Zinc Toxicity among Galvanization Workers in the Iron and Steel Industry

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Galvanization is the process of coating steel or cast iron pieces with zinc, allowing complete protection against corrosion. The ultimate goal of this work was to assess the effect of occupational exposure to zinc in the galvanization process on different metals in the human body and to detect the association between zinc exposure and its effect on the respiratory system. This study was conducted in 111 subjects in one of the major companies in the iron and steel industry. There were 61 subjects (workers) who were involved in the galvanization process. Fifty adult men were chosen as a matched reference group from other departments of the company. All workers were interviewed using a special questionnaire on occupational history and chest diseases. Ventilatory functions and chest X rays were assessed in all examined workers. Also, complete blood counts were performed, and serum zinc, iron, copper, calcium, and magnesium levels were tested. This study illustrated the relation between zinc exposure in the galvanization process and high zinc levels among exposed workers, which was associated with a high prevalence rate of metal fume fever (MFF) and low blood copper and calcium levels. There was no statistically significant difference between the exposed and control groups with regards to the magnesium level. No long-term effect of metals exposure was detected on ventilatory functions or chest X rays among the exposed workers.

Key words: **galvanization; zinc toxicity; heavy-metal interaction; zinc fume fever**

Introduction

Galvanization is the process of coating steel or cast iron pieces of any size, weight, shape, and complexity with zinc, allowing complete protection against corrosion. There are many types of galvanization processes. The one that we are concerned with in this work is hot-dip galvanization. The process is preceded by preparation of the surface of the basic ignoble metal and refinishing. The prepared article is dipped into a bath of molten zinc that is kept at a temperature between 815° and 850°F (435° and 455°C). Fabricated items are immersed in the bath long enough to reach bath temperature. The articles are slowly withdrawn from the galvanizing bath and the excess zinc is removed by draining, vibrating, and/or centrifuging. The chemical reactions that result in the formation and structure of the galvanized coating continue after the articles are withdrawn from the bath for as long as these articles are near bath temperatures. After galvanization, the surface may be shiny or dull grey. Due to the difference of electrochemical potential between zinc and steel (cathodic protection), a zinc coating can protect steel in such a way that vigorous forces, such as cutting, scratching, or piercing are protected against corrosion.[1]

Zinc goes through a reaction with the iron molecules within the steel to form galvanized steel. The outermost layer is all zinc, but successive layers are a mixture of zinc and iron, with an interior of pure steel. These multiple layers are responsible for the amazing property of the metal to withstand corrosion-inducing

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circumstances, such as saltwater or moisture. The primary concern in the operation of a hot-dip galvanizing plant is the particulate emission (smoke) that escapes from the surface of the molten zinc bath as the article to be galvanized is dipped. The emission is caused by the volatilization of flux and is primarily ammonium chloride, although zinc oxide is also present. The inhalation of zinc oxide fume usually causes metal fume fever (MFF), but chemical pneumonitis is also reported on rare occasions.[2] Zinc is redox-inactive and, as a result of efficient homeostatic control, does not accumulate in excess. However, adverse symptoms in humans are observed on inhalation of zinc fumes or accidental ingestion of unusually large amounts of zinc. Also, high concentrations of zinc have been found to kill bacteria, viruses, and cultured cells.[3]

With continued exposure, a potentially fatal blood disorder may arise. Zinc interferes with the utilization of copper and iron in the production of red blood cells. Excessive zinc intake will eventually affect the balance and proper ratios to numerous other important nutrients that may include iron, calcium, selenium, nickel, phosphorus, copper, as well as Vitamins A, B1, and C. This can lead to a hemolytic anemia in which the red blood cells are destroyed by the body itself, since they are abnormal, and it can also cause neutropenia. Impaired cholesterol metabolism, decreased levels of high-density lipoprotein cholesterol, may also result from excess intake of zinc.[4] Manifestations of both acute and chronic zinc toxicity include vomiting, diarrhea, lack of appetite, lethargy, and pale gums. High levels of zinc exposure may also cause acute kidney failure.[5] Long-term overdosing on zinc may also cause loss of libido, impotence, prostatitis, ovarian cysts, menstrual problems, depressed immune functions, and muscle spasms.

Aim of the Work

The ultimate goal of this work is to assess the effect of occupational exposure to zinc in the galvanization process on different metals in the human body, namely copper, calcium, magnesium, and iron. It is also designed to detect the association between zinc exposure and health hazards, including respiratory system affection.

Subjects and Methodology

This study was conducted in one of the major iron and steel manufacturing companies in Egypt during the period from July to September 2005. The studied group comprised 61 workers in the galvanization process, and they constituted the whole working force in the production line. They were adult men aged between 19 and 40 years (28.86 ± 5.46), working on the basis of 12 h/day. None of the workers used any protective equipment during working hours, although this equipment was provided by the factory. A referent group of 50 males from the same factory (administrative department), who were matched for age, which ranged from 21 to 41 years (27.34 ± 6.19), sex, socioeconomic status, and smoking habits, were also enrolled in our study.

All workers were interviewed using a special questionnaire involving occupational history, and included a full clinical examination. The following investigations were performed after taking individual consent:

1. Complete blood picture.
2. Blood metal level by using the atomic flame absorption analyzer spectrophotometer to determine serum iron, zinc, copper, calcium, and magnesium levels.
3. Blood serum analyses for calcium and magnesium were routinely performed by flame atomic flame absorption. There is often a limitation of the sample volume, but the high serum concentrations of calcium and magnesium permit large dilutions of small sample volumes. However, for the analysis of trace elements, such as zinc and copper, much smaller dilutions are used to keep the analyte concentration within the available working range. We

TABLE 1. Symptoms Experienced by the Studied Groups

	Control group ($N = 50$)		Exposed group ($N = 61$)			
	N	%	N	%	X^2	P-value
Metal fume fever	0	0	15	24.59	14.21	<0.0001
Dyspnea	6	12	22	36.06	8.43	<0.05
Asthma	3	6	7	11.47	1.005	>0.05
Easy fatiguability	6	12	9	14.75	0.18	>0.05
Muscle cramps and twitches	2	4	15	24.59	12.34	<0.001

used zinc-free heparin to evaluate serum zinc in our samples.Ventilatory function tests: Spirometric tests included measurement of: FVC, FEV_1, FEV_1/FVC, $FEF_{25–75\%}$, and PEF.

4. Chest X ray.

Results and Discussion

Galvanizing is the practice of immersing clean, oxide-free iron or steel into molten zinc in order to form a zinc coating that is metallurgically bound to the surface of the iron or steel. The zinc coating protects the surface against corrosion by providing protection to the iron. The article to be galvanized is immersed in a bath of molten zinc at between 815° and 850°F (435° and 455°C). During the galvanizing process, zinc metallurgically binds to the steel, creating a series of highly abrasion-resistant zinc–iron alloy layers, commonly topped by a layer of impact-resistant pure zinc. The primary concern in the operation of a hot dip galvanizing plant is the particulate emission (smoke) that escapes from the surface of the molten zinc bath as the article to be galvanized is dipped.[6]

It has been reported that inhaling large amounts of zinc (as zinc dust or fumes from smelting or welding) can cause a specific short-term disease called MFF, which is generally reversible once exposure to zinc ceases.[7] The effects of inhalation exposure to zinc and zinc compounds vary somewhat with the chemical form of the zinc compound, but the majority of the effects seen will occur within the respiratory tract. Following inhalation of zinc oxide, and to a lesser extent zinc metal and many other zinc compounds, the most commonly reported effect is the development of "metal fume fever." The term "metal fume fever" describes an acute industrial illness characterized by a variety of symptoms, including fever, chills, dyspnea, muscle soreness, nausea, and fatigue, that occur in workers following the inhalation of finely dispersed particulate matter formed when certain metals are volatilized. The oxides of a number of metals, including zinc, can cause this acute, reversible syndrome. Zinc fume from galvanized coatings is a common cause. The description of the effects has been cited extensively, and the condition has been called variously brass founder's ague, zinc chills, zinc fever, Spelter's shakes, and metal shakes.[8] The incidence of MFF is in accordance with our results shown in Table 1. By applying the questionnaire and medical examination for the studied groups, we found a statistically significant higher prevalence of MFF among the exposed groups (~25%) compared to the control group (0) (Table 1). This indicates the high level of metal fumes and the absence of safety measures in the working environment. A statistically significant higher prevalence of muscle cramps and twitches in the exposed groups compared to the control groups is explained later by the lower level of ionized calcium with exposure to zinc fumes that is known to prevent absorption of calcium.

Since MFF is generally short, transient, and severe, serious complications are not common

TABLE 2. The Relation between Duration of Employment and the Prevalence of Symptoms of Metal Fume Fever, Asthma, Easy Fatigue Dyspnea, and Muscle Cramps and Twitches

	Duration of exposure pound < 5 y ($N = 32$)		Duration of exposure >5 y ($N = 29$)			
Exposed group	N	%	N	%	X^2	P-value
Metal fume fever	11	34.37	4	13.79	0.079	>0.05
Easy fatiguability	6	18.75	3	10.34	0.478	>0.05
Asthma	3	9.37	4	13.79	0.699	>0.05
Dyspnea	11	34.37	11	37.93	0.796	>0.05
Muscle cramps and twitches	8	25.00	7	24.14	0.534	>0.05

TABLE 3. Ventilatory Function Test Results among the Examined Groups

	Exposed group ($N = 61$) Mean ± SD	Control group ($N = 50$) Mean ± SD	t-test	P-value
FVC% (L/s)	89.98 ± 5.35	91.14 ± 4.21	1.24	>0.05
FEV_1% (L/s)	90.24 ± 5.69	91.60 ± 4.85	1.33	>0.05
FEV_1/FVC%	79.47 ± 2.52	80.26 ± 2.06	1.79	>0.05
PEF% (L/s)	79.42 ± 4.28	80.88 ± 3.14	1.99	>0.05
$FEF_{25-75\%}$% (L/s)	75.29 ± 4.62	76.46 ± 4.49	1.34	>0.05

and individuals tend to develop tolerance, and consequently the duration of employment may not be considered as an aggravating factor in the incidence of this disease. Symptoms might occasionally be followed by pulmonary edema or pneumonia.[9] The size of the ultrafine zinc oxide particles appears to be critical in the development of the syndrome, with the particles needing to be small enough to reach the alveoli when inhaled.[10] In our study, workers with a longer duration of employment in the galvanization process did not show a statistically significant higher prevalence of MFF or easy fatiguability, dyspnea, asthma-like symptoms, or muscle cramps and twitches than those with a shorter duration of employment (Table 2).

A number of case reports have demonstrated the acute effects of zinc fume inhalation in occupational settings. Reversible clinical signs and radiological effects, including aches and pains, dyspnea, dry cough, lethargy, neutrophil leukocytosis, pyrexia, and widespread abnormality of both lung fields, with multiple nodules measuring 3–4 mm and becoming confluent and ill-defined in some areas, were seen when an individual was exposed to zinc fumes in a shipyard over a 3-week period.[10] Our study illustrated that there was no statistically significant difference between the exposed and the control groups as regards the test results of the ventilatory function (Table 3). Exposure to zinc fumes may cause respiratory impairment, but here this impairment does not affect the ventilatory functions. All subjects were disease-free in chest X-ray evaluation. These results are in accordance with past results obtained, and the occurrence of MFF had been noticed in some subjects after the installation of an electric furnace in a steel plant.[11] The survey studied the relation between exposure to fumes of zinc oxide and impairment of ventilator function. They measured FVC, FEV_1, FEV_1/FVC, PEF, and $FEF_{25-75\%}$, and reported that there were no significant differences in pulmonary functions between exposed and control workers. Although the effects on pulmonary function were minimal, it is likely that they represent a subclinical response to the inhalation of small quantities of zinc oxide.

TABLE 4. Results of the Investigations Performed for the Studied Group

	Control group ($N = 50$) Mean ± SD	Exposed group ($N = 61$) Mean ± SD	t-test	P-value
Zinc (μg/dL)	76.97 ± 14.17	87.57 ± 42.88	1.64	<0.001
Copper (μg/dL)	73.51 ± 10.13	52.19 ± 10.25	10.96	<0.05
Iron (mg/dL)	92.80 ± 17.66	81.88 ± 30.91	2.21	>0.05
Ionized calcium (mg/dL)	4.21 ± 0.36	0.89 ± 0.23	54.8	<0.0001
Magnesium (mg/dL)	2.12 ± 0.36	1.91 ± 1.11	1.24	>0.05
Hb (g/dL)	13.91 ± 1.50	10.74 ± 2.50	4.82	<0.001

Also a cross-sectional analysis, conducted on spirometric lung-function parameters in zinc welders, nonwelders with exposure to welding fumes, and control subjects, revealed no differences in lung function between the two groups, and changes in lung function over five consecutive work shifts were not related to the exposure level. However, recent studies following occupational exposure to zinc oxide fumes have demonstrated some changes in pulmonary function and/or radiological abnormalities, which are reversible following cessation of exposure.[12] Concerning the chest X ray, all our subjects were completely disease-free, which is explained by the disappearance of radiological findings after acute attacks of MFF had subsided. In our study, the exposed workers gave a history of having MFF, but they were not suffering at the time of examination, which explains the absence of X-ray findings and abnormalities in ventilatory function. The last time a worker had suffered from MFF was 3 weeks before our survey, denoting that there was enough time for clearing lung fields before X-ray filming. There was an acute lung reaction in an individual working with heated zinc who experienced chills, muscle ache, and dyspnea; radiographic examination revealed diffuse nodular infiltrates, which cleared after 10 days away from the job.[13]

The association between exposure to zinc and zinc compounds in the galvanization process and different metals in the exposed group is shown in Table 4. We demonstrated a statistically significant higher blood zinc level in the exposed group compared to that in the control group. It has been stated that most manifestations of zinc toxicity are due to its metal interaction.[5]

TABLE 5. Correlation Coefficient between Serum Zinc Levels and Different Metals

Exposed group	R	F-test	P-value
Iron	0.046	0.363	>0.05
Copper	−0.182	0.16	>0.05
Ionized calcium	−0.65	0.043	<0.05
Magnesium	0.019	0.88	>0.05

Our work demonstrated a statistically significant lower copper level in the exposed group compared to the control group (Table 4). Similarly, it has been reported that elevated intake of or exposure to zinc has been shown to induce copper deficiency in terrestrial invertebrates.[14] From our study we observed that there was also a negative correlation between blood zinc level and blood copper level, but this relation does not reach the level of significance (Table 5). On the contrary, it was detected that among brass workers levels of both copper and zinc were significantly higher in the study group with no negative correlation between the two metals.[15]

Our results pointed out that there is a lower level of serum iron in the exposed group compared to the control, but this difference does not reach the level of significance (Table 4). There is also no statistically significant correlation between blood zinc level and serum iron level. Our result is in agreement with that of another study, which reported that increased zinc level alone does not appear to have a clinically important negative effect on iron status.[16] However, a different research study revealed that there was negative correlation between zinc level and iron level.[17]

Zinc interferes with copper and iron utilization in the production of red blood cells. This can lead to a hemolytic anemia, in which the red blood cells are destroyed by the body itself since they are abnormal and can also cause neutropenia.[4] This clarifies our finding of anemia in our studied group. According to the typical anemia definition as a hemoglobin (Hb) level of pound 11 g/dL, we encountered approximately 43% of subjects involved in the galvanization process; the mean level of Hb for the whole exposed group was 10.74 g/dL. A study reported that iron deficiency is a major contributor to anemia.[18]

Our results showed that there was a statistically significant lower ionized calcium level in the exposed group than in the control group (Table 4). There was also a statistically significant negative correlation between zinc level and ionized calcium, as shown in Table 5. Complaints of recurrent muscle cramps and twitches may be a manifestation of low ionized calcium levels encountered in our exposed workers. In accordance with our results, a separate team reported that high levels of calcium impair zinc absorption in mammals, and, conversely, a high zinc level impairs ionized calcium.[19] Such an effect could be predicted based on the free-metal ion activities. Calcium did not seem to have a direct effect on metal assimilation. The separate team also reported that high zinc levels reduced calcium absorption, but calcium absorption was not affected when calcium intake was very high (800 mg/day).

Our work revealed that there was no statistically significant difference between the exposed group and the control group as regards the magnesium level, as shown in Table 5, and that there was no correlation between blood zinc level and blood magnesium level in the exposed group, as shown in Table 4. In accordance with our results, another team reported that the process of absorption of magnesium is similar to that of calcium—some people absorb or retain much more magnesium than calcium or more calcium than magnesium—so the commonly suggested supplemental intake ratio of 2:1 for calcium and magnesium is really an arbitrary value that can change significantly under various individual circumstances, and this has no direct relation to the level of zinc.[20]

Conclusion

The implications of this work illustrated the relationship between zinc exposure in the galvanization process and a high serum zinc level among exposed workers and the high incidence rate of MFF. The fact that zinc exposure causes other metal interactions should be taken into account when monitoring programs are carried out. The low blood copper and calcium levels demonstrated in our exposed workers are important findings that may add to manifestations of zinc toxicity. We found no statistically significant difference between the exposed and control groups, as regards the magnesium level. No long-term effect of zinc exposure was detected on ventilatory functions or chest X ray among the exposed workers.

Recommendations

We recommend implementation of periodic environmental assessment procedures for emitted dust and fumes to comply with EPA and NIOSH exposure-limit values. Pollution-control agencies in general have ruled that these fumes must be collected using the best available technology. This is done by using a tightly enclosed fume hood around the molten zinc bath (galvanizers refer to this bath as the "kettle") and a type of air filter known as a baghouse. This filter is equipped with a powerful suction fan and cloth bags through which the air is filtered, and it may be thought of as a very large vacuum cleaner. The fume hood also makes a significant contribution to personnel safety by containing the splatter of hot zinc that sometimes results when work is dipped. The combination of fume hood and baghouse filter will capture most of the particulate emission.

Health education programs should be carried out periodically to raise the awareness of workers. The use of protective respiratory equipment for all workers involved in the process of galvanization is mandatory. The galvanizers should also wear eye protection and burn-resistant long-sleeve clothing.

Specific nutritional supplementation with iron, calcium, and copper should be provided to workers exposed to zinc, as these metals are known to be depleted in zinc toxicity; they also inhibit the absorption of zinc. Because calcium absorption was reported to be unaffected by zinc exposure if calcium intake was above 800 mg daily, we advised all workers involved in the galvanization process to take supplementary calcium in a dose of 800 mg/day. Factory physicians should be alert for early manifestations of acute and chronic zinc toxicity. Finally, zinc should be added to the Egyptian Compensable Occupational Diseases Schedule.

Conflicts of Interest

The authors declare no conflicts of interest.

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