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# Childhood lead poisoning in Gaza Strip, the Palestinian Authority

Jamal M. Safi[a,b,*], Maged M. Yassin[a,c], Yasser Z. El-Nahhal[a,d], Yehia A. Abed[e], Mohamed J. Safi[a], Hassan D. Suleiman[a]

[a] Environmental Protection and Research Institute, Gaza Strip, Palestine
[b] Faculty of Agriculture and Environment, Al-Azhar University-Gaza, Palestine
[c] Faculty of Medicine, The Islamic University of Gaza, Gaza Strip, Palestine
[d] Faculty of Science, The Islamic University of Gaza, Gaza Strip, Palestine
[e] College of Public Health, Al Quds University, Gaza Strip, Palestine

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ABSTRACT

*Purpose:* To assess lead poisoning among a pediatric population in Gaza Strip, the Palestinian Authority.
*Methods:* A total of 1705 questionnaires and blood samples were collected from children aged 2–6 years, by the finger stick capillary procedure, for the assessment of blood lead level (BLL), using the LeadCare kits. The samples were collected from children living close to lead processing units (hotspots) and far 100–500 m away (general population). Management of elevated BLL was achieved by gavage of chelating agent D-penicillamine at a dose of 30 mg $kg^{-1}$ body weight/day for two weeks for children having BLL above 20 μg/dl. Data were statistically analyzed using SPSS computer program version 22.
*Results:* Distribution of children in Gaza Strip by sampling process illustrated those 326 children (19.1%) living in lead processing units (hot spots) and 1379 children (80.9%) from location far away 100–500 m from host spot (general population). The mean BLL was 10.4 μg/dl. A total of 440 children (25.8%) were found to be having BLL ≥ 10 μg/dl while 1265 children (74.2%) have BLL < 10 μg/dl. BLL < 10 μg/dl was taken as a cut point due to CDC standards. The prevalence of BLL in hotspot areas in children who were exposed to lead and have BLL ≥ 10 μg/dl was 95.7% while in general population it was 9.3%. The difference between the study population was statistically significant ($p < 0.01$). Statistical significant differences between the study populations were found among several independent variables of risk factors such as household location and exposure sources, and occupational exposure. Gavage of D-penicillamine significantly reduced BLL to the acceptable level (BLL < 10 μg/dl).
*Conclusions:* Childhood lead poisoning accounts for a substantial burden in Gaza Strip. Hotspots of lead-related industries are the high risk areas that contributing to high BLLs in children. D-Penicillamine was effective in the treatment of lead poisoning among children. Health education and treatment campaigns should be designed to minimize or prevent childhood lead poisoning in Gaza Strip.

## 1. Introduction

Lead is a useful, but toxic substance, which has been known and used in hundreds of products and processes over millennia. Lead poisoning is an international problem and one of the most common and preventable pediatric health problems of environmental origin. The distribution and severity of lead toxicity are determined largely by lead in gasoline emissions, proximity to environmental sources, point sources, hotspots, and episodic exposures, sometimes from food sources [1,2]. The challenged priority is to establish the preventive measures to minimize lead exposure hazards, particularly in children and then the early diagnosis of lead poisoning in terms of medical surveillance such as measuring BLL and clinical examination would be a corner stone in the treatment strategy. D-Penicillamine is one of chelating agents used for treatment of lead poisoning [3].

Infants and children are at higher risk than adults for lead exposure due to their smaller size and proportionately larger dose of ingested toxins, their proximity to ground dirt and indoor dust, their energy and curiosity, their oral exploratory and pica behaviors, their proportionately larger daily water and milk intake, and dietary preferences that differ markedly from those of adults [4,5]. As an environmental toxicant lead may deleteriously affect most of the body systems including

* Corresponding author at: Environmental Protection and Research Institute, PO Box 1175, Gaza Strip, Palestine.
*E-mail address:* eprigaza@palnet.com (J.M. Safi).

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the nervous, hematopoietic, renal, digestive, and reproductive systems [6]. In acute poisoning, typical neurological signs are pain, muscle weakness and paraesthesia. Hemolysis, abdominal pain, damage to kidneys, nausea, vomiting, diarrhea, and constipation are other acute symptoms [7]. Signs of chronic exposure include loss of short-term memory or concentration, depression, nausea, abdominal pain, loss of coordination, and numbness and tingling in the extremities. Fatigue, problems with sleep, headaches, stupor, slurred speech, and anemia are also found in chronic lead poisoning [7,8].

Until recently, a BLL of 10 μg/dl was considered as a threshold for intervention [9], but new data suggests that there is no such threshold and any BLL is dangerous for children [10]. As a result, lead exposure remains a public health concern both because exposure is still high in developing countries and because increasing evidence indicates health effects at any levels below 10 μg/dl and even a possible steeper dose–response relationships at very low levels [11]. Epidemiologic studies showed associations between even low BLL and lowered intelligence quotient in children [4,12]. In this context, the National Toxicology Program of USA concluded in June 2012 that the existence of a decrease in intelligence in association with blood lead levels below 10 μg/dl and adverse health effects occur at levels below 5 μg/dl.

In the Middle East, the major reported sources of lead exposure are currently industrial sources, including smelters, battery factories, and radiator repair shops; flour from traditional stone mills; leaded gasoline; lead-based paints and traditional homemade cosmetic called Kohl used on women' eyes and on the eyes of their young children [13–15]. Elevated BLLs were recorded as a consequence of exposure to such sources, particularly in children living in hotspots where higher environmental lead levels than the general environment and so have the potential to cause severe lead poisoning in young children, sometimes leading to mortality [16,17]. This will even be exacerbated in developing poor and crowded areas such as the Gaza Strip.

Although uncontrolled lead industrial development combined with rapid population growth in Gaza Strip represents a serious environmental public health problem particularly for children, little information are available on general population-wide sources of lead pollution and poisoning as well as from hotspots in crowded areas. To the best of our knowledge, the only available data on childhood lead exposure in Gaza Strip emerged from the Middle Eastern regional cooperation project carried out in 1996–2000, and published in 2006 [13]. The present research is aimed to (1) assess the distribution of BLLs in children living in and away from hotspots and general population, (2) provide an up-to-date identification of the potential sources of lead exposure and poisoning, including hotspots, (3) manage elevated BLL of poisoned children, and (4) relate BLL with various risk factors of lead exposure.

### 1.1. Study area

The Gaza Strip is a part of the Palestinian coastal plain located in an arid to semi-arid region. It is bordered by Egypt from the South, the Negev desert from the East, and the Mediterranean sea from the West. The total surface area of the Gaza Strip is only 365 $km^2$, where about two million people live and work, making it the most densely populated area in the world [18]. The Gaza Strip is divided geographically into five Governorates: Northern, Gaza, Mid-Zone, Khan Younis and Rafah. The economic activity of most Palestinians include agriculture, fishing, forestry, mining, quarrying, manufacturing, and construction [19].

## 2. Materials and methods

### 2.1. Study population

This study is targeting children, aged 2–6 years, in Gaza Strip as eligible for participation in the study. Lead exposure of children at this age to the outdoors and crawl zones would exceed that of younger infants. Two groups of children were selected, the first are children living in lead processing zone (hotspots), with higher lead exposure chances and the second group was selected from zones far 100–500 m a way from hotspot (general population) where the chances of exposure are less. Differing population distributions, age patterns, residential distribution and anticipated prevalence were considered.

### 2.2. Sampling and sample size

The sampling scheme of household and respondents is considered as a multistage combination of stratification, and clustering. In order to ensure that the sample is geographically representative, the study covered five Governorates in Gaza Strip. These were Northern, Gaza, Mid-Zone (Deir al Balah and Mid-refugee camps), Khan Younis and Rafah. The percentage of each Governorate population of the total Gaza Strip population was computed according to population distribution.

Each Governorate was divided into a number of strata representing the rural area, the urban area, and the refugee camps according to the classification of PCBS (2016). Each Geographical unit is called Primary Sample Unit (PSU). Based on this design, the entire Gaza Strip was divided into 48 geographic areas (48 PSUs) which in turn was identified and selected. From the census records, we obtained percentage of the total population of each in each Governorate. In each PSU around 6 children were selected from lead processing zone (hotspot), and around 28 children were selected from locations far away 100–500 m of hotspots (general population zones). The distribution is proportional and covered the hot spots and the general population. The calculated samples for each Governorate were distributed equally between the PSUs inside each Governorate.

A total of 1705 children were selected from the whole five Governorates, 326 Children (19.1%) from lead processing zones (hotspot) and 1379 children (80.9%) from zones far 100–500 m away from (hotspot) general population. For hotspots: we identified a point source of environmental lead contamination in the 48 PSUs in Gaza Strip Governorates. Such main sources (high-risk zone) were lead battery manufacturing units, smelters, battery recycling unit and other industries using lead. We went to the house located nearest to the source. We examined a child 2–6 years of age in that house and went from house to house till we completed the required number of children in that PSU. The houses were selected non-randomly. Only one child from each house was included in the study, the selection of the child was also non-random in case of a house having only a child. For general population: in each PSU we selected localities at least 500 m away from the 48 hot spots in any direction. A cluster of around 1379 houses were identified after field investigation to ensure absence of hot spots. In each selected house only one 2–6 years child was selected. We then went from house to house till we completed the required number of children in that PSU. So far, about 25 and 49 families from lead processing (hotspot) and general population zones did not agree to participate in the study.

### 2.3. Institutional review board confirmation and ethical issues

This study was carried out in accordance with the directions of the Institutional Review Board (IRB) for Ethics in Human's Medical Studies (The Helsinki Committee) in the Ministry of Health in Gaza Strip, and under its approval. A parent or legal guardian gave written and oral informed consent for each child. The children's parents or legal guardians received a complete explanation about the research purpose, full disclosure about the nature of the study, length of investigation, the investigation institute (Environmental Protection and Research Institute), the subject's right to refuse participation, risks and benefits, how they have been selected, confidentiality and sponsorship.

### 2.4. Questionnaire interview

The questionnaire for the study was specially designed and prepared to complete information relating to the objectives of the study. The questionnaire included questions on: socio-demographic, household location and exposure sources, familial and occupational exposure, child information and day care, and child and lead sources. Most questions were one of two types: the yes/no question, which offers a dichotomous choice; and the multiple choice question, which offers several fixed alternatives [20]. The questionnaire was validated by six specialists in the fields of epidemiology, toxicology, environment, and public health. Questionnaires were filled by face-to-face interviews of children's parents or legal guardians. A questionnaire was piloted and modified as necessary to improve reliability. The interviews were completed by trained and qualified interviewers.

### 2.5. Blood lead survey

Team members of well-trained laboratory technicians in collaboration with the primary care physicians, as directed by the IRB Committee, collected finger stick capillary blood samples from eligible children, because it is convenient and less costly than venous sampling. Previous studies have reported a high correlation between capillary and venous sampling [21]. The team conducted field work from late morning to evening using the LeadCare kits; Esa Biosciences Inc., Chelmsford, MA, USA [22]; a validated method for accurately measuring lead levels in finger stick blood specimens. Calibration of lead care unit was conducted every measurement using standard materials supplied by; Esa Biosciences Inc., Chelmsford, MA, USA. To insure stability and precision of the method, low and high control samples were used. LeadCare analyzer read “Low” and “High” when blood lead test result less than 3.3 μg/dl and higher than 65 μg/dl, respectively. In some cases samples were determined twice and standard concentration was determined as a known sample. An average was calculated if necessary. Quality assurance/quality control assessments of the finger stick method determined the reliability, accuracy, and precision of the method. The team used the LeadCare Quality Control Sheet for testing standards (one low, one high) before and after each testing session. Blood samples were analyzed within 24 h of collection.

### 2.6. Management of elevated BLL

Children with BLL below 10 μg/dl were considered safe according to CDC recommendation whereas those having elevated BLL (above 10 μg/dl) were considered at risk. Therefore, children at risk were subdivided into two groups: Group 1 included children who had BLL up to 39.9 μg/dl and group 2 included children who had BLL ≥ 40 μg/dl. Group 1 and 2 received oral tablets of D-penicillamine at a dose of 30 mg $kg^{-1}$ body weight/day for two weeks. Four weeks after treatment of children, BLL was measured again and compared with the pretreatment level. Children who still have BLL above 10 μg/dl were subjected to another round of treatment until their BLL reaching the acceptable level (< 10 μg/dl).

### 2.7. Study limitations

The political upheavals and episodic violence in the Gaza Strip sometimes restrict the work of the field team. Many parents or legal guardians were hesitated to make their children to participate in the study and the team took a considerable time to convince them, and they finally agreed voluntary. So far 25 and 49 families from the hotspot and general population zones did not agree to participate in the study. Inconsistent power supply is a major problem in Gaza Strip. We were unable to directly carry out follow-up by confirming BLL > 10 μg/dl with a venous sample.

### 2.8. Data processing and statistical analysis

The collected data were introduced to the computer using SPSS/PC (Statistical Package for the Social Science Inc., Chicago, Illinois, USA, version 22.0) program. Data were checked for entry errors using a frequencies and logical checks on all variables by using simple frequency. Data analysis was carried as follows: descriptive analysis to examine the distribution of different factors among the study population. The dependent variable in the study is the BLL among the participants, the independent variables include socio-demographic factors, and variables related to exposure to lead as stated in the questionnaire. Chi-square ($\chi^2$) was used to identify the significance of the relations, associations, and interactions among various variables. Statistical significant differences are reached when $p$-value is less than 0.05. SPSS program version 22.0 was also used for histogram plotting of BLLs of children in Gaza Governorates.

## 3. Results

BLL measurements using lead care unit showed stability and precision during determination of BLL in all samples. The standard materials used were accurate. Determination of standards as unknown samples showed high accuracy to the point that no need for a correction factor or calculation of an average. Accordingly the samples were determined according to described methodology.

### 3.1. BLL and its prevalence among children in Gaza Strip Governorates

Statistical analysis indicated that the range of BLL was 61.9 μg/dl from 3.2 μg/dl to 65.1 μg/dl (> 65 μg/dl) with mean level of 10.4 ± 12.3 μg/dl (Fig. 1). The prevalence of BLL in children of Gaza Strip Governorates by 2 and 5 groups is illustrated in Tables 1 and 2, respectively. The prevalence of BLL in hotspot areas (Table 1) in children who were exposed to lead and have BLL ≥ 10 μg/dl were 95.7% while in general population it was 9.3%. Table 1 shows that 440 children (25.8%) are exposed to lead and have BLL ≥ 10 μg/dl while 1265 children (74.2%) have BLL < 10 μg/dl. The difference between the study population (hotspot and general population) was statistically significant ($p$ < 0.01). In Table 2, classification of BLL among children by five groups in the 5 Governorates indicated that 1265 children (74.2%) have BLL < 10 μg/dl while 260 children (15.2%), 98 children

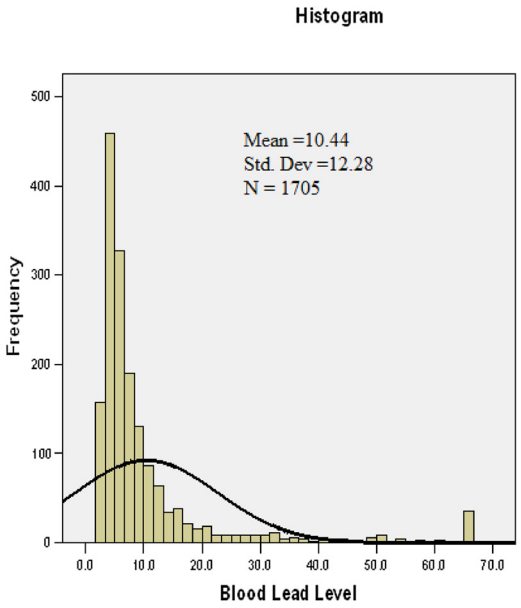


**Fig. 1.** Histogram of BLLs (μg/dl) of children in Gaza Governorates.

**Table 1**
Prevalence of BLL in Gaza Strip Governorates by 2 Groups.

| Area | Blood lead level | | | | Total | | *p*-value |
|---|---|---|---|---|---|---|---|
| | Normal Up to 9.9 μg/dl | | Exposed ≥10 μg/dl | | Number | % | |
| | Number | % | Number | % | | | |
| Hot Spot | 14 | 4.3 | 312 | 95.7 | 326 | 100 | < 0.01 |
| General population | 1251 | 90.7 | 128 | 9.3 | 1379 | 100 | |
| Total | 1265 | 74.2 | 440 | 25.8 | 1705 | 100 | |

(5.7%), 47 children (2.8%) and 35 children (2.1%) have BLL from 10–19.9, 20–39.9, 40–65 and > 65 μg/dl, respectively. Statistical significant differences between the study population are reached ($p < 0.01$).

### 3.2. Distribution of BLL in children by socio-demographic variables

Table 3 revealed that the exposed (BLL ≥ 10 μg/dl) males (27.0%) were more than females (24.0%). The difference between the two groups did not reach a statistical significant level ($p > 0.05$). Among father's education only 68 of the exposed children (18.7%) came from fathers who had > 12 years of education while 130 (26.6%) and 232 (28.5) of the children came from fathers who had 1–8 and 9–12 years of education, respectively. Statistical significant differences among the father's education are reached ($p < 0.01$). Conversely, mother's education showed no significant differences ($p > 0.05$). One hundred twenty three (50.4%) children from father lead-related job are found to have BLL ≥ 10 μg/dl. Statistical significant differences among the father's job are reached ($p < 0.01$). Mother's job displayed no significant difference ($p > 0.05$). However, floor status showed significant differences ($p < 0.05$), with the highest percentage of the exposed children living on one floor above. Among Gaza Strip Governorates 195 (32.5), 59 (26.2), 80 (22.9), 43 (21.0) and 63 (19.4) of the exposed children came from Gaza, Mid-Zone, Khan Younis, Rafah and Northern Governorates, respectively. Statistical significant differences among the Governorates are reached ($p < 0.01$).

### 3.3. Distribution of BLL in children by household location and exposure sources

As illustrated in Table 4, a total of 110 children (52.6%) have BLL ≥ 10 μg/dl and their homes are near smelter while 95 children (62.9%) who have BLL ≥ 10 μg/dl their homes are ≤50 m distance from smelters. Statistically significant difference ($p < 0.01$) is found between the two groups. Only 54.9% and 70.8% of children are found to be exposed and have BLL ≥ 10 μg/dl. They are living ≤50 m from battery manufacturing. Statistically significant difference ($p < 0.01$) is found between the two groups. Similarly, 202 children (57.5%) and 150 children (74.6%) are exposed and have BLL ≥ 10 μg/dl among children living ≤50 m distance from battery recycling ($p < 0.01$). One hundred and thirteen (47.1%) and 90 (51.4%) of children are exposed and living ≤50 m distance from electronics ($p < 0.05$). Significant difference is

**Table 3**
Distribution of BLL in children by socio-demographic variables.

| Variable | Normal (up to 9.9 μg/dl) | | Exposed (≥10 μg/dl) | | *p*-value |
|---|---|---|---|---|---|
| | No. | % | No. | % | |
| Gender | | | | | |
| Male | 753 | 73.0 | 278 | 27.0 | 0.18 |
| Female | 512 | 76.0 | 162 | 24.0 | |
| Father years of education | | | | | |
| 0 | 28 | 73.7 | 10 | 26.3 | < 0.01 |
| 1–8 | 359 | 73.4 | 130 | 26.6 | |
| 9–12 | 583 | 71.5 | 232 | 28.5 | |
| > 12 | 295 | 81.3 | 68 | 18.7 | |
| Mother years of education | | | | | |
| 0 | 23 | 79.3 | 6 | 20.7 | 0.24 |
| 1–8 | 246 | 71.1 | 100 | 28.9 | |
| 9–12 | 789 | 74.1 | 276 | 25.9 | |
| > 12 | 207 | 78.1 | 58 | 21.9 | |
| Father job | | | | | |
| Employee | 465 | 80.6 | 112 | 19.4 | < 0.01 |
| Lead-related job | 121 | 49.6 | 123 | 50.4 | |
| Business | 80 | 71.4 | 32 | 28.6 | |
| Unemployed | 310 | 76.5 | 95 | 23.5 | |
| Worker | 289 | 78.7 | 78 | 21.3 | |
| Mother job | | | | | |
| Employee | 45 | 68.8 | 20 | 31.2 | 0.35 |
| House wife | 1220 | 74.4 | 420 | 25.6 | |
| Floor status | | | | | |
| Basement | 15 | 88.2 | 2 | 11.8 | 0.03 |
| Ground | 549 | 77.3 | 161 | 22.7 | |
| One floor above | 263 | 70.7 | 109 | 29.3 | |
| Two floor or higher | 438 | 72.3 | 168 | 27.7 | |
| Governorate | | | | | |
| Northern | 262 | 80.6 | 63 | 19.4 | < 0.01 |
| Gaza | 405 | 67.5 | 195 | 32.5 | |
| Mid-zone | 166 | 73.8 | 59 | 26.2 | |
| Khan Younis | 270 | 77.1 | 80 | 22.9 | |
| Rafah | 162 | 79.0 | 43 | 21.0 | |

**Table 2**
Prevalence of BLL in Gaza Strip Governorates by 5 groups.

| Area | Blood lead level (μg/dl) | | | | | *p*-value |
|---|---|---|---|---|---|---|
| | ≤9.9 | 10–19.9 | 20–39.9 | 40–65 | ≥65.1 | |
| Hot spot | 14 (4.3%) | 140 (42.9%) | 96 (29.4%) | 44 (13.5%) | 32 (9.8%) | < 0.01 |
| General population | 1251 (90.7%) | 120 (8.7%) | 2 (0.1%) | 3 (0.2%) | 3 (0.2%) | |
| Total | 1265 (74.2%) | 260 (15.2%) | 98 (5.7%) | 47 (2.8%) | 35 (2.1%) | |

**Table 4**
Distribution of BLL in children by household location and exposure sources.

| Variable | Normal (up to 9.9 μg/dl) | | Exposed (≥10 μg/dl) | | *p*-value |
|---|---|---|---|---|---|
| | No. | % | No. | % | |
| Smelter near home | | | | | |
| Yes | 99 | 47.4 | 110 | 52.6 | < 0.01 |
| No | 1166 | 77.9 | 330 | 22.1 | |
| Smelter distance | | | | | |
| ≤50 m | 56 | 37.1 | 95 | 62.9 | < 0.01 |
| ≥51 m | 39 | 75.0 | 13 | 25.0 | |
| Battery manufacturing near home | | | | | |
| Yes | 82 | 45.1 | 100 | 54.9 | < 0.01 |
| No | 1183 | 77.7 | 340 | 22.3 | |
| Battery manufacturing distance | | | | | |
| ≤50 m | 31 | 29.2 | 75 | 70.8 | < 0.01 |
| ≥51 m | 51 | 67.1 | 25 | 32.9 | |
| Battery recycling near home | | | | | |
| Yes | 149 | 42.5 | 202 | 57.5 | < 0.01 |
| No | 1116 | 82.4 | 238 | 17.6 | |
| Battery recycling distance | | | | | |
| ≤50 m | 51 | 25.4 | 150 | 74.6 | < 0.01 |
| ≥51 m | 98 | 66.2 | 50 | 33.8 | |
| Electronic near home | | | | | |
| Yes | 127 | 52.9 | 113 | 47.1 | < 0.01 |
| No | 1138 | 77.7 | 327 | 22.3 | |
| Electronic distance | | | | | |
| ≤50 m | 85 | 48.6 | 90 | 51.4 | 0.02 |
| ≥51 m | 41 | 65.1 | 22 | 34.9 | |
| Gas station near home | | | | | |
| Yes | 95 | 80.5 | 23 | 19.5 | 0.10 |
| No | 1170 | 73.7 | 417 | 26.3 | |
| Gas station distance | | | | | |
| ≤50 m | 30 | 68.2 | 14 | 31.8 | < 0.01 |
| ≥51 m | 65 | 87.8 | 9 | 12.2 | |

**Table 5**
Distribution of BLL in children by familial and occupational exposure.

| Variable | Normal (up to 9.9 μg/dl) | | Exposed (≥10 μg/dl) | | *p*-value |
|---|---|---|---|---|---|
| | No. | % | No. | % | |
| Smoking cigarettes | | | | | |
| Yes | 569 | 71.9 | 222 | 28.1 | 0.04 |
| No | 696 | 76.1 | 218 | 23.9 | |
| Using Kohl by child | | | | | |
| Yes | 210 | 76.4 | 65 | 23.6 | 0.37 |
| No | 1055 | 73.8 | 375 | 26.2 | |
| Using Kohl by mother | | | | | |
| Yes | 533 | 76.3 | 166 | 23.7 | 0.11 |
| No | 732 | 72.8 | 274 | 27.2 | |
| Smelting works | | | | | |
| Yes | 32 | 28.3 | 81 | 71.7 | < 0.01 |
| No | 1233 | 77.4 | 359 | 22.6 | |
| Battery manufacturing | | | | | |
| Yes | 0.0 | 0.0 | 35 | 100 | < 0.01 |
| No | 1265 | 75.7 | 405 | 24.3 | |
| Battery recycling | | | | | |
| Yes | 3 | 7.0 | 40 | 93.0 | < 0.01 |
| No | 1262 | 75.9 | 400 | 24.1 | |

*Note*: Statistically significant differences are not found among other occupational exposure variables including plumbing, electric, painting and renovating works.

also found among children living ≤50 m distance from gas stations.

### 3.4. Distribution of BLL in children by familial and occupational exposure

Table 5 demonstrates that in smoking cigarettes only 222 children (28.1%) are exposed to lead (≥10 μg/dl) while 218 children (23.9%) are exposed in non-smoking cigarettes. The difference between the two groups is statistically significant ($p < 0.05$). On the other hand, the differences among children who are using (65, 23.6%) and not using Kohl (375, 26.2) or their mothers are using (166, 23.7%) and not using (274, 27.2%) Kohl are not significant ($p > 0.05$). Eighty one (71.7%) children and 359 children (22.6%) had BLL ≥ 10 μg/dl came from houses in which one or more persons worked in smelting or not. The differences among the groups are statistically significant ($p < 0.01$). Thirty five children (100%) and 405 children (24.3%) had BLL ≥ 10 μg/dl; they came from houses including persons worked in battery making and not respectively. Statistically significant differences are found ($p < 0.01$). The percent of the exposed children who came from houses having one working in battery recycling or not are 40, 93.0% and 400, 24.1%, respectively and statistically significant ($p < 0.01$). However, statistically significant differences are not found among other occupational exposure variables including plumbing, electric, painting and renovating works ($p > 0.05$).

### 3.5. Distribution of BLL by child information and day care

Table 6 pointed out that 10 (50.0%) and 430 (25.5%) of the exposed children either regularly visit a private day care home or not, respectively. The difference between the two groups was statistically significant ($p < 0.01$). One hundred ninety two children (23.1%) and 190 children (28.8%) have BLL ≥ 10 μg/dl; they are staying outdoors either ≤25 h/week or ≥26 h/week, respectively. Statistical significant difference ($p < 0.01$) was obtained on this variable. On contrary, other variables include if the child or not: regularly attend a preschool nursery or attend a licensed day care center showed no significant differences ($p > 0.05$).

### 3.6. Distribution of BLL by child and lead sources

Data presented in Table 7 revealed no any statistical significant differences among the groups of the studied variables of child index and lead sources except child play with fishing sinkers, electronics, jewelry or bullets. For instance, 400 (24.9%), 9 (56.2%), 20 (33.3%) and 11 (55.0%) of the exposed children had never, rarely, sometimes and frequently play with fishing sinkers, electronics, jewelry or bullets, respectively. The differences between the groups are statistically significant ($p < 0.01$).

**Table 6**
Distribution of BLL by child information and day care.

| Variable | Normal (up to 9.9 μg/dl) | | Exposed (≥10 μg/dl) | | *p*-value |
|---|---|---|---|---|---|
| | No. | % | No. | % | |
| Attend preschool nursery | | | | | |
| Yes | 295 | 72.7 | 111 | 27.3 | 0.42 |
| No | 970 | 74.7 | 329 | 25.3 | |
| Attend a licensed day care center | | | | | |
| Yes | 136 | 72.7 | 51 | 27.3 | 0.63 |
| No | 1129 | 74.4 | 389 | 25.6 | |
| Visit a private day care home | | | | | |
| Yes | 10 | 50.0 | 10 | 50.0 | 0.01 |
| No | 1255 | 74.5 | 430 | 25.5 | |
| Stay out home (h/week) | | | | | |
| ≤25 | 640 | 76.9 | 192 | 23.1 | 0.01 |
| ≥26 | 470 | 71.2 | 190 | 28.8 | |

**Table 7**
Distribution of BLL by child and lead sources.

| Variable | Normal (up to 9.9 μg/dl) | | Exposed (≥10 μg/dl) | | *p*-value |
|---|---|---|---|---|---|
| | No. | % | No. | % | |
| Child suck fingers | | | | | |
| Never | 1107 | 74.6 | 376 | 25.4 | 0.61 |
| Rarely | 21 | 65.6 | 11 | 34.4 | |
| Sometimes | 76 | 71.7 | 30 | 28.3 | |
| Frequently | 61 | 72.6 | 23 | 27.4 | |
| Child put toys in mouth | | | | | |
| Never | 1113 | 74.1 | 389 | 25.9 | 0.14 |
| Rarely | 16 | 64.0 | 9 | 36.0 | |
| Sometimes | 127 | 78.3 | 35 | 21.7 | |
| Frequently | 9 | 56.2 | 7 | 43.8 | |
| Child eat paint chip | | | | | |
| Never | 1182 | 73.9 | 418 | 26.1 | 0.36 |
| Rarely | 12 | 66.7 | 6 | 33.3 | |
| Sometimes | 68 | 81.9 | 15 | 18.1 | |
| Frequently | 3 | 75.0 | 1 | 25.0 | |
| Child play with fishing sinkers, electronics, jewelry or bullets | | | | | |
| Never | 1209 | 75.1 | 400 | 24.9 | < 0.01 |
| Rarely | 7 | 43.8 | 9 | 56.2 | |
| Sometimes | 40 | 66.7 | 20 | 33.3 | |
| Frequently | 9 | 45.0 | 11 | 55.0 | |

### 3.7. Management of elevated blood lead levels

Elevated BLL levels of up to 39.9 μg/dl in group 1 (358 children) was successfully reduced to below 10 μg/dl during only one round of oral administration of D-penicillamine tablets at a dose of 30 mg $kg^{-1}$ body weight/day for two weeks. However, in group 2 (82 children) where BLL ≥ 40 μg/dl, one round of treatment was not enough. Accordingly a second round of treatment was given which resulted in reducing BLL in 75% of the cases. The remaining 25% still have elevated BLL and they were kept in the hospital for daily follow up.

## 4. Discussion

Data on childhood lead poisoning and potential exposure sources among children in Gaza Strip are very limited. To the best of our knowledge, only one survey study was carried out in 1996–2000, as a part of a Middle Eastern regional cooperation project, investigated childhood lead exposure among children in Gaza Strip and the results were published in the year 2006 [13]. Since that time many uncontrolled lead-related industries and activities, particularly battery manufacturing and recycling are flourished in Gaza Strip, in part, due to inconsistent power supply, lead batteries are routinely used in homes and businesses to back up computer systems, lights, and appliances when outages occur. This necessitates an up-to-date data at a national level on BLLs and exposure sources. The present study is the largest survey ever has been conducted in the Palestinian territories or even in the Middle East to assess lead poisoning among 1705 children in Gaza Strip.

The mean BLLs recorded in our children (10.4 μg/dl) are approaching those of the Middle Eastern countries [15,23], but higher than those of Europe, Japan and the United States of America, where mean BLLs in children range between 1.5 and 3.0 μg/dl [24–26]. The findings, taken together with the results of the previous survey in the Palestinian territories [13] showing mean level of 8.6 μg/dl, suggest that the relative increase in BLLs in children in the Gaza Strip may be attributed to increase lead-related activities in the area and we inspect most of the hotspots including those in poorer and crowded areas, or high-risk situations. The cluster design enabled us to sample groups throughout the Gaza Strip Governorates in many different exposure settings. Therefore, a multi-action plan and regulations to improve prevention and control of childhood lead poisoning should be implemented in the Gaza Strip, particularly in hotspot areas.

The overall prevalence of BLL ≥ 10 μg/dl among the exposed children (2–6 years) in hotspots and general population in Gaza Governorates is 25.8%, a finding consistent with estimates for many developing countries including the neighboring ones [27–29]. According to the CDC recommendation, an area is considered as a high risk if 12% or greater of children tested are found with the BLL of ≥10 μg/dl [30]. Nevertheless, the new reference value is 5 μg/dl on the 97th percentile of blood lead levels in US Children aged 1–5 years as measured by the agency's National Health and Nutrition Examination Survey [31].

Therefore, the findings of this study indicate a serious health problem in children living in Gaza Strip. This needs urgent intervention and prevention programs at the nation level. In the United States of America, the primary prevention was the most effective way in reducing the prevalence of BLL ≥ 10 μg/dl in children aged 1–5 years from 4.4% in 1991 to 0.8% in 2010 [6].

While comparing the number of the exposed male and female children (BLL ≥ 10 μg/dl) in the present study, males were more than females but the difference was not statistically significant. This result can be explained by the fact that boys spend more time in outdoor activities than girls and are subjected to greater lead exposure. Similarly, no association was noticed between age groups of children and BLL. The lowest percentage of the exposed children came from fathers who had > 12 years of education. An inverse relationship between child BLL and parental education attainment has been reported [32]. More than half of the exposed children (50.4%) have their parents engaged with lead-related jobs, reflecting a strong association with BLL of the children. Parental occupation in a lead battery factory was identified as a significant risk factor which increased children's BLLs [33]. Our findings also demonstrate that living on the higher floors is a risk factor for child lead poisoning. Living on the ground floor or above may facilitate the contact with lead dust and smoke than living in the basement [34]. About one third of the exposed children live in Gaza Governorate, the largest Governorate where many lead-related industries and activities, particularly smelting works, battery manufacturing and recycling, exist.

Distribution of BLL in children by household location and exposure sources revealed that more than half of children have BLL ≥ 10 μg/dl and their homes are near smelter, battery manufacturing or recycling plants while the majority of children who have BLL ≥ 10 μg/dl their homes are ≤50 m distance from these facilities. Similar trend was generally observed in children live near electronic workshop or gas station. It is known that all of the above lead facilities are potential sources of lead emission and the mean BLL of the exposed children is expected to be elevated. Gottesfeld and Pokhrel reviewed studies from 37 developing countries published from 1993 to 2010, and the mean BLL of children who lived nearby battery manufacturing and recycling plants was 29.0 μg/L [35]. In this context, shorter housing distance from the lead battery factory or smelting industries was reported as a risk for elevated BLL [33,36]. It is worth mentioning that some illegal and uncontrolled lead workshops are existed in the middle of residential areas in the Gaza Strip, which exacerbate the problem and can put children in the area at a real threat of lead poisoning.

Familial exposure illustrates that parental smoking at home is associated with elevated BLL in the exposed children. This suggests that cigarette smoke is a predictive source of lead for Gaza children. Higher BLL in children with passive smoking has been reported by other authors [25,37], and was ascribed to the fact that cigarette smoke contains lead [38]. Children could be exposed to lead by inhaling tobacco smoke and by digesting floor dust containing lead that may be partially from indoor smoking. Studies showed that indoor smoking is one of the predictors for lead level in floor dust, which is associated with higher BLLs [39]. In the present study we did not find significant associations between BLLs of children and Kohl use. However, this needs further

investigation as we did not analyze lead content in the used Kohl or even we did not ask about its type or nature. In this study, the household occupations which significantly revealed higher mean BLLs in the exposed children were only smelting, battery manufacturing and battery recycling. There is a compelling body of literature describing the importance of 'take home' lead as an exposure source for children with high BLLs including lead smelting, battery manufacturing and recycling workers 'take home' lead exposure [40,41]. Children may be exposed to lead through touching their parents' clothes, shoes, skin, hair, or may be breathing the air contaminated with lead shaken from the clothes. In his recent article entitled "What parents need to know about the risks of lead exposure for children", Moreno asked parents who work in a job that has exposure to lead to change their clothes and shower when finished, and to wipe their feet on mats when they enter their homes [42].

Our data concerning distribution of BLL by child information and day care indicated that regularly visit a private day care home or stay out home ≥ 26 h/week are two risk factors associated with elevated BLL in the exposed children. Analysis of BLLs of 400 Egyptian children showed that playing outdoors, and duration of exposure to lead in residential areas were significantly correlated with high BLLs [15]. Consistent with this study and as a part of the Middle East culture, boys and girls in our society have increased outdoors playing activities, particularly in the crowded residential areas. Mean BLLs were also found to be significantly higher among children who attended school outside the home [17]. Anyway, stay out home is more likely to expose children to higher levels of environmental lead. In addition, distribution of BLL by child and lead sources revealed that playing with fishing sinkers, electronics, jewelry or bullets is a risk factor for elevated BLLs in the children. Similar results were previously documented [43–45]. It is worth mentioning that Gaza Strip is a Mediterranean coastal area, where fishing is an important source of income [19]. Fishermen used fishing nets which usually contain lead sinkers in their ropes. These nets are discarded inappropriately, in the backyards of fishermen' storage houses and at ports, giving an axis for children exposure to lead.

In the present work, the chelating agent D-penicillamine was proven to be efficient in reducing lead poisoning in children. Beattie concluded that D-penicillamine is the only effective oral lead chelator and can be used satisfactorily in a dose of 500–1000 mg per day [46]. At a BLL up to 39.9 μg/dl as in group 1 children, lead concentration is still distributed in blood and accordingly one round of D-penicillamine treatment was enough to chelate it and excrete it in urine. On the other hand, at high BLL (≥ 40 μg/dl) as in group 2, lead concentration is distributed in blood and probably stored in bone, teeth and other organs. Under these conditions more than one round of D-penicillamine treatment are needed to reduce elevated BLL. Regardless the fact that we did not observe any clinical symptom among children during the usage of D-penicillamine treatment, a possible iron and calcium deficiency in children whose BLLs are equal or superior to 5 μg/dl may have occurred because D-penicillamine can chelate iron and calcium. This is in accordance with previous studies [47,48] that revealed the ability of the used drug (CaNa2EDTA) for lead poisoning treatment to chelate iron and zinc, as well as lead and other metals. However, these interrelations are beyond the scope of this study and need further investigations.

## 5. Conclusions

Lead remains a public health problem in Gaza Strip. More than quarter of children population have BLLs ≥ 10 μg/dl. The prevalence of BLL in hotspots in children who are exposed to lead and have BLL ≥ 10 μg/dl are 95.7%. Therefore, an important impact of this study is the increased acquaintance for the need of BLL determinations mainly in lead processing units (hotspot) in Gaza Strip. Until now, these tests are done only on a research basis, and are still being not used in pediatric hospitals of the Gaza Strip. If authorities will decide to introduce the BLL assessment in hotspot areas at least, the experience gained from this research will be of use not only locally, but also at regional and international levels. High BLLs in children were significantly associated with several risk factors such as household location and exposure sources, and occupational exposure. Oral administration of D-penicillamine provided a successful management of lead poisoning among children below 6 years old in Gaza Strip.

## 6. Recommendations

Surveillance and episodic checks at hotspots, including corridors along smelters and battery workshops are highly recommended. This necessitates establishment of primary medical care center in Gaza Strip and equipping it with LeadCare kits. We also need to promote a combined environmental awareness programs with lead regulatory strategies to reduce lead exposures and emissions from lead-related industries. Further studies of lead exposure assessment as an essential way should be conducted to boost the health of children in Gaza Strip, particularly who are living in hotspot areas. D-Penicillamine tablets is recommended for successful management of lead poisoning. Finally, the implementations of these study findings contributed to the protection from lead exposure and poisoning.

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## Conflicts of interest

The authors declare no conflicts of interest.

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