data sheet (SDS), hexavalent chromium and limestone were contained within those products. The content (%) of hexavalent chromium and crystalline silica was quantified from samples of six powder coating products. For hexavalent chromium, a fixed amount of the batch was diluted with 5 mL of alkaline solution made with 2% sodium hydroxide (NaOH), 3% sodium carbonate (Na_2CO_3) and distilled water in a beaker. It was extracted for 90 minutes at 115°C in a hot plate. The extracted solution was analyzed for hexavalent chromium in an ion chromatography-visible absorbance detector (ICS-3000; ThermoFisher Scientific Dionex Inc., Sunnyvale, CA, USA). X-ray diffraction (XRD, D8 Advance; Bruker Inc., Karlsruhe, Germany) was used to analyze quartz in the samples of six powder coating products.

We took airborne samples from the same process and work that the patient performed or handled. Personal samples were taken for over five hours to estimate inhalation exposure to hexavalent chromium, total dust and respirable dust during dust removal and the powder coating painting process. In addition, area samples for these hazardous agents were also



(A) (B) (C) (D)

Fig. 2. The process of spray painting with powder coatings by the steps: (A) cleaning, (B) air blowing, (C) spray painting with powder coatings and (D) coating.

(A) (B)

Fig. 3. The work scene inside a spray booth of (A) yellow powder coatings piled up on the floor and (B) the spray painter wearing a general dust mask.

taken according to the distance from the spray booth. The airborne samples were collected on polyvinyl chloride filters (PVC filter; SKC Inc., Eighty Four, PA, USA; 5.0 µm, 37 mm) equipped in three-piece cassettes (Sureseal™ cassette; SKC Inc., Eighty Four, PA, USA, 3 Piece, 37 mm) with sampling pumps (AirChek XR5000; SKC Inc., Eighty Four, PA, UAS) at a flow rate of 2 L min^{-1}. We followed the sampling and analytical methods (#7605 for hexavalent chromium, #0500 for total dust and #0600 for respirable dust) recommended by the National Institute for Occupational Safety and Health (NIOSH). Airborne quartz samples were not taken because quartz was not detected in the six powder coating samples.

RESULTS

The hexavalent chromium contents (%) quantified in the yellow-green and red powder coating samples were 0.27% and 0.95%, respectively, but it was not detected in the other powder coating samples (Table 2). The quartz level was found to be lower than limit of detection (LOD) in all powder coating samples.

The levels of exposure to hexavalent chromium and respirable dusts during spray painting with powder coating inside the spray booth were 216.9 µg m^{-3} and 8.1 mg m^{-3}, respectively. The level of total dusts could not be quantified due to the overload of dust collected on the filter (Table 3). The level of exposure to hexavalent chromium was 18 times higher than the permissible exposure limit (PEL) of lead chromates (12 µg m^{-3}) as regulated by Ministry of Employment and Labor (MOEL). During cleaning, the levels of exposure to hexavalent chromium, total suspended particulates and respirable dusts assessed were 11.5 µg m^{-3}, 5.2 mg m^{-3} and 1.2 mg m^{-3}, respectively (Table 3). The level of hexavalent chromium during cleaning (11.5 µg m^{-3}) was close to the PEL of lead chromates and the levels of total and respirable dusts were significantly high as well. High levels of hexavalent chromium, total dusts and respirable dusts were detected in every process at the work location.

DISCUSSION AND CONCLUSION

We assessed the inhalation exposure to hexavalent chromium of a patient who developed lung cancer and evaluated the likelihood that the patient's job history of 13.5 years as a spray painter caused his lung cancer. The powder coating that the patient used was found to contain hexavalent chromium, based both on our analysis of bulk samples and SDS information (Table 2). The current exposure level to hexavalent chromium (216.9 µg m^{-3}) assessed during spray painting with powder coating was found to be far higher than the MOEL-PEL for lead chromates (12 µg m^{-3}), even though current working conditions were generally regarded to have improved compared to those of the past. His past exposure level to hexavalent chromium can be assumed to be higher than that at present during spray painting. Also, we can estimate long term exposure that is approximately 37,480 µg yr (156.2 µg day × 240 working day) if he nor mally works.

Electrostatic powder coating as performed by this patient is one of the most common powder coating methods. Electrostatic powder coating uses an electrostatic charge generated in a spray gun aimed at a target in order to easily adhere to the surface of the target. The particle size of powder coating has become gradually finer through the advance of manufacturing technology, given that particle size is an important factor in the painting quality (Lothongkum *et al*., 2007). The fine particle size of powder coatings can contribute to elevating deposition into the lower part of the respiratory system among spray painters due to the fact that powder coating is mainly composed of particles of respirable size and may be easily aerosolized and dispersed during the process of powder coating painting (Mazumder *et al*., 1997). Sabty-Daily *et al*. (2005) reported that 71.8% of hexavalent chromium in paint spray aerosol may deposit in the airway region of a spray painter, and 2.0 and 1.4% of hexavalent chromium may potentially deposit in the alveoli and tracheobronchial region, respectively. This shows that powder coating containing hexavalent chromium may reach and accumulate in the alveoli. According to our exposure assessment

Table 2. The content (%) of hexavalent chromium (Cr^{6+}) in the quantitative analysis results and safety data sheets (SDS) for the sample of six powder coating products.

Manufacturer	Type of bulk product	This study	SDS
H	Green	*LOD*	*NI*
H	Apricot	*LOD*	*NI*
K	Yellow green	0.27	1–10
C	Gray	*LOD*	*NI*
C	Red	0.95	1–10
C	White	*LOD*	*NI*

[a] LOD: Limit of detection.
[b] NI: No information.

Table 3. The airborne levels of hexavalent chromium (Cr^{6+}), total suspended particulate (TSP) and respirable dusts.

Site sampled	Type of sampling	Distance from booth	Cr^{6+} (μg m^{-3})	TSP (mg m^{-3})	Respirable dust (mg m^{-3})
Spray painting [a]	Personal	-	216.9	Overload [c]	8.1
Cleaning	Personal	1 m	11.5	5.2	1.2
Outside booth	Area	1 m	2.8	1.9	0.3
Cleaning	Area	3 m	0.8	0.5	0.1
Entrance [b]	Area	10 m	0.5	0.2	0.1

[a] Spray painting with powder coating.
[b] Entrance of the powder coating painting factory.
[c] Over 10 mg/sample in a gravimetric analysis.

results, the patient was exposed to high levels of respirable dusts which mostly consisted of powder coatings (Table 3). These exposure characteristics may have significantly contributed to the development of his lung cancer.

The IARC reported that chromium pigments containing lead chromates, barium chromates and chromium oxide have been commonly used in paint for many years in order to produce various colors (IARC, 1990). This report did not clearly mention whether powder coating products contain hexavalent chromium compounds. Based on our results, yellow-green and red colored powder coating products contained 0.27% and 0.95% hexavalent chromium, respectively. Our results are supported by SDS information showing that 1–10% lead chromates were included.

The spray painting that the patient performed was classified as Group 1 among working group categories associated with lung cancer by the IARC (IARC, 2010). Several cohort studies also reported that the incidence of respiratory diseases, including lung cancer, among spray painters was significantly associated with the painting process (OPCS, 1971; Chiazze *et al*., 1980; Dalager *et al*., 1980; IARC, 2012). In addition, the IARC indicated that a main factor in lung cancer among spray painters was exposure to pigments containing zinc or lead chromates, which are products containing hexavalent chromium compounds (IARC, 1990, 2012). A multi-industry field study conducted from 1999 through 2001 by NIOSH found that about 62% of all US painters had been exposed to greater than 0.25 μg m^{-3} of hexavalent chromium as an eight-hour time weighted average (TWA) (Blade *et al*., 2007). These reports also suggest that lung cancer risk among spray painters is likely to be caused by high exposure to hexavalent chromium.

In South Korea, Kim *et al.* (2013) reported a lung cancer patient who performed painting in an automobile bumper shop and identified an association with exposure to hexavalent chromium (24 μg m^{-3}) during spraying gray and yellow paints, even though the workload of painting with yellow associated with hexavalent chromium was minor on a daily basis. In addition, NIOSH found painters who performed multiple tasks, such as spraying, sanding and clean up, were exposed to high levels of hexavalent chromium with a 16 μg m^{-3} eight-hour TWA (NIOSH, 2013). According to a study conducted by the US Air Force, the eight-hour TWA of strontium chromates among spray painters in the primer spray painting process was 179.9 μg m^{-3} (95% confidence limit: 107.3 μg m^{-3}–494.2 μg m^{-3}) (Carlton, 2003), which is similar to our exposure level (216.9 μg m^{-3}). These results cited above demonstrate that a spray painter can be exposed to a higher level of hexavalent chromium than the occupational exposure limit even when the spray painter only briefly conducts work related to exposure to hexavalent chromium.

Park *et al.* (2004) estimated the excess lifetime risk of lung cancer mortality for specified concentrations of hexavalent chromium. It estimated that exposure to 20 μg m^{-3} of hexavalent chromium caused a six-percent increase in lung cancer deaths over 45 years, which is comparable in the general population to the effect of smoking (6% increase in deaths). Over 13.5 years, the same cumulative exposure would result from 67 μg m^{-3} (20 × 45/13.5) of hexavalent chromium. This is far below the level of exposure to hexavalent chromium of the patient. Therefore, it is considerably more likely that the patient's lung cancer was caused by exposure to hexavalent chromium than by smoking.

Our patient reported wearing a general dust mask with low protective efficiency from the fine powder coatings (Fig. 3(b)). The patient was also found not to be trained in correctly wearing the dust mask. Overall fit factors of the general dust mask which is currently available in the domestic market were not outstanding for workers who are not trained in their use (Kim *et al*., 2013). Such dust mask use does not provide sufficient prevention of exposure to hexavalent chromium. In addition, prior to working as a spray painter, he had worked for approximately 24 years at various construction sites where lung cancer carcinogens such as crystalline silica or asbestos might exist (Koshinen *et al*., 2002; Rappaport *et al*., 2003; Engholm and Englund, 2005; Tjoe Nij and Heederik, 2005). He was likely exposed to several lung cancer carcinogens, such as crystalline silica or asbestos, over the approximately 24 years at various construction sites prior to assuming a job as a spray painter. However, this exposure was not estimated in this study due to a lack of exposure information.

We can conclude that he was substantially exposed to several lung cancer carcinogens, including hexavalent chromium, over approximately 37.5 years: a high level of hexavalent chromium exposure for 13.5 years as spray painter and direct or indirect exposure to crystalline silica and asbestos for 24 years as construction worker. These past exposure characteristics to carcinogens over the job history can be significantly associated with the development of lung cancer. Particularly, exposure characteristic to hexavalent chromium could substantially contribute to the development of his lung cancer, despite of the sole case of exposure assessment.

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