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From biomonitoring studies to lowered occupational exposure limits for hexavalent chromium

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ABSTRACT

Occupational exposure to the carcinogen hexavalent chromium [Cr(VI)] occurs during stainless steel production, welding, and chrome plating. Two sister-projects, SafeChrom and SAM-Krom, were initiated in Sweden and Denmark, respectively, to inform stakeholders, decision-makers and regulators on current occupational exposure to Cr(VI), and preventive measures prior to revision of national occupational exposure limits (OELs) for Cr(VI). Both studies were cross-sectional, involving exposed workers and controls. Cr(VI) exposure was assessed as inhalable Cr(VI), urinary Cr and Cr(VI) content in red blood cells. Both studies found increased air Cr(VI) concentrations associated with increased levels of urinary Cr and Cr(VI) in red blood cells. Air levels of Cr(VI), urinary Cr and blood levels of Cr(VI) were highest among Danish chrome platers. Furthermore, Cr(VI) exposure levels exceeding Danish OEL were found for trainees performing welding at a vocational school. Interviews with managers at Swedish workplaces indicated that OELs have an important role as baseline for acceptable exposures, but revealed low awareness of the socio-economic trade-offs for the Cr(VI) OELs. The two studies enabled evidence-based decision-making resulting in lower Cr(VI) OELs in Denmark and Sweden in 2025–2026, highlighting the value of a coordinated Nordic collaboration and stakeholder engagement in supporting evidence-based regulation.

Societal impacts

Stainless steel is an iron-based alloy containing at least 10.5 % chromium. Occupational exposure to hexavalent chromium [Cr(VI)] occurs during stainless steel production, but also during welding and chrome plating. In the 1990s, it was estimated that around 21,000 workers in Sweden were occupationally exposed to Cr(VI). Similarly, in a recent report, it was estimated that 10,300–21,500 Danish workers were exposed to Cr(VI) [1]. Cr(VI) has been recognised as a carcinogen since the early 1970s, and was classified as an occupational carcinogen by the International Agency for Research on Cancer (IARC) in 1990. In 2017, SCOEL published a risk assessment of Cr(VI) [2] based on a systematic review [3], suggesting relatively high risk estimates for cancer risk as compared to the European OEL (10 μg/m^3) and the national OELs (5 μg/m^3) in Denmark and Sweden at that time.

It has been estimated that exposure to air concentrations of 5 μg/m^3 corresponds to 20 extra lung cancer cases per 1000 exposed workers after 40 years of occupational exposure (i.e. lifetime risk) [3]. In Germany and the Netherlands, acceptable risk is considered to be an additional risk of < 4 cases per 100,000 after 40 years, and tolerable risk (during a transitional period) is considered to be < 4 per 1000 [4]. Recently, these levels have also been adopted by the Advisory Committee on Safety and Health at Work as a low to high risk level range, within which future EU OELs should be set [5].

In Denmark and Sweden, the OELs are set by the respective working environment authorities and in Denmark enforced by the Minister of

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Employment. In both countries, the OELs are often based a negotiation with the Social Partners based on scientific evidence regarding health-based risk estimates and consideration of technical and economic aspects, resulting in OELs that reflect a trade-off between health-based and technical and economic aspects. In the beginning of our research projects, the Danish OEL for Cr(VI) was lowered from 5 μg/m^3 to 1 μg/m^3 on July 1st, 2020 (https://bm.dk/nyheder/pressemeddelelser/2020/02/graensevaerdi-for-chrom-6-i-arbejdsmiljoeet-skaerpes/), whereas the Swedish OEL was still 5 μg/m^3.

The two sister-projects SafeChrom and SAM-Krom were initiated in 2021 and 2019 in Sweden and Denmark, respectively. Their aim was to inform stakeholders, decision-makers and regulators on current occupational exposure to Cr(VI) and occupational preventive measures prior to revision of the national OELs for Cr(VI). The Swedish SafeChrom study was funded by the Swedish Research Council FORTE and Afa Insurance, and SAM-Krom was funded by the Danish Working Environment Research Fund in response to a specific call. Here, we describe how SafeChrom and SAM-Krom supported the lowering of OELs, and thereby reducing the risk of occupational cancer.

Methodology

SafeChrom was a cross-sectional study of Cr(VI) exposure in the Swedish work environment, and was carried out by all seven Occupational and Environmental Medicine clinics in Sweden in collaboration with their corresponding university divisions. SafeChrom recruited non-smoking men and women from 14 companies with potential Cr(VI) exposure (n = 113), and controls from six companies without Cr(VI) exposure (n = 72) [6]. SAM-Krom was a cross-sectional study carried out by NFA, FORCE Technology, the departments of Occupational and Environmental Medicine, Copenhagen University Hospital and Occupational and Social Medicine, Holbæk University Hospital. The study included 60 volunteers, including 24 in company controls, recruited from six companies and one vocational school, all with possible Cr(VI) exposure [7]. The occupational exposure assessment, along with the sampling of air, blood, and urine were performed by standard operating procedures (SOPs) used by all partners in SafeChrom and SAM-Krom. To ensure comparability, the study designs were harmonized as much as possible with the HBM4EU study [8].

Cr(VI) exposure was assessed by air measurement in the inhalation zone of Cr(VI) exposed workers, by stationary monitors for office workers and as chromium content in red blood cells. Chromium content in red blood cells is a biomarker of Cr(VI) exposure over the last four months, as only Cr(VI) is able to pass through the cell membrane of red blood cells. Total chromium, also including Cr(III), was assessed in pre- and post-shift urine as a biomarker of Cr(VI) exposure during the working day or in post-shift samples only. The biological samples were collected after three to four days of work. Genotoxicity was assessed by measurement of micronuclei in peripheral blood reticulocytes, telomere length, mitochondrial DNA copy number, oxidative DNA damage, and epigenetic changes (the latter only in SafeChrom). In SafeChrom, representatives of the workplace management were interviewed before and after measurements about perception and operationalisation of regulatory requirements regarding Cr(VI) exposure [9,10]. The use of occupational safety and health (OSH) risk prevention measures in the SAM-Krom study were assessed through triangulation of interviews, a questionnaire and systematic observations [7].

The SafeChrom study continuously informed the Swedish Working Environment Authority throughout the project duration. The SAM-Krom study had a National Advisory Board consisting of the Danish Working Environment Authority, the Danish Environment Protection Agency, Department of Occupational and Environmental Medicine, Bispebjerg Hospital, Copenhagen University, ATV SEMAPP and from the social partners: Danish Industry (employer organisation), The Confederation of Danish Employers, Employees organisations: FH (https://fho.dk/), 3F (https://www.3f.dk/english), Dansk Metal (https://www.danskmetal.dk/) and CO-Industry (https://www.co-industri.dk/).

Results and implications

The Swedish SafeChrom study showed that average air concentrations of Cr(VI) (geometric mean) of 0.15 μg/m^3 (95 % CI: 0.11–0.21) were associated with increased levels of Cr(VI) in red blood cells, and increased levels of urinary chromium [6]. For eight of the 113 exposed workers (7 %), the Swedish OEL of 5 μg/m^3 was exceeded, and analysis with the Bayesian tool ExpoStats estimated the share of OEL exceedances be on average 8.8 %, with a 95 % credible interval upper limit was 19.6 % for stainless steel welders [6]. Workers within steel production showed the highest concentrations of inhalable, urinary and red blood cell chromium. Furthermore, both those working in bath plating companies and those working with manufacturing/processing of metal products, i.e. mainly welders, had statistically elevated urinary chromium levels as compared to controls (Table 1). Workers with inferred non-acceptable local exhaustion ventilation showed significantly higher inhalable Cr(VI), urinary and RBC chromium concentrations compared with those with inferred acceptable ventilation [6].

Based on the Swedish job-exposure-matrix, where the impact of demands in authorization and restrictions under REACH was taken into account in the estimates, approximately 17,900 Swedish workers were estimated to be occupationally exposed to Cr(VI) today (6). Self-reported perceptions Cr(VI) exposure-related risk among participating workers did not correlate with their measured Cr(VI) exposure levels [10]. Interviews with managers at the Swedish workplaces indicated that OELs have an important role as a baseline for acceptable exposures. However, there was low awareness of the socio-economic trade-offs in the Swedish OELs among managers [9,10]. These findings emphasise the need for continuously updated OELs that reflect risk acceptance levels and current protective standards as well as robust exposure assessments to inform workplaces' risk management. Increased levels of biomarkers of cancer risk (oxidative stress, telomere length and epigenetic changes) [7,11,12] were found with increasing Cr(VI) exposure, highlighting the exposure-related health risks.

The SAM-Krom study in Denmark demonstrated significant occupational exposure to Cr(VI), particularly among chrome platers, and in spite of relatively high compliance with OSH preventive measures [7]. Thus, the geometrical mean for Cr(VI) in the air was 0.26 μg/m^3 (95 % CI: 0.12–0.57) for all potentially exposed workers, 0.81 μg/m^3 (95 %CI: 0.46–1.40) for the exposed workers at bath plating companies (Bath plating) and 0.13 μg/m^3 (95 %CI: 0.04–0.41) for employees within

Table 1
Comparison of post-shift urinary Cr in employees within 'Bath plating' (mostly chrome platers) and 'Manufacture/processing of metal products' (mostly welders) in the SAM-Krom and SafeChrom studies with biological limit values corresponding to different occupational exposure limits and in persons not exposed to Cr(VI).

	BLV or median density adjusted urinary Cr content in μg/L, (P5, P95)	OEL or Cr(VI) air concentration as geometric mean, μg/m^3 (95 %CI)
French BLV and OEL	2.5	1
Finnish BLV and OEL	~ 10	5
Bath plating in SAM-Krom (N = 9–11)	4.15 (1.96, 42.63)	0.81 (0.46–1.40)
Manufacture/processing in SAM-Krom (N = 13–15)	0.62 (0.26, 4.11)	0.13 (0.04; 0.41)
Bath plating in SafeChrom (N = 17)	0.72 (0.10, 19.78)	0.16 (0.07–0.35)
Manufacture/processing in SafeChrom (N = 56)	0.53 (0.12, 2.49)	0.13 (0.07–0.23)
Controls in SafeChrom (N = 72)	0.10 (0.06, 0.56)	N.D.

manufacture/processing companies (mostly welders). Furthermore, we measured Cr(VI) exposure levels (GM: 3.69 μg/m^3, 95 %CI: 1.47–9.25) for trainees performing MMA welding at a vocational school. In addition, the Cr(VI) content in red blood cells as well as urinary chromium levels were statistically significantly increased for chrome-platers, but not for employees within manufacture and processing, as compared to within company controls (Table 1). Furthermore, Cr(VI) exposed worker had significantly increased levels of micronuclei, a biomarker for cancer risk [7]. The difference in Cr(VI) exposure in bath plating companies in Denmark and Sweden probably reflects differences in safety culture at the work places.

Comparison of the urinary chromium levels of chrome platers to the French and Finnish biological exposure limits for Cr(VI), showed that the urinary chromium levels were higher than the biological limit value corresponding to the observed Cr(VI) levels in the air (Table 1). This suggested that other exposures routes in addition to inhalation (i.e. skin exposure and/or hand-to-mouth) contributed to the observed Cr(VI) exposure levels. Thus, the Sam-Krom study results indicated that Danish chrome platers were occupationally exposed to Cr(VI) by inhalation and by other exposure routes, while no statistically significant effects were observed for welders. In the previous mapping of Cr(VI) exposure in Denmark [1], chrome platers were estimated to constitute only 10–49 of the estimated 10,300–21,400 potentially Cr(VI) exposed workers, while welders were estimated to constitute the majority (5 000–20 000 workers) of potentially Cr(VI) exposed workers. Thus, the highly exposed chrome platers only constitute a minor fraction of the Cr(VI) exposed Danish employees, while the majority of Cr(VI) exposed workers were exposed at much lower exposure levels (Table 1).

The first SafeChrom results were published on Dec 5, 2023 [5]. The SafeChrom study informed the Swedish Working Environment Authority in Sept 2022 and Sept 2023 about the results of the study, and held workshops for the trade organisation and the companies in April, 2024, as well at the national meeting in Occupational and Environmental Medicine in May, 2024. The study participants were informed after the first study [5] was published via letters informing about their individual blood and urine chromium levels, as well as the main results of the study. The Swedish OEL for Cr(VI) is set to be lowered to 1 μg/m^3 on April 9, 2026, and SafeChrom results were specifically drawn upon to show that the new lower OEL is achievable for Swedish workplaces, as 82 % of the air measurements were below the new OEL of 1 μg/m^3.

In Denmark, the Employment Committee of the Danish Parliament was informed about the Swedish SafeChrom by the Danish Minister of Employment when the study was published (https://www.ft.dk/samling/20231/almdel/BEU/bilag/272/2908997.pdf). The National Advisory Board of the Danish SAM-Krom study were also informed at the same time.

In the Sam-Krom study, for ethical reasons, all employees at the Danish chrome plating companies were informed about their occupational exposure to Cr(VI) as soon as the data were analysed, and prior to the scientific publication of the results primo 2024. The Danish Minister of Employment, the Employment Committee of the Danish Parliament, the Working Environment Authority and the members of the National Advisory Board were also confidentially informed about the results at the same time. The Employment Committee of the Danish Parliament and The National Advisory Board of the SAM-Krom study were officially informed on the day of publication of the study (September 2024). The Danish OEL for Cr(VI) was subsequently lowered to 0.25 μg/m^3 on Jan 1st, 2025. The lowered OELs in Sweden and Denmark are in alignment with the EU decision of a 4:1000 tolerable cancer risk level (corresponding to 1 μg/m^3 Cr(VI) in air).

Both studies underscore the need to focus on applying the upper levels of the hierarchy of controls in reducing occupational exposure to Cr(VI) through eliminating or substituting Cr, more effective technical solutions (e.g. automation and use of local exhaust ventilation), as well as organizational solutions. The worker-focused measures, such as use of respiratory protective equipment (RPE), should be used only to supplement the other solutions in reducing occupational exposure to Cr (VI), and should be preceded by individual fit tests for RPE. In addition, focus should include other exposures routes in addition to inhalation such as through skin exposure and/or hand-to-mouth.

In conclusion, the current study illustrates that for hazardous chemical occupational exposures, close collaboration and harmonised efforts between Nordic countries in combination with active engagement and dialogue with stakeholders may enable evidence-based decision-making resulting in legislative measures. It also shows the importance of having up-to date OELs, as these have a strong signal value regarding acceptable exposures, and the importance of following the hierarchy of control in order to reduce the exposure to Cr(VI) in the workplace. Finally, it demonstrates the necessity to investigate early biomarkers related to cancer risk below the OEL.

CRediT authorship contribution statement

Zheshun Jiang: Data curation, Formal analysis, Writing – review & editing. **Anne Thoustrup Saber:** Writing – review & editing, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Karin Broberg:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Pete Kines:** Writing – review & editing, Methodology, Funding acquisition, Data curation, Conceptualization. **Malin Engfeldt:** Writing – review & editing, Validation, Methodology, Data curation. **Maria Albin:** Writing – review & editing, Methodology, Data curation, Conceptualization. **Martin Tondel:** Writing – review & editing, Methodology, Formal analysis, Data curation. **Ulla Vogel:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Linda Schenk:** Writing – review & editing, Validation, Methodology, Formal analysis, Data curation, Conceptualization.

Ethics statement

We hereby confirm that we have written the manuscript ourselves with **no** use of AI tools. All authors have agreed on the final version of the manuscript.

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Declaration of conflict of interest

Linda Schenk and Anne Thoustrup Saber are members of the Nordic Expert Group for Criteria Documentation of Health Risks from Chemicals and disclose intellectual conflict of interest.

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