La Medicina del Lavoro

Med Lav 2020; 111, 1: 22-31
DOI: 10.23749/mdl.v111i1.8869

Assessment of exposure to cobalt and its compounds in Italian industrial settings

Alberto Scarselli, Davide Di Marzio, Sergio Iavicoli

Department of Occupational and Environmental Medicine, Epidemiology and Hygiene, Italian Workers' Compensation Authority (INAIL), Rome, Italy

Key words: Carcinogenic risk; exposure assessment; prevention database; occupational health; surveillance systems

Parole chiave: Rischio cancerogeno; valutazione dell'esposizione; banca dati prevenzionale; salute sul lavoro; sistemi di sorveglianza

Summary

Background: *Adverse health effects of occupational exposure to cobalt and its compounds are well-documented.* **Objectives:** *The aim of the study is to evaluate exposures to cobalt in Italian industrial settings.* **Methods:** *Data on cobalt and its compounds were collected from an occupational exposure registry. Statistical analysis was carried out for some exposure-related variables (i.e., cobalt compound, activity sector, occupational group, firm size). The number of workers potentially exposed was estimated for selected industrial sectors.* **Results:** *Overall 1,701 measurements were analyzed in the period 1996-2016. The geometric mean of cobalt airborne concentration was 0.33 µg/m*^{3}. *Most exposures occurred in the manufacture of fabricated metal products (50%) and among metal finishing-, plating- and coating-machine operators (42%). A total of 30,401 workers potentially exposed to cobalt was estimated, over 72% were male.* **Conclusions:** *Identifying professional groups at high-risk of exposure can help to control the most dangerous situations for workers' health. Surveillance systems based on occupational exposure registries contribute to support systematic improvement of working conditions.*

Riassunto

«Valutazione dell'esposizione a cobalto e ai suoi composti nei contesti industriali italiani». **Introduzione**: *Gli effetti avversi dell'esposizione professionale al cobalto e ai suoi composti sulla salute dei lavoratori sono ben documentati.* **Obiettivi**: *L'obiettivo dello studio è valutare le esposizioni al cobalto nei contesti industriali italiani.* **Metodi**: *I dati sul cobalto e sui suoi composti sono stati raccolti tramite il registro delle esposizioni professionali. È stata condotta un'analisi statistica per alcune variabili correlate all'esposizione, quali il composto di cobalto, il settore di attività economica, il gruppo professionale e la dimensione dell'impresa. Il numero di lavoratori potenzialmente esposti è stato stimato per alcuni settori industriali.* **Risultati**: *Complessivamente sono state analizzate 1.701 misurazioni nel periodo 1996-2016. La media geometrica della concentrazione nell'aria di cobalto è risultata pari a 0,33 µg/m*^{3}. *La maggior parte delle esposizioni si è verificata nella fabbricazione dei prodotti in metallo (50%), e tra gli operatori delle macchine per la finitura, la placcatura e il rivestimento dei metalli (42%). È stato stimato un totale di 30.401 lavoratori potenzialmente esposti al cobalto, di cui oltre il 72% uomini.* **Conclusioni**: *L'identificazione di gruppi professionali ad alto rischio di esposizione può aiutare a controllare le situazioni più pericolose per la salute dei lavoratori. I sistemi di sorveglianza basati sui registri di esposizione professionale contribuiscono a sostenere il processo di miglioramento sistematico delle condizioni di lavoro.*

Received 19.9.2019 - Revised version 25.11.2019 - Accepted 16.12.2019

Corresponding author: Alberto Scarselli, Istituto Nazionale per l'Assicurazione contro gli Infortuni sul Lavoro (INAIL), Dipartimento di Medicina, Epidemiologia, Igiene del Lavoro ed Ambientale, Viale Stefano Gradi 55, 00143 Roma (Italy) - Tel. +390654872392 - Fax +390654872762 - E-mail: a.scarselli@inail.it

INTRODUCTION

Exposure to cobalt and its compounds is known to produce adverse health effects, including lung cancer, on the exposed workers (1). In 1991, the International Agency for Research on Cancer (IARC) classified cobalt and its compounds in group 2B (possibly carcinogenic to humans), noting that the interpretation of the available data on cobalt carcinogenicity was made difficult by the concurrent exposure of workers to other carcinogens (e.g., nickel), and therefore inadequate to classify them in group 2A (9). The last update of the IARC on cobalt and its compounds was in 2006, classifying cobalt metal with tungsten as probably carcinogenic to humans (group 2A) (10). Moreover, some of its compounds are classified in group 2A by the EU, such as cobalt sulfate and cobalt chloride (EC Regulation n. 1272/2008). Cobalt is a transition element with magnetic properties and, like nickel, promotes oxidation and reduction reactions. The main industrial use of cobalt is in the production of rechargeable batteries and superalloys, and cobalt compounds are utilized as pigments, driers for paints, catalysts and adhesives (16). The primary route of exposure to cobalt is by inhalation and the highest levels of cobalt in the workplace were found in hard metal manufacture, production of cobalt salts, and metallurgical-related industries (16). Cobalt alloys are also used in metal surgical implants and the health risk may be related to the releasing of cobalt ions into the body. Another source of occupational exposure to cobalt is the electronic industry, particularly the manufacture of integrated circuits and semiconductors. Some epidemiological studies have reported increased lung cancer risk among workers exposed to cobalt with tungsten carbide in the hard metal industry (10). Other documented adverse health effects are on the respiratory tract and cardiovascular system (1). Of great interest to the scientific community, with regard to risk assessment, is the possibility of having available estimates on exposed workers. On the other hand, being able to assess the average exposure levels is useful in weighing and setting professional limit values, in order to improve the protection of exposed workers. In Italy, the occupational exposures to cobalt compounds in the period 2000-2003 were estimated at about 28,615 by the Carcinogen Exposure (CAREX) project (14). The Carcinogen Exposure (CAREX) Canada project estimated that approximately 33,000 workers (85% male) have been professionally exposed to cobalt in Canada (4). No occupational exposure limit value has yet been established in Italy, to our knowledge, for cobalt or one of the cobalt compounds. In the U.S.A., the American Conference of Governmental Industrial Hygienists (ACGIH) recommended a threshold limit value (TLV) of 0.02 mg/m^3 for an 8-h time-weighted average (TWA) exposure to cobalt and cobalt inorganic compounds, and of 0.1 mg/m^3 to cobalt carbonyl and cobalt hydrocarbonyl (2).

The aim of this study is to evaluate the levels of occupational exposure to cobalt and its compounds in Italy during the period 1996-2016. An estimation of the number of workers potentially exposed to cobalt and its compounds by economic sector was also performed.

METHODS

Data collection

Data were selected from the Italian Information System on Occupational Exposure to Carcinogens (SIREP), a relational database that collects information on exposures to carcinogens in the workplace. The SIREP system has been fully described elsewhere (19). In brief, according to the Italian regulation on health surveillance at the workplace (Law Decree n. 81/2008), data on exposures have to be collected by employers and regularly sent (every three years) to the SIREP system. Employers are required to report the carcinogens used or produced by industrial process, data on exposed employees and the exposure levels. The core information sent by employers follow a standardized schema, which includes: economic activity and size of the firm; personal and occupational data on the workers; and the levels of exposure in terms of intensity, frequency and duration. One or more exposure measurements are recorded for each worker and work period. Employers are responsible for the exposure measurement procedures and air sampling methods, to be carried out in accordance with European standards which provide technical guidance on the implementation of air monitoring strategies (5, 6).

Data selection and classification

For the purposes of this study, measurements of airborne cobalt concentration in the exposure period 1996-2016 were selected from the SIREP database. Other than cobalt as metal, cobalt compounds included in the analysis were identified on the basis of the IARC classification (9, 10). In detail, the compounds selected for the analysis were: cobalt nitrate, cobalt sulfate, cobalt nitrate hexahydrate, cobalt sulfate heptahydrate, cobalt chloride hexahydrate, cobalt acetate tetrahydrate, cobalt chloride, cobalt acetate, cobalt oxide, cobalt hydroxide, and cobalt carbonate. The term "exposure" refers to a specific job task of a worker involving exposure to cobalt or its compounds. The exposure measurements recorded in SIREP refer only to the TWA-8 value (inhalable fraction), i.e. the average result of the sampling procedure of air inhalable fraction over a typical workday (8-h). Measurements that were below the analytical limit of detection (LOD) were processed with NDExpo software (Flot 0.8.1, Montreal, Canada; http://www.expostats.ca/site/app-local/NDExpo/). The software uses a log-probit regression method, replacing the <LOD measurements with estimated values on the basis of their rank among the set of detected values (7). The year of measurement, if not available, was set equal to the year of first exposure (occurring in 34% of measurements). Exposure-related variables selected for the descriptive analysis were: exposure agent, occupational group, economic activity sector and firm's workforce size. Occupational groups were coded using the international standard classification of occupations (ISCO-88) at the lowest group level (four-digit code); activity sectors were classified using the international statistical classification of economic activities (NACE rev. 1) at the group level (three-digit code); and workforce sizes were categorized into five classes: 1-9, 10-19, 20-49, 50-99, ≥100 workers.

Descriptive statistical analyses were carried out to estimate the arithmetic mean (AM) and geometric mean (GM) of exposure levels, the standard deviation (SD), the geometric standard deviation (GSD) and the 25th-75th interquartile range (IQR). A sample size of 50 measurements was set as the minimum number required to perform reliable descriptive statistics.

Estimating numbers of exposed workers

The number of workers potentially exposed to cobalt and its compounds was estimated for the economic activity sectors that were best represented in the SIREP database. The conditions for selecting a sector were set as follows: total reported workforce (exposed together with non-exposed) resulting from SIREP (RW_i) equal or greater than 1% of the total workforce (W_i), i.e. $RW_i/W_i>=1\%$, where RW_i= reported workforce in SIREP, W_i=total workforce, and *i*=i-*th* economic sector. The total workforce (W_i) for each sector was estimated from national statistics of the Italian Institute for Statistics (ISTAT) (11). Moreover, to include a sector, at least three firms had to be recorded in SIREP for such sector. For the selected industrial sectors (shown in table 3), the number of workers potentially exposed to cobalt was reconstructed using the percentage of exposed workers in relation to both the workforce size of firms recorded in SIREP and the national statistics on workforce (i.e., $PE_i=W_i*(E_i/RW_i)$, where PE_i=Potentially exposed workers, W_i=ISTAT total workforce, RW_i=reported workforce in SIREP and E_i=SIREP exposed workers). The SIREP exposed workers (E_i) represents the total number of workers having cobalt exposure measurements recorded in SIREP (including those with levels below the LOD), for the i-*th* activity sector. In order to have economic activity sectors encoded in a comparable manner to the coding system of ISTAT census, the NACE revision 2 international classification was used.

RESULTS

Descriptive statistics

A total of 1,701 measurements (personal or environmental) collected over a full (8-h) work shift for 1,354 exposures to cobalt and its compounds were selected from the SIREP database. The airborne concentration of cobalt for 264 exposures was measured repeatedly over time (two or more times), and 581 measurements below the LOD value were replaced as indicated in the methods. Overall, the mean level of exposure (GM) to airborne concentration of cobalt was 0.33 μg/m^3, and was slightly higher in women (0.44 μg/m^3) than in men (0.32 μg/m^3). Cobalt sulfate heptahydrate was the compound with the highest level of exposure (GM=1.09 μg/m^3) while cobalt nitrate had the lowest value (GM=0.11 μg/m^3). The distribution of exposure levels (GM) and 95% confidence limits by cobalt compound (with number of measurements >=50) is shown in figure 1. Manufacture of basic metals was the industrial sector where the cobalt as metal was largely reported (mainly for metal melters, casters

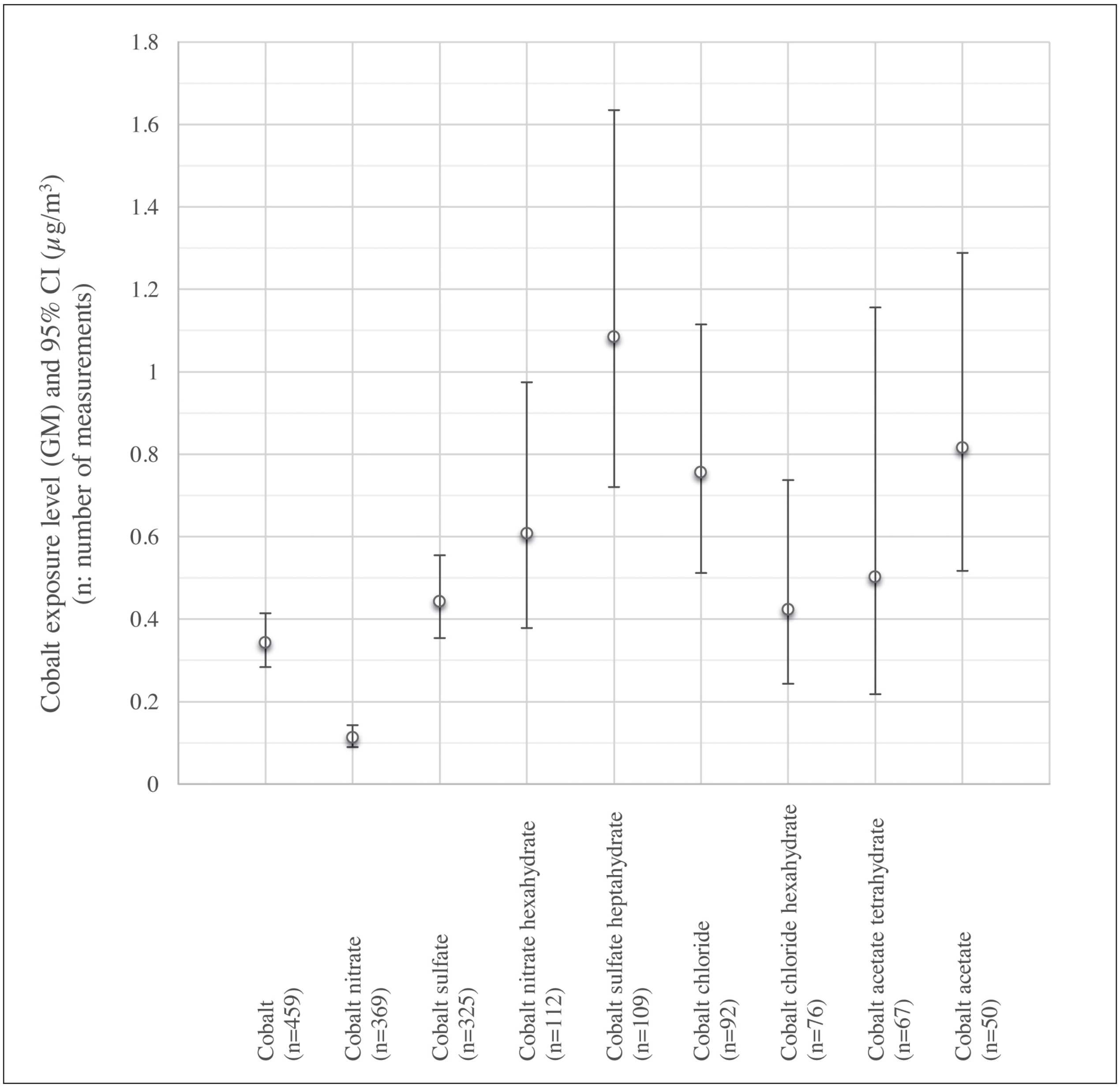

Figure 1 - Distribution of exposure level (GM) and 95% CI by cobalt and its compounds (SIREP 1996-2016)

and rolling-mill operators), while the cobalt nitrate was principally reported in the manufacture of fabricated metal products (mainly for metal finishing-, plating- and coating-machine operators). Exposures to cobalt sulfate were quite widespread in all sectors except for the manufacture of basic metals. The highest frequency of the cobalt exposure level was found below 0.1 μg/m^3 (31% of measurements). Figure 2 describes the distribution of cobalt measurements (%) by exposure level within each activity sector (at division level, two-digit code). The economic sector at higher risk was the manufacture of fabricated metal product in both genders, given its high number of exposure situations. Particularly, the manufacture of cutlery, tools and general hardware showed the highest GM value (3.69 μg/m^3, men). The distribution of exposure mean levels by gender and economic activity sector is displayed in table 1. The occupational group most at risk was the machine-tool setters and setter-operators (GM=5.32 μg/m^3, men), even though it is based on a relative low number of measurements (N=50). The distribution of exposure mean levels by gender and occupational group is shown in table 2. With regards to the distribution of cobalt exposure levels by size of firm's workforce, micro-firms (1-9 workers) showed the highest GM value of cobalt exposure (1.06 μg/m^3), while the lowest (0.07 μg/m^3) was found in medium-sized firms (50-99 workers). Figure 3 shows the temporal trend of mean exposure level (GM) by year of measurement. No significant temporal trend for cobalt exposure mean level was found in the regression analysis. In the last decade the numbers of measurements notified to the SIREP system was steady, with an average value of 138 measurements per year (81% of total measurements). Results are presented as cobalt concentration regardless of the specific compound in use by each firm.

Estimating numbers of exposed workers

Overall, 30,401 workers (72% men), were estimated potentially at risk of exposure to cobalt in the selected industrial sectors. The most represented sector was the "Treatment and coating of metals (NACE Rev.2 code: 25.61.0)" with 14,223 workers (77% male), which also showed the highest percentage of exposed workers with respect to the work-

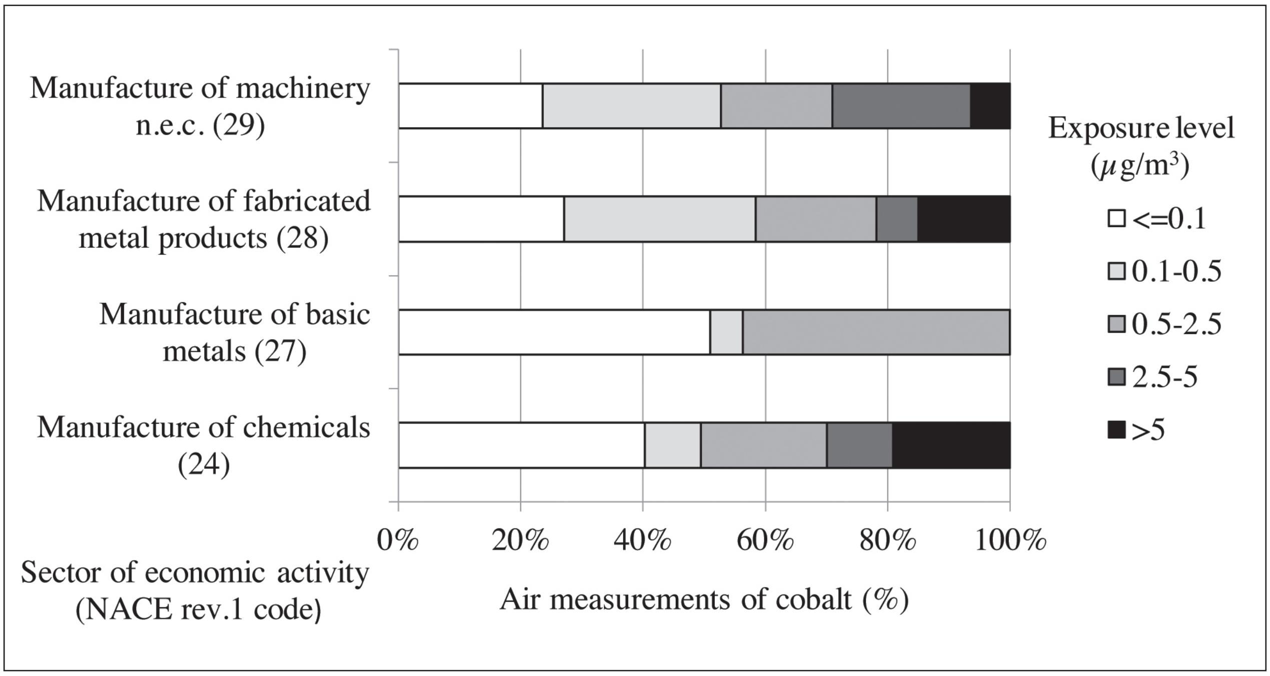

Figure 2 - Distribution of cobalt measurements (%) by exposure level within each activity sector (SIREP 1996-2016)

Table 1 - Distribution of mean levels of cobalt exposure with variability metrics by gender and activity sector, and overall (SIREP 1996-2016)

Gender	Sector of economic activity (NACE Rev. 1 code)	N	AM	SD	GM	GSD	IQR
Women	Treatment and coating of metals; general mechanical engineering (28.5)	71	3.56	15.47	0.48	6.14	0.20-5.0
	Other sectors	138	-	-	-	-	-
	Overall	209	3.79	10.92	0.44	12.92	0.09-4.50
Men	Manufacture of other chemical products (24.6)	156	3.55	6.97	0.10	32.77	0.002-1.8
	Manufacture of basic iron and steel and of ferro-alloys (ECSC) (27.1)	193	0.37	0.31	0.22	2.96	0.08-0.70
	Treatment and coating of metals; general mechanical engineering (28.5)	642	5.29	32.59	0.31	6.29	0.08-1.0
	Manufacture of cutlery, tools and general hardware (28.6)	93	7.32	8.46	3.69	2.71	5.0-7.0
	Manufacture of other fabricated metal products (28.7)	126	0.75	1.66	0.16	4.38	0.06-0.84
	Manufacture of agricultural and forestry machinery (29.3)	53	0.27	0.23	0.13	2.53	0.04-0.50
	Other sectors	229	-	-	-	-	-
	Overall	1,492	3.73	21.90	0.32	8.28	0.08-2.0
All		1,701	3.73	20.86	0.33	8.81	0.08-2.0

N: Number of 8-h TWA exposure measurements ($\mu g/m^3$); AM: Arithmetic Mean; SD: Standard Deviation; GM: Geometric Mean; GSD: Geometric Standard Deviation; IQR: 25th-75th percentile; only sectors with at least 50 exposure measurements are shown; NACE: Statistical classification of economic activities in the European Community, French acronym; SIREP: Italian Information System on Occupational Exposure to Carcinogens

Table 2 - Distribution of mean levels of cobalt exposure with variability metrics by gender and occupational group (SIREP 1996-2016)

Gender	Occupational group (ISCO-88 code)	N	AM	SD	GM	GSD	IQR
Women	Metal finishing-, plating- and coating-machine operators (8223)	84	3.75	14.46	0.58	7.55	0.20-2.0
	Other groups	125	-	-	-	-	-
Men	Machine-tool setters and setter-operators (7223)	50	5.98	1.79	5.32	1.91	5.0-7.0
	Metal melters, casters and rolling-mill operators (8122)	187	0.35	0.31	0.19	3.41	0.08-0.7
	Chemical-processing-plant operators not elsewhere classified (8159)	102	1.25	3.80	0.04	24.03	0.002-0.5
	Metal finishing-, plating- and coating-machine operators (8223)	722	4.79	30.83	0.28	8.82	0.08-1.0
	Mechanical-machinery assemblers (8281)	51	0.28	0.23	0.15	4.00	0.05-0.5
	Manufacturing labourers (9320)	58	1.61	2.14	0.37	7.58	0.03-5.0
	Other groups	322	-	-	-	-	-

N: Number of 8-h TWA exposure measurements ($\mu g/m^3$); AM: Arithmetic Mean; SD: Standard Deviation; GM: Geometric Mean; GSD: Geometric Standard Deviation; IQR: 25th-75th percentile; only sectors with at least 50 exposure measurements are shown; ISCO-88: International Standard Classification of Occupations; SIREP: Italian Information System on Occupational Exposure to Carcinogens

force of the sector (39.29%). Detailed data on the number of exposed workers by activity sector are shown in table 3. In some sectors, the percentage of exposed female workers was higher than in male workers (e.g., manufacture of optical instruments; testing and technical analysis of products, etc.), but these sectors contributed overall to a small number of the total potentially exposed workers (12%).

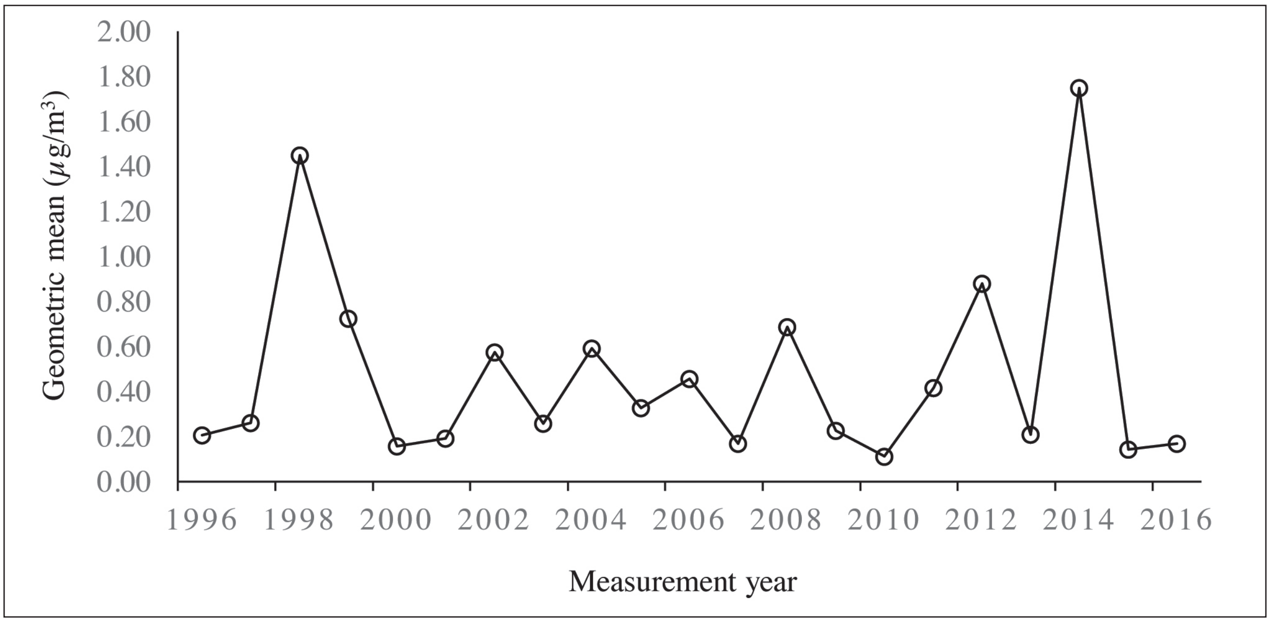

Figure 3 - Temporal trend of cobalt exposure level (geometric mean) by year of measurement (SIREP 1996-2016)

Table 3. Estimates of potentially exposed workers to cobalt in the selected sectors of economic activity (SIREP 1996-2016).

Sector of economic activity (NACE Rev 2 code)	N. of Firms[a]	% of Firms[b]	N. of Workers[c]	% of Workers[d]	% of Exposed[e]	N. of Exposed[f]	% of Men
Manufacture of other inorganic basic chemicals (20.13.0)	3	1.32	5,883	1.60	13.83	814	79
Manufacture of other organic basic chemicals (20.14.0)	3	1.21	10,526	5.84	1.14	120	82
Manufacture of organic chemicals from basic products derived from fermentation processes or vegetable raw materials (20.59.2)	3	1.97	1,248	7.85	6.12	76	80
Manufacture of other chemical products for industrial use (including anti-knock and antifreeze preparations) (20.59.4)	17	2.91	9,913	6.79	19.17	1,900	74
Manufacture of basic pharmaceutical products (21.10.0)	11	6.79	11,870	18.23	3.97	472	63
Manufacture of pharmaceutical preparations (21.20.0)	28	4.54	50,855	15.54	3.02	1,538	60
Treatment and coating of metals (25.61.0)	73	1.73	36,201	3.88	39.29	14,223	77
Manufacture of hand tools, interchangeable parts for machine tools (25.73.1)	3	0.13	20,607	1.72	24.29	5,006	79
Manufacture of other fabricated metal products (25.99.9)	10	0.21	42,273	2.48	6.10	2,579	72
Manufacture of optical instruments (32.50.5)	3	0.26	18,302	19.37	0.28	52	43
Testing and technical analysis of products (71.20.1)	7	0.20	15,382	2.95	9.47	1,457	48
Other research and experimental development on natural sciences and engineering (72.19.0)	10	0.18	17,494	2.86	12.38	2,165	49

[a] Number of firms in SIREP; [b] Percentage of firms in SIREP with respect to the latest industry census data; [c] Number of workers reported by firms (exposed + non-exposed) in SIREP; [d] Percentage of workers reported by firms in SIREP with respect to the latest industry census data; [e] Percentage of exposed workers with respect to non-exposed workers reported by firms in SIREP; [f] Number of estimated exposed workers; SIREP: Italian Information System on Occupational Exposure to Carcinogens.

Discussion

This study is part of a series of studies carried out using the same data source as well as a similar methodology for estimating exposure levels and workers potentially exposed to some of the main occupational carcinogens. The main occupational carcinogens have been selected based on the following criteria: classification of carcinogenicity at European and international level, number and frequency of data notifications to the surveillance system (SIREP), quality of the recorded data and relevance to community practice. Previous studies have analyzed, among others, occupational exposure to PAHs, chromium VI and nickel compounds (20-22).

In this study, the most relevant sector entailing cobalt exposure risk, based on the number of exposed workers, is the manufacture of fabricated metal products, particularly, the treatment and coating of metals. A large number of exposures occurred among metal finishing-, plating- and coating-machine operators in both genders, while metal melters, casters and rolling-mill operators, and chemical-processing-plant operators were mostly men. The number of potentially exposed workers estimated in our study (30,401) is consistent with that previously assessed by the CAREX project (28,615) (14), and comparable with that resulting from CANADA study taking into account the respective differences (structure of active population and selected economic sectors) (4). The highest mean level of exposure to cobalt (GM) was reached in 2014 while the largest number of measurements was recorded in the period 2007-2016 (figure 3). No significant temporal trend of cobalt levels detected by our analysis could indicate an insufficient attention in implementing protection measures in relation to this group of agents but, given the lack of statistical significance, this result must be evaluated with caution. The highest GM value for cobalt exposure was found in micro-firms, probably due to the fact that smaller firms often pay less attention to health and safety at work, while larger industries generally adopt more effective prevention technical measures (3).

Regarding occupational exposure to cobalt and its compounds, a lot of studies have been performed in the hard metal industry, where the cobalt, acting as a binder matrix, forms an alloy (hard metal) with the tungsten carbide. Some studies assessed the risk of cancer among exposed workers finding increased risk to develop cancer (15, 25), others the mean level of cobalt airborne concentration in the workplace (13, 24). A recent study in the Swedish hard metal industry has found low mean cobalt levels with data ranging from 0.00027 to 0.057 mg/m^3, and only 6% of measurements exceeded the Swedish OEL of 0.02 mg/m^3 (12). A similar conclusion was achieved in a study based on data from a large hard metal plant in Austria (8). Based on our data, low mean exposure levels (25th-75th percentile 0.08-2.0 µg/m^3) were found among workers exposed to cobalt and its compounds, confirming previous results. Concerning other industrial sectors, a cancer incidence study among Finnish male workers in cobalt production has found no increased overall cancer risk or lung cancer risk, except for tongue cancer. The study, however, concluded that the results had to be interpreted with caution due to the small number of analyzed cases (18). An earlier study on blue dyes among plate painters has evidenced adverse health effects on the thyroid gland of workers occupationally exposed to cobalt (17). Our data highlighted the presence of cobalt, as metal, mainly in the manufacture of basic metals, while cobalt nitrate and cobalt sulfate were found largely in the manufacture of fabricated metal products. However, different compounds have different effects on the worker health, and in our results the cobalt compounds have mean levels of exposure that differ from one another (figure 1) (23). These differences should be taken into consideration in reading the results. The highest frequency of exposures above 2.5 µg/m^3 was found in the manufacture of chemicals (30%), while in the manufacture of basic metals about 50% of the measurements were less than 0.1 µg/m^3 (figure 2). Particular attention should be focused on the presence of exposed female workers in the sector of treatment and coating of metals due to the possible adverse effects on newborns, even if, to our knowledge, studies on reproductive effects in humans after cobalt inhalation exposure have not yet been conducted (1).

Currently, the SIREP exposure surveillance system covers most of the industrial sectors entailing carcinogenic exposure risk. Weaknesses and strengths of the SIREP system have been extensively described elsewhere (20-22). In brief, data collection and selection of analytic/sampling method are under the responsibility of the employer, some potential factors affecting cobalt air concentrations are not always reported (e.g., environmental conditions, control measures, measurements uncertainty), and the number of exposure measurements are not uniformly distributed among industrial sectors and by firms size (e.g., small firms are underreported). The variety of methods applied by employers for sampling and analyzing cobalt in workplaces air may have generated differences in the result of the measurements. The most commonly analytical methods used were those developed by the US National Institute for Occupational Safety and Health (30% of measurements). The impossibility of known the type of measurement (personal or environmental) is another limit (known only in the 10% of measurements). Exposure measurements were in large quantities for some industries/occupations (e.g., treatment and coating of metals, N=713), but limited for others (e.g., manufacture of machinery, N=53). Consequently, in some situations the reported data has a high degree of variability and should be treated with caution. Conversely, the large sample size helps to ensure the accuracy of the estimates and, to further increase the precision of the analysis, a minimum of 50 recorded measurements was required to include sectors and/or occupations in the descriptive analysis. When lowering this limit, in fact, some results showed an excessively large variability, losing precision. A possible selection bias could result from a lesser account of small firms in the SIREP database, both because small firms are usually less directed towards adopting prevention measures, and because they represent the majority of firms (about 95%) (3, 11, 26). Such distortion, if confirmed, would lead to an underestimate of the overall exposure levels. Uncertainties may also have been introduced as a result of differences in the carcinogenicity classification of the agents/compounds considered. Some of them, including cobalt as single agent not bound to other elements, are not classified as carcinogens in groups 1A or 1B by the EU, and therefore notification of exposure data to the SIREP system is not yet mandatory for these agents/compounds. Likewise, the purpose of recording exposure data used in this study (regulatory compliance for legislative obligations) may also have generated a further underestimation. The number of workers potentially exposed to cobalt in each sector was calculated assuming the same ratio between exposed workers and non-exposed workers in firms notifying and not notifying their exposure data to the SIREP system. This assumption may have introduced a bias into the estimates, leading to an over estimate, that may be assessed only by evaluating compliance of firms to the law with a specific survey. On the other hand, only those sectors better characterized in the database were taken into account to estimate the number of potentially exposed workers. A consequence of this selection is that some economic sectors were excluded only because of limited information on the size of the reported workforce (RW_i), such as, e.g., the sector of manufacture of paints, varnishes and similar coatings, printing ink and mastics (RW_i=0.2). This percentage (RW_i, fifth column of table 3), together with the percentage of firms in SIREP with respect to the ISTAT industry census data (third column of table 3), provide indications on the goodness of the estimates, i.e. the higher these percentages are and the more reliable is the estimate.

In conclusion, to our knowledge, this is the first large-scale study concerning occupational exposure to cobalt and its compounds in Italy. The mean level (GM) of the cobalt airborne concentration in the workplaces was 0.33 $\mu g/m^3$, lower than the current ACGIH TWA-TLV value (2). A total of 30,401 workers were estimated potentially at risk of exposure across the selected industrial sectors. The manufacture of fabricated metal products was the sector most at risk for cobalt exposure, and a large number of workers among metal finishing-, plating- and coating-machine operators resulted exposed. This study may contribute to the ongoing discussion on the definition of occupational limit values for cobalt and its compounds by providing useful data, and to the promotion of a prevention culture in occupational health practice by disseminating information.

No potential conflict of interest relevant to this article was reported by the authors

References

1. Agency for Toxic Substances and Disease Registry (ATSDR): Toxicological Profile for Cobalt. Atlanta, GA: ATSDR; 2004
2. American Conference of Governmental Industrial Hygienists (ACGIH): Threshold limit values for chemical substances and physical agents and biological exposure indices. Cincinnati, OH: ACGIH, 2015
3. Aragòn-Correa JA, Hurtado-Torres N, Sharma S, Garcia-Morales VJ: Environmental strategy and performance in small firms, A resource-based perspective. J Environ Manage 2008; 86:88-103
4. CAREX Canada: Cobalt Occupational Exposures. Vancouver, BC: CAREX Canada; 2019. Available on line at: https://www.crexcanada.ca/profile/cobalt-occupational-exposures/ (last accessed 27-06-2019)
5. European Committee for Standardization (CEN): Workplace atmospheres - General requirements for the performance of the procedures for the measurements of chemical agents, EN 482. Brussels: CEN; 1994
6. European Committee for Standardization (CEN): Workplace atmospheres - Guidance for the assessment of exposure by inhalation to chemical agents for comparison with limit values and measurement strategy, EN 689. Brussels: CEN; 1995
7. Helsen DR: Nondetects and data analysis: Statistics for censored environmental data. New York: John Wiley and Sons, Inc; 2005
8. Hutter H-P, Wallner P, Moshammer H, Marsh G: Dust and Cobalt Levels in the Austrian Tungsten Industry, Workplace and Human Biomonitoring Data. Int J Environ Res Public Health 2016; 13: 931
9. International Agency for Research on Cancer (IARC): Monographs on the Evaluation of Carcinogenic Risks to Humans: Cobalt and its compounds. Vol. 52. Lyon: IARC; 1991
10. International Agency for Research on Cancer (IARC): Monographs on the Evaluation of Carcinogenic Risks to Humans: Cobalt in Hard Metals and Cobalt Sulfate, Gallium Arsenide, Indium Phosphide and Vanadium Pentoxide. Vol. 86. Lyon: IARC; 2006
11. Italian National Statistics Institute (ISTAT): 9th Industry and Services Census. Rome: ISTAT; 2011. Available on line at: http://dati-censimentoindustriaeservizi.istat.it/Index.aspx (last accessed 10-01-2019)
12. Klasson M, Bryngelsson IL, Pettersson C, et al: Occupational Exposure to Cobalt and Tungsten in the Swedish Hard Metal Industry, Air Concentrations of Particle Mass, Number, and Surface Area. Ann Occup Hyg 2016; 60: 684-699
13. Kraus T, Schramel P, Schaller KH, et al: Exposure assessment in the hard metal manufacturing industry with special regard to tungsten and its compounds. Occup Environ Med 2001; 58: 631-634
14. Mirabelli D, Kauppinen T: Occupational Exposures to carcinogens in Italy: An Update of CAREX Database. Int J Occup Environ Health 2005; 11: 53-63
15. Moulin JJ, Wild P, Romazini S, et al: Lung cancer risk in hard-metal workers. Am J Epidemiol 1998; 148: 241-248
16. National Toxicology Program (NTP): Report on Carcinogens, Fourteenth Edition: Cobalt-Related Exposures. Research Triangle Park, NC: U.S. Department of Health and Human Services, Public Health Service; 2016
17. Prescott E, Netterstrom B, Faber J, et al: Effect of occupational exposure to cobalt blue dyes on the thyroid volume and function of female plate painters. Scand J Work Environ Health 1992; 18: 101-104
18. Sauni R, Oksa P, Uitti J, et al: Cancer incidence among Finnish male cobalt production workers in 1969–2013, a cohort study. BMC Cancer 2017; 17: 340
19. Scarselli A, Montaruli C, Marinaccio A: The Italian Information System on Occupational Exposure to Carcinogens (SIREP): Structure, Contents and Future Perspectives. Ann Occup Hyg. 2007; 51: 471-478
20. Scarselli A, Binazzi A, Di Marzio D, et al: Hexavalent chromium compounds in the workplace, assessing the extent and magnitude of occupational exposure in Italy. J Occup Environ Hyg 2012; 9: 398-407
21. Scarselli A, Di Marzio D, Marinaccio A, Iavicoli S: Assessment of Work-Related Exposure to Polycyclic Aromatic Hydrocarbons in Italy. Am J Ind Med 2013; 56: 897-906
22. Scarselli A, Di Marzio D, Marinaccio A, Iavicoli S: Nickel compounds in the workplaces, Occupations and activities involving high-risk exposures in Italy. Am J Ind Med 2018; 61: 968-977
23. Simonsen LO, Harbak H, Bennekou P: Cobalt metabolism and toxicology - a brief update. SciTotal Environ 2012; 432: 210-215
24. Stefaniak AB, Day GA, Harvey CJ, et al: Characteristics of dusts encountered during the production of cemented tungsten carbides. Ind Health 2007; 45: 793-803
25. Wild P, Perdrix A, Romazini S, et al: Lung cancer mortality in a site producing hard metals. Occup Environ Med 2000; 57: 568–73
26. Yangho K, Jungsun P, Mijin P: Creating a Culture of Prevention in Occupational Safety and Health Practice: Safety and Health at Work 2016; 7: 89-96

ACKNOWLEDGEMENTS: *The authors are grateful to the staff at Occupational and Environmental Epidemiology Laboratory of the Department of Medicine, Epidemiology, Occupational and Environmental Hygiene (INAIL), for the support provided in the archiving and managing of data.*