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REVIEW ARTICLE

Occupational Exposure Assessment of Chromium (VI): A Review of Environmental and Biological Monitoring

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ABSTRACT

Chromium (VI) compounds are used in various industries like metal coatings, protective paints, dyes and pigments for their properties especially anti-corrosive ones. Exposure to Cr (VI) may induce cancer, and cause irritation or damage to the respiratory tract, eyes, and skin. In addition, it may lead to mutagenic, genotoxic, and reproductive effects on humans. Workers are often exposed to airborne Cr (VI) via the inhalation of dust, fume or mist. There are various procedures for Cr (VI) exposure assessment as part of risk characterization and implementing a monitoring program. Analysis of chromium in environmental or biological samples must be considered. Air sampling and chromium analysis by different instruments and techniques, biological monitoring by different procedures to detect biomarkers, investigation of carcinogenicity and genotoxicity mechanism, medical examinations, and occupational exposure limits in workplace air and biological matrices are the important factors to be considered in the risk assessment strategy of Cr (VI). The purpose of this article was to review the literature and provide useful information about different methods for environmental and biological monitoring of chromium (VI) in order to assess quantitatively the risk of exposure to this compound.

KEYWORDS: *Chromium (VI), Exposure assessment, Sampling and analysis, Biological monitoring*

INTRODUCTION

Chromium (Cr) is classified as a heavy metal usually found at work environment and industrial wastewater of metal processing sites, plating industries, textile, leather tanneries, agricultural fertilizer, paint, steel, iron mill, fireproof products, chromate, and chromate pigment, welding, and so on [1-5]. Some of the jobs in which workers may be exposed to chromium (VI) are listed in Table 1 [2]. The elemental chromium is found with different valence states from -4 to +6 [6]; out of them, metal Cr (0), Cr (III) and Cr (VI) are more common. Chromium (VI) is usually found in natural aquifers, while Cr (III) is commonly found in urban wastewater which is rich in organic material [1,7-8].

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Comparing with Cr (III), the toxicity of Cr (VI) is higher, up to 100 times; it is also a carcinogen agent and induces mutation. This element affects the liver, kidney, and lung [1, 9]. Like many other contaminants, Cr (VI) is emitted as particles or mists at work environment and its main exposure route is inhalation [10]. Somewhat, due to the lack of adequate exposure information, the health effects and exposure control studies for Cr (VI) are not addressed in workplaces. Therefore, following the ascending trend of chromium use since industrial revolution, it is necessary to monitor and quantify workers' exposure to this hazardous agent [11].

Chromium (VI) Exposure Limits: According to the American Conference of

Governmental Industrial Hygienists (ACGIH), Threshold Limit Value-Time Weighted Averages (TLV-TWA) for eight-hour exposure to Cr (VI) are 0.050 and 0.01mg/m^3 for soluble and insoluble fractions, respectively. Moreover, the both forms of chromium are classified in "A" class of carcinogen agents [12-14]. The 8-h exposure limit to Cr (VI) according to OSHA and NIOSH are 0.005 and 0.0002 mg/m^3, respectively. Occupational exposure limits for Cr (VI) compounds can be seen in Table 2 [15-16].

United States Environmental Protection Agency (U.S.EPA) used a mathematical model to estimate the probability of a person developing cancer from continuously breathing air containing a specified concentration of Cr (VI). The EPA calculated an inhalation unit risk estimate of 1.2×10^{-2} (μg/m^3)$^{-1}$. According to this agency, the risk of developing cancer is no more than one-in-a-million for one is exposed to average of 0.00008 μg/m^3 airborne chromium over lifetime. In addition, EPA demonstrates that the cancer risk would not increase greater than one-in-a-hundred thousand and one-in-ten-thousand for one exposed to 0.0008 and 0.008 μg/m^3 of chromium during lifetime, respectively. According to EPA, the Reference Concentration (RfC) that signifies the amount of chromium (VI) particles with no significant risk of noncancer effects during lifetime is 0.0001 mg/m^3 based on respiratory effects in animal studies. Accordingly, the human studies on respiratory effects indicate that the RfC is 0.000008 mg/m^3 for Cr (VI) [17] (Fig. 1).

Worldwide authorities have fixed more stringent requirements concerning Cr (VI) presence in drinking water (0.1 mg/l in the USA and 0.05 mg/l in Canada). Fortunately, modern technologies for purification of wastewater and water have been developed with the help of significant enhancement in economics and living standard [22-24] (Table 1, 2).

Table 1. Some Industries Where Occupational Exposure to Cr (VI) May Occur [2]

Battery manufacturers	Metal cleaners
Aircraft painters	Laboratory workers
Boiler scalers	Metal workers
Candle manufacturers	Painters
Cement workers*	Pottery glazers
Chemical workers	Refractory brink manufacturers
Chromate workers	Steel workers
Chromium platers	Textile workers
Crayon manufacturers	Wood preservative

*The concentration of Cr (VI) in portland cement is considered too low to pose a significant health risk and is, therefore, excluded from the scope of the chromium (VI) standards. However, workers are still at significant risk for skin irritation and dermatitis.

Table 2. U.S. occupational exposure limits for Cr (VI) compounds [12, 15-16] *

Agency	OEL	Cr(VI) compound(s)	8-hr TWA μg Cr(VI)/m^3
NIOSH	REL	All	0.2
OSHA	PEL		5.0
ACGIH	TLV	Water-soluble	50.0
		Insoluble	10.0
		Chromite ore processing	50.0
		Calcium chromate	1.0
		Lead chromate	12.0
		Strontium chromate	0.5
		Zinc chromate	10.0

*Specific Cr (VI) compounds such as calcium, lead, and strontium chromate may have distinct OELs

The aim of the present study was to review different sampling and analysis methods for environmental and biological monitoring of chromium (VI). Findings of the review can be helpful to quantify the workers' exposure accurately as well as assess the existing risk in order to select the suitable control measures at workplace.

Health effects of exposure to chromium (VI): Chromium (VI) is absorbed faster and easier than the other valences through inhalation, skin, and digestion. It is reduced to chromium (III) inside the body [25-26]. Lungs are the first organ in body affected, followed by kidney, liver, skin, and immunity system [26]. Like other heavy metals, Cr

(VI) is accumulated in kidney after absorption. The severe exposure to Cr (VI) and its accumulation in kidney results in renal tubule disorders [26-27]. The accumulation of chromium in proximal tubule of kidney leads to toxic effects on adjacent cells [26, 28]. Some international organizations such as IARC [29-31], EPA [32], and WHO [33] have proved the direct carcinogenicity of chromium (VI) in the lung cancer. In addition, occupational exposure to Cr induces other effects such as the skin hyperesthesia, nasal septal perforation [34-36], contact dermatitis [37-38], respiratory system allergy, liver and renal effects [34, 38-39], occupational asthma [40-41], cardiovascular effects [42], DNA mutation [43-44], and carcinogenic effects [39, 45-48]. In addition, there are evidence for accumulation of chromium in placenta [49], reproductive system disorder [50], chromosome aberrations [44, 51-52] and further damages to body organs (Fig. 2).

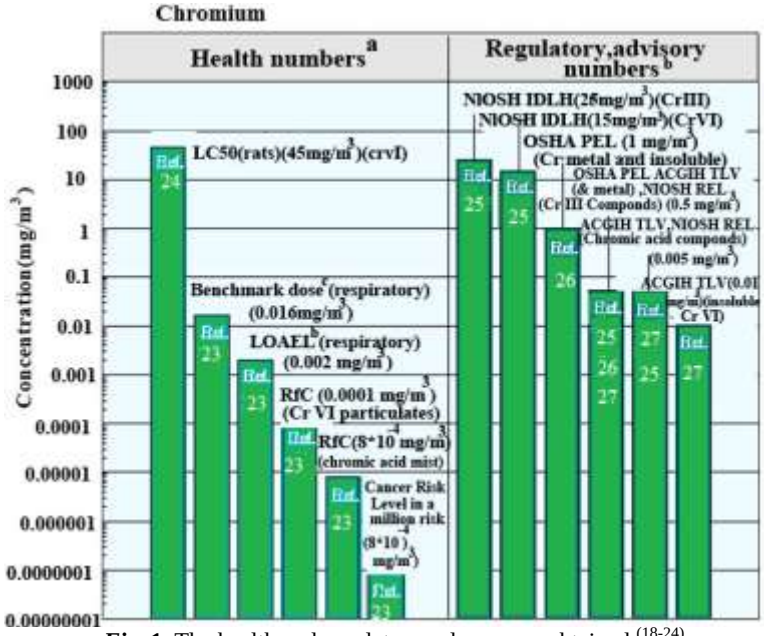

***Fig*. 1.** The health and regulatory values were obtained [18-24]

[a] Health numbers are toxicological numbers from animal testing or risk assessment values developed by EPA.

[b] Regulatory numbers are values that have been incorporated in Government regulations, while advisory numbers are nonregulatory values provided by the Government or other groups as advice. OSHA numbers are regulatory, whereas NIOSH and ACGIH numbers are advisory.

[c] The benchmark dose is from the critical study used as the basis for the EPA's RfC for Cr(VI) particulates.

[d] The LOAEL is from the critical study used as the basis for the EPA's RfC for chromic acid mists and dissolved Cr (VI) aerosols

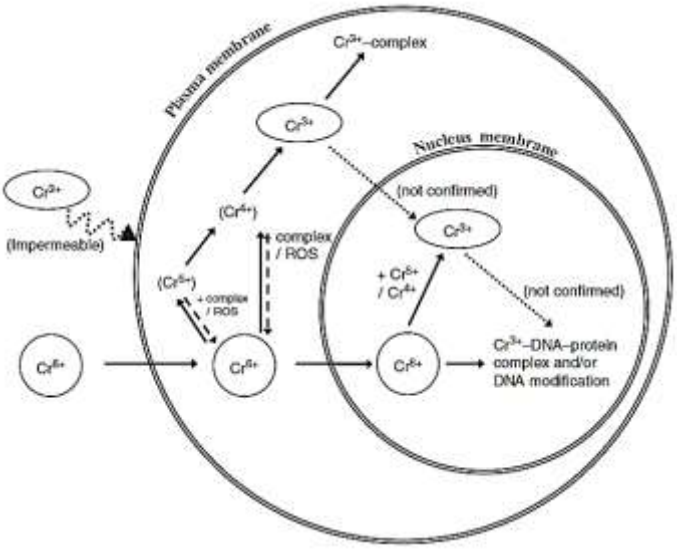

***Fig*. 2.** Schematic diagram of toxicity and mutagenicity of Cr (VI). The intracellular Cr (VI) reductants naturally available are frequently obligatory one electron reducers, which generate Cr (V) and a large amount of ROS that causes the deleterious effects of Cr (VI) [12]

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EXPOSURE ASSESSMENT AND MONITORING

Sampling and Analytical Methods for Cr (VI): Different analytical methods have been developed to determine hexavalent chromium (Cr [VI]) concentrations in workplace air. NIOSH Method 7605 for Cr (VI) determination in the laboratory and NIOSH Method 7703 for Cr (VI) determination in the field are available in the NIOSH Manual of Analytical Methods. Quantification of Cr (VI) at trace levels and its measurement in soluble and insoluble chromate compounds can be performed by these methods. NIOSH Method 7605, OSHA Method ID-215, and international consensus standard analytical methods can be used to determine exposure at the recommended exposure limit. American Society for Testing and Materials (ASTM) Method D6832-02, "Standard Test Method for the Determination of Hexavalent Chromium in Workplace Air by Ion Chromatography and Spectrophotometric Measurement Using 1,5-Diphenylcarbazide," is used for quantification of airborne Cr(VI) [53-55].

Factors Affecting Air Sampling Methods: A key factor in determining concentration of Cr (VI) is sampling duration. The longer the sampling duration have shown, the less the readable concentration [3, 56-58]. In a study on parameters influencing hexavalent chromium mist sampling, Cr (VI) mist had acidic properties throughout electroplating process, so it dries out in air with increasing the sampling duration [59]. Drying out the mist leads to the smaller particle size and higher acidity, reducing Cr (VI) to Cr (III) upon decreasing pH [55]. The sampling of chromium mist was studied and confirmed the mentioned phenomenon [57]. Increasing the sampling duration resulted in decreasing the measured concentration of chromium (VI) so that the reduction was greater with increasing the sampling duration. According to results, sampling for 30 min showed only 8% reduction of Cr (VI), while sampling for 120 and 180 min led to 19% and 23.1% reductions, respectively. Trivalent chromium is the most stable form of chromium, contrary to Cr (VI) with an average experimental half-life of 13 h in the air. In fact, the element is reduced to Cr (III) in presence of reductants such as organic and acidic agents and interfering factors. Thus, the shorter sampling duration causes the measured concentrations of Cr (VI) to be closer to true values, leading to reliable more results [3, 56-58].

Storage time is another important parameter to determine the concentration of Cr (VI). Cr (VI) concentration in samples analyzed immediately after sampling was higher than that of in samples with longer storage time [3-4, 56-57, 60]. The reaction between Cr (VI) and polymeric and algometric material in the sampling filter can be a reason for reduction of this element [4]. Collected mist had an acidic effect on the filter and increasing the storage time leads to reduction of larger portion of Cr (VI) because of its instability in acidic environment [3, 56]. The extractions of Cr (VI) were indicated after the storage times of 0, 24, 48, and 72 h are 90%, 82%, 81%, and 80%, respectively [60]. The concentration of Cr (VI), sampled on PVC filter, was reduced to 90.8% and 83.1% of its initial value, respectively [57]. Therefore, it is recommended to reduce sample storage time as much as possible to obtain reliable more results. In other words, decreasing the sample storage time may result in less serious problems due to the reduction of Cr (VI) to Cr (III).

The higher temperature leads to chemical more reaction and keeping the samples in the refrigerator is recommended by majority of standard sampling procedure, but inverse results were reported in respect of Cr (VI) [56, 61-62]. No significant differences between the samples were kept at ambient (20-25 °C) and refrigerator temperature (4°C) for 0-72 h [56]. They kept the samples in glass vials with PTEF caps and these different results may be related to no contact with air and interfering factors. The absorption of Cr (VI) ions on alginate calcium beads in temperatures ranging from 15 to 35 °C showed no significant differences [61-62]. These findings are inconsistent with Teixeira, Araujo [63], Shin, and Pike [57]. It was reported by Teixeira and Araujo [63] that the temperature in the range of 10-27 °C increases the absorption of Cr (III) on alginate calcium beads. Paike and Shin kept PVC filter impregnated with chromic acid solution in different conditions (at ambient temperature, capped vial at ambient air, capped vial at 4 °C, the basic solution in contact with air, basic solution at 4 °C) [57]. The maximum reductions reported for the samples at ambient temperature were 75.7% and 72% for 4 and 8 d, respectively. The observed differences may be due to the direct contact of filter with ambient air leading to faster drying out of it, storing the samples for long time (more than 3 d) and adding basic solution to the filter to decrease the reduction of Cr (VI). Given the inconsistency between different studies about the effect of storing temperature on decreasing the reduction of Cr (VI), it is recommended to examine the effect of various parameters like adding oxidative agents to the filter to avoid reduction of Cr (VI) during storage time.

The filter type is another effective parameter to determine the concentration of Cr (VI). According to health safety executive (HSE) directions [64], OSHA [65], NIOSH [66], and Golbabaei et al [56], PVC and BQFF filters (Binderless Quartz Fiber Filters) should be used for Cr (VI) sampling. There is the minimum risk of Cr

(VI) reduction when these filters are used. BQFF filters were introduced as the best option in comparison with PVC filters. BQFF filters showed more efficiency (97.9±1.45) than PVC ones (94.98±5.6) [56]. The BQFF filters have the other advantage. There is no static charge during taking this type of filter out of the cassette. The electrostatic charge accumulates between the PVC filter and polystyrene cassette that may cause a portion of Cr (VI) to cling to the sides of the cassette instead of the filter. Anyway, the reduction of Cr (VI) is inevitable with increasing the sampling time when the BQFFs are used. A drawback of BQFF is a need for centrifuging the solution extracted from the filter for 10 min. This step is not required for the PVC filters and their preparation is simpler and shorter. On the other hand, HSE reported that because of the hydrophobicity of PVC filters, there are some difficulties to rinse them completely with acidic solutions, resulting in problems with the extraction of Cr (VI) from the filter [64]. In addition to the impact of ambient air on drying out the chromium mists, air passing through the filter can also be effective in this case [56]. Consequently, BQFFs are relatively better than PVC filters. Nevertheless, the reduction of Cr (VI) is inevitable with increasing the sampling duration and storage time on the filters that it should be taken into account when using BQFF.

The effect of humidity on performance of respirators' filters to absorb Cr (VI) has been reported by some studies. The lower the humidity the higher the performance was reported [5, 67-70]. The competition of air moisture content with Cr (VI) mist and decreasing the electrostatic force required for particulate removal can lead to reducing the filter performance. However, the filter material and the high electrostatic charge play more roles that are effective in the filtration of aerosols in comparison with the relative moisture of air and the sign of existing charge [71]. The relative humidity has a negative impact on the performance of filters to remove the Cr (VI) mist; so better performance is expected at the lower humidity.

Some parameters may affect determining the Cr (VI) concentration, such as the particle size distribution, uniform or non-uniform emission of particles, air flow rate and its direction, flow rate through the sampler inlet, geometry and diameter of the inlet and the probability of particles settling on the filter medium, sampler material (to be conductive or not, electrical charge) [72].

The effect of operational factors was studied on the distribution of Cr (VI) [56, 73-76]. Golbabaei et al. [56] investigated two welding types including the Shielded Metal Arc Welding (SMAW) and Gas Tungsten Arc Welding (GTAW). The operational factors like electrode diameter, flow rate of shield gas, type of base metal and type of consumed electrode were considered. The sampling was performed by closed-face filter cassettes based on NIOSH method. The percentage of consumed electrodes is significantly correlated to the emission of Cr (VI) in both of welding types. The finding did not confirm the effect of electrode diameter, the flow rate of shield gas, and type of base metal. Under the constant conditions, the electrode type is the main factor affecting the Cr (VI) concentration, so that using the electrode types containing Cr (VI) significantly increases the concentration of this element [56]. In steel welding process the evaporation of the base metal generates only 10% of total welding fumes [73]. Large portion (60%-90%) of chromium emitted from shielded metal arc welding is soluble Cr (VI) [74]. The concentration of Cr (VI) is a function of shield gas flow rate [75]. Despite the inconsistency between studies, different findings have indicated the consumed electrode is the main factor in emission rate of Cr (VI). Furthermore, operational parameters and process type should be considered in comparing the results of different studies.

Instrumental Analysis of Chromium (VI)

Among different methods introduced to determine Cr (VI), atomic absorption spectrometry is one of the most commonly used [76-79]. Other elemental analytical methods to analyze Cr (VI) are mass inductively coupled plasma mass spectrometry (ICP-MS) [80-82], inductively coupled plasma atomic emission spectrometry (ICP-AES) [83-85], X-Ray Fluorescent [86], charged particle X-ray emission spectrometry, and neutron activation analysis [87]. The ICP-AES is a powerful system for elemental analysis. ICP-AES have used in studies on Cr (VI) [88-89].

Atomic absorption spectrometry and ICP-MS have been recommended by NIOSH 7024 and 7300 to detect the airborne Cr (VI) [90]. These methods are also effective for determining total chromium content [84]. Spectrophotometric [91] and colorimetric methods [92] are also suggested to determine the Cr (VI) [93-94, 58]. The most common colorimetric technique is chromium selective reaction using 1 and 5-diphenylcarbazide (DPC) under the acidic condition [87]. In this method, Cr (VI) is reduced to Cr (III) and forms a red complex in reaction with DPC determined using UV-VIS spectroscopy [95]. The reasonable cost is the main advantage of UV-VIS spectroscopy but some interfering factors may cause problems with analyzing Cr (VI) [96].

Several studies have used high-performance liquid chromatography (HPLC) in combination with GFAAS [97], FAAS [98-99], ICP-MS [100-101], ICP-AES [74, 102], and UV-VIS spectroscopy [73] for determining the Cr (VI). HPLC is one of the most powerful techniques for separation that in combination with element selective detectors leads to faster, easier, and more

accurate results, and attenuates losing and contamination of samples [85]. In addition, electrochemical methods such as voltammetry especially stripping voltammetry are prevalent methods to analyze the Cr (VI) [103-104]. Turyan and Mandler used self-assembled monolayer-based Cr (VI) ion selective electrode to determine this element [105].

Supported liquid membranes (SLM) is used to extract ionic contaminants such as Cr (VI) from industrial effluents [106] and ground water [107]. In some investigations, SLM based methods have been also used for chromium speciation in natural water. In these cases, two series connected SLM were used [108]. In the past, ultrasonic extraction methods were used for extracting Cr (VI) from solid samples [103, 109].

Ion chromatography method is widely used to detect Cr (VI) [110-111]. This method has been explained in detail in ASTM D5281-92, D 5281-92 [112], EPA 218.6 [113] and EPA 3060A [114], NIOSH 7604 [90].

The different techniques used in various surveys were listed for chromium determination, including atomic absorption furnace and flame spectrometry (23%), ICP-AES (2.5%), different combined techniques (9%), UV-VIS spectroscopy (33%), and chromatographic techniques (11%) (Fig. 3) [114-115].

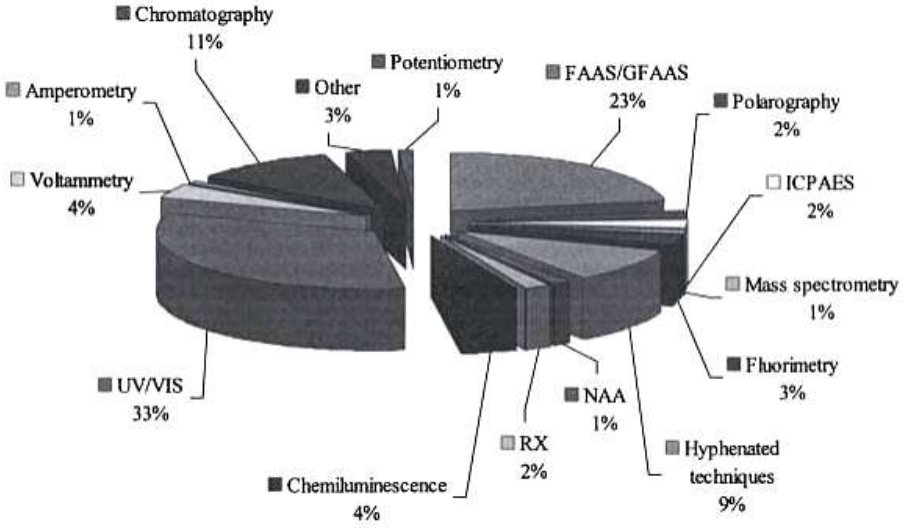

Fig. 3. Different techniques used to determine Cr (VI) and Cr (III) [(139)]

BIOLOGICAL MONITORING OF CR (VI)

Biomarkers of exposure: Biomarkers of exposure give an indication of the toxic substance or its metabolites in the body and can be used as measures of their internal doses [116]. Biomarkers indicate the presence of chemical elements affecting the biological mechanisms of living beings. Biomarkers are the observable indicators in a chain of events caused by exposure to environmental factors [117]. They can also be used to evaluate the intensity and duration of exposure, the effectiveness of control measures and the symptoms at early stage of diseases [118].

Some of biological markers determine the level of Cr(VI), while the others determine level of chromium based on changes in distribution of Cr (III) and (VI) in different body organs. Inhalation is the primary way of exposure to Cr (VI). After entering, the inhaled Cr (VI) may accumulate in the respiratory system, reduce or enter bloodstream. It may be reduced to Cr (III) inside the lung or plasma and excreted in the urine. However, the unreduced portion of Cr (VI) may enter lymphocytes and erythrocyte [119]. Therefore, the distribution process of chromium can result in its monitoring in the urine, whole blood, plasma, blood cells, expired air, hair, and nail. Among these, increase of chromium content in the blood and urine is more reliable biological indicator [120-121]. According to IOM [122] the urinary concentration of chromium is 2-3 nmol/l (0.10-0.16 µg/l), and the mean of urinary excretion of chromium is 0.22 µg/l (0.2µg/day). The concentration of chromium is 0.01-0.17 µg/l (mean of 0.06 µg/l) in serum [123], 0.24-1.8 µg/l (mean 0.4 µg/l) in urine [124], and 0.234mg/kg in hair [125].

Measurement of chromium in urine: Chromium level in urine is a measure of exposure to total chromium as Cr (VI), reduced to Cr (III) in the body. Lindberg and Vesterberg measured the level of urinary chromium in plating workers and concluded that there was an obvious increase in the

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level of this element in urine [126]. The level of chromium in body fluids such as urine, serum, and even erythrocyte is a reliable marker of exposure to Cr (VI) [127, 130]. The concentration of chromium was measured in erythrocyte, plasma, and urine of 103 welders and found that their urinary chromium concentration (5.40-229.4 µg/l) was 5 to 200 times higher than the unexposed persons [131]. The chromium level was measured among dichromate production workers and found a relationship between exposure to chromium, urine, and blood chromium concentration [132].

A high correlation was found between workplace chromium concentration and post-shift urinary chromium among welders [133]. The urinary chromium was 40-50 µg/L representing the occupational exposure to 50 µg Cr/m^3. In addition, studies have found the significant correlation between concentration of airborne chromium and blood/urinary chromium level among workers of chromium alloy production [134]. Individual differences in reducing Cr (VI) have also been confirmed; so that the concentration of urinary chromium varies between individuals with different physical states. Therefore, the concentration of urinary chromium might not be a reliable measure of occupational exposure [119].

Measurement of chromium in blood, blood cells, and plasma: The level of chromium in plasma and whole blood are markers of exposure to total chromium, considering the reduction of Cr (VI) to Cr (III). Intra-cellular chromium level is the marker of exposure to hexavalent chromium, because contrary to the Cr (III), Cr (VI) diffuses readily through the cell membrane [135]. The monitoring of chromium in blood cells has two advantages over urinary analysis; the sampling time is relatively independent of exposure duration and the Cr (VI) can be measured specifically instead of total chromium [136, 137]. Various variables may influence the level of chromium in the blood including diet, the individual physical state to reduce the Cr (VI) and the type of occupational exposure. Thus, the high chromium level in blood plasma may indicate either exposure to chromium or inability of body to reduce the Cr (VI) [138]. There is an increased level of Cr (VI) in plasma and erythrocyte in workers exposed to that [127,131].

Biomarkers for evaluating the organic effects of Cr (VI): The exposure to chromium affects the various organs of body such as respiratory system [139-141], liver [142-143] gastrointestinal tract [144], hematological [145], immunological [146-147], endocrine [148], skin [149-150], eyes [34], metabolic [151], neurologic [139,152], and reproduction systems [153-154], and the body weight [155]. Although chrome is not the only element that may induce such effects, these can be further evaluated by physical tests and experiments. Renal system is one of the systems influenced by chromium. The concentration of special proteins and enzymes in urine are the initial signs of exposure to Cr (VI). Liu et al. [156] measured level of N-acetyl-ß- glucosaminidase (NAG), ß2-microglobulin (ß2M), whole protein, and urinary microalbumin among the workers at chromium plating site. They were exposed to high level of airborne chromium (geometric mean of TWA: 4.2 µg Cr/m^3), and the highest level of urinary NAG (geometric mean: 4.9 IU/g creatinine). While there was no change in other biomarkers level, NAG level was significantly high among hard chromium plating workers. Comparing with control group, workers in a chromate industry showed higher level of brush border protein and retinol-binding protein in urine [157]. Depending on intake dose of Cr (VI) and its accumulation in the kidney, damages to organs varies from slight proteinuria to aminoaciduria. The β2Mu is a protein (molecular weight: 12 KD) produced in lymphatic systems and easily filtered by glomerular filtration system due to its light molecular weight. Under the normal condition, β2Mu is reabsorbed by renal tubules, so the presence of this protein in urine is a symptom of malfunction of filtration or reabsorption functions [158].

N-acetyl-beta-glucose aminidase (NAG) is an enzyme (molecular weight: 140 KD) primarily produced by lysosomal in the proximal tubule cells of kidney. This marker cannot be filtered by renal glomerular system and its level increase in urine in case of any tubular cells damage due to exposure to Cr (VI) [119, 146]. The mean concentration of chromium and NAG in urine of workers is a reliable marker of exposure to Cr (VI) and consequent damages to kidney [158-161]. On the other hand, the concentration of urinary β2M is not sensitive enough to monitor exposure to chromium (VI) mist and damages to kidney [160, 162, 27]. These findings are not consistent with those by Lindberg and Vesterberg [126] in this case. The exposure duration to chromium per shift and concentration of exposure may explain the different results. For instance, exposure duration in the study of Golbabaei et al. [160] was 8h/day and the average level of urinary chromium was 9.5 µg Cr/m^3. These findings in Lindberg and Vesterberg [126] were 12h/day and 24.5 µg Cr/m^3. The mean concentration of chromium and NAG in urine of workers exposed to chromium mist can be taken as a reliable marker of exposure to Cr (VI) and consequent damage to kidney, while under the same condition, urinary concentration of β2M has no enough sensitivity for monitoring the exposure to Cr (VI) and renal damage by this contaminant. The cytotoxicity mechanism of Cr (VI) is not completely clear, although many studies have demonstrated Cr (VI) exerts some biological

mechanisms like oxidative stress, DNA damage, apoptotic cell death, and altered gene expression [163].

CONCLUSION

Chromium (VI) is very hazardous element and causes different adverse health effects as lung cancer in humans. In this review article, different aspects of the quantitative risk assessment of Cr (VI) were described based on literature. Although there are various techniques for evaluating and monitoring of Cr (VI) in air samples and biological matrices, selecting the proper ones depends on some parameters considered when sampling and analysing Cr (VI). Among the factors affecting air-sampling methods, collecting samples in shorter period, decreasing the sample storage time, using PVC and BQFF for sampling preferably in lower humidity are recommended. In addition, the spectrophotometric and electrochemical techniques may be the useful and proper ones to analyse the Cr (VI) in routine cases like workplace assessments. The blood and urine are more reliable and available biological matrices for biological monitoring of chromium (VI). In addition, the concentration of chromium and NAG enzyme in urine is an appropriate marker of exposure to Cr (VI) and consequent damages to kidney. Finally, proper information should be provided for workers about hazards of their work and employers must be informed about industrial hygiene programs at workplaces and quantitative risk assessment in workers exposed to hazardous compounds.

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The authors declare that there is no conflict of interests.

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