Lead Absorption in Indoor Firing Range Users

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Abstract: To determine if users of indoor firing ranges may be at risk from lead exposure, we studied a law enforcement trainee class during three months of firearms instruction. Blood lead levels were obtained before training and at four-week intervals during training. Air lead levels were measured three times during instruction. Blood lead levels rose from a pre-training mean of 0.31 μmol/L to 2.47 μmol/L. Mean air lead levels were above 2,000 μg/m^3, more than 40 times the Occupational Safety and Health Administration's standard of 50 μg/m^3. Cumulative exposure to lead and the change in blood lead were positively correlated. Control measures need to be studied to determine their efficacy in decreasing or eliminating this health risk. (*Am J Public Health* 1989; 79:1029–1032.)

Introduction

Indoor firing ranges have been the subject of several studies of occupational lead toxicity. These investigations have documented elevated blood lead levels and associated adverse health effects in employees and instructors at these ranges.[1–5]

Lead exposure in indoor firing ranges occurs primarily through inhalation of lead particulates suspended in the range air. The major sources of airborne lead in the breathing area of the shooter result from the ignition of primer material containing lead styphnate (a highly explosive compound used to initiate the combustion of gunpowder in the cartridge) and, because the gun barrel and the bullet do not always align exactly, the shearing of lead particulates off of the bullet as it passes through the weapon. Fragmentation of bullets when they strike the target or backstop may also contribute to the overall air lead concentration in the firing range.[1,6–8]

In 1985, the Colorado Department of Health began an Occupational and Environmental Disease Surveillance Program monitoring exposure to heavy metals as well as other environmental exposures and work-related outcomes. Through this program, laboratories were requested to report elevated values for lead, cadmium, arsenic, and mercury. (Since October 1988, elevated blood or urine levels for lead, cadmium, arsenic, and mercury have been required to be reported to the Colorado Department of Health.) During 1985 and 1986, 11 reports of elevated blood lead levels were received; about half from employees of indoor firing ranges and the rest from frequent users of indoor firing ranges. These persons had blood lead levels determined for various reasons; awareness that use of an indoor firing range may be a health hazard, physician impression of lead toxicity, and requirement for an employment physical. While occupational studies have suggested that exposure to lead from indoor firing ranges may be a health risk for frequent users of these ranges,[2,6,9] the extent of risk among users has not been documented. This concern prompted us to conduct a study to determine the amount of lead absorbed into the body by regular users of an indoor firing range.

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Methods

Seventeen members of a beginning law enforcement trainee class were enrolled in this study on January 29, 1987, before the start of any firearm training or practice on the range. After informed consent was obtained, questionnaires to obtain demographic information and to determine any other potential sources of lead exposure were completed and blood was drawn to obtain baseline values for blood lead and free erythrocyte protoporphyrin (FEP) levels. A second questionnaire was administered on May 3, 1987, after firearms training was complete, to assess any self-reported symptoms of lead toxicity and to again ascertain any other potential sources of lead exposure which may have occurred during the training period.

The class began firearms instruction on February 3, 1987, and ended on April 28, 1987. A log was kept by the trainees indicating the booth each person occupied and the time spent on the range for each day of training. Smith and Wesson* stainless steel K frame Model 66 .357 caliber revolvers and .38 special caliber + P, reloaded, lead semiwad cutter cartridges, manufactured by 3D INV* were used throughout the firearms training.

Blood was drawn at approximately four-week intervals (January 29, March 3, March 31, and May 3) to determine blood lead and FEP levels. After training was complete, the class dispersed throughout the state; only nine of the 17 trainees were available for blood sampling six weeks after completion of training. No physical examinations or other medical tests were done. Laboratory analyses were performed by ESA Laboratories in Bedford Massachusetts, using anodic stripping voltammetry without digestion for blood lead levels and the Chisolm Brown extraction method for FEP levels.[10–13] Since 0.24 μmol/L was the lower level of detection for blood lead, results that were <0.24 μmol/L on January 29 were set at 0.12 μmol/L for statistical analyses.

Air samples were taken from each occupied booth on the firing range on February 3, March 3, and March 31. Air sampling was also done in the classroom directly across the hall from the firing range and in the control room to determine exposure levels while in either room. Battery powered SKC model 224-37 universal flow personal air sampling pumps coupled with 37-mm mixed cellulose ester filters and closed cassettes were used for air sampling. The pump flow rate was set at approximately 2 liters per minute. Sampling pumps were calibrated before and after every sampling period using

*Throughout this paper, any mention of commercial names or products is for identification purposes only and does not constitute endorsement by the authors or the agencies for which they work.

a 2-liter bubble buret. Filters were analyzed by the Colorado Department of Health Laboratory using atomic absorption spectrophotometry. Field blanks were submitted with each set of samples for quality control. Pumps in the classroom and the control booth were placed on counter tops. The pumps on the range were attached to the overhead structure about six inches above the trainee's head. They were turned on when the trainees entered the range and turned off after their shooting session was completed.

During this study, two changes were made to the ventilation system of the firing range. The first, on February 5, corrected the positive pressure inside the range that had allowed lead-contaminated air to flow from the range into other parts of the building whenever the range door was opened. On March 9, final adjustments consisted of placing fins on the air supply grill to cause smoother air flow across the firing line and to decrease air turbulence. Air lead levels were determined before and after adjustments to the ventilation system. The air lead levels on February 3 were used as exposures for February 3 and 4 only. Air lead levels measured on March 3, were used as estimates of exposure levels from February 5 through the day before final adjustments were made. Results from the third air sample on March 31 were used as exposure levels after changes to the ventilation system were complete. In addition to the regular training, the March 31 session also included a very short (3 to 12 minutes) session of "dual-image" shooting with only one recruit on the range at a time. The air lead concentration determined for this session was used as the approximate exposure for the five times "dual-image" shooting was conducted.

Data were categorized into time periods based on the dates of blood sampling and firearms training: *Period 1*, January 29–March 2; *Period 2*, March 3–March 30; and *Period 3*, March 31–May 3. Each person's approximate exposure to airborne lead was established for each time period based on time spent on the firing range, the booth each person occupied, and air lead concentrations for each booth as determined from the three air samplings. For Period 1, we examined the change in the blood lead levels by the cumulative exposure to airborne lead. Cumulative exposure was obtained by multiplying the air lead concentration at each booth by the time spent on the range for each trainee each day of training and adding the totals for the six training days during this time period.

To assess the effect of using jacketed ammunition on the air lead concentrations, a final air sampling was done on April 30 using three different types of ammunition. Each test period consisted of the firearm instructors firing 60 rounds in approximately 10 minutes. In the first sampling period, copper-jacketed bullets were used; in the second, nylon-clad bullets; and in the third, the lead bullets that were normally used.

Results

Fifteen of the 17 trainees (ages 24 to 40, mean 30.7) were males. Only one person had a history of potential occupational exposure to lead during the previous year. His blood lead level upon entry into the study was the highest of the group, at 1.11 μmol/L. Baseline blood lead levels for the others were at or below 0.53 μmol/L, with a mean for these 16 of 0.26 μg/dl and a mean for all 17 of 0.31 μmol/L (Table 1).

TABLE 1—Blood Lead Levels of Law Enforcement Trainees, μmol/L, Colorado, 1987

	Date Sample Was Taken				
Trainee	1/29/87	3/03/87	3/31/87	5/03/87	(6/10–6/18)
1	0.53	1.73	1.59	1.59	1.01
2	0.29	2.32	2.46	1.93	
3	0.48	2.61	1.30	1.11	0.58
4	0.34	2.61	2.12	1.74	
5	<0.24	2.87	1.98	1.59	1.16
6	0.29	2.36	2.75	2.46	1.26
7	<0.24	2.99	2.51	2.08	
8	0.29	3.19	2.61	2.46	1.74
9	<0.24	1.50	1.69	1.79	
10	1.11	1.93	2.04	2.32	
11	0.29	2.79	1.93	2.03	
12	<0.24	2.03	1.59	1.25	
13	0.29	no data	no data	1.59	1.16
14	<0.24	3.52	2.65	2.22	1.45
15	0.29	1.98	1.88	1.79	0.97
16	0.24	2.37	2.12	2.12	
17	0.29	2.75	2.99	2.32	1.45
Mean	0.31	2.47	2.14	1.91	1.20
Median	0.29	2.49	2.08	1.93	1.16

Mean change 1/29–3/03 = 2.16 μmol/L
Mean change 3/03–3/31 = −0.34 μmol/L
Mean change 3/31–5/03 = −0.23 μmol/L

During firearms training, the class was on the range a total of 17 days: six days in *Period 1*; five in *Period 2*; and six in *Period 3*. The time spent on the range each day varied, depending upon the type of training being done. In addition, the number of rounds fired by each trainee each day also varied, but was approximately 120 rounds per hour of training (Table 2).

At the end of Period 1, after just seven hours of shooting over that four-week period, the blood lead levels were elevated, from a pre-training mean of 0.31 μmol/L to 2.47 μmol/L (Table 1). Thereafter the levels decreased slightly. The blood lead levels for all nine trainees who had a fifth blood sample drawn decreased between the fourth and fifth sample, from a mean of 1.90 μmol/L to 1.20 μmol/L.

The FEP levels rose throughout the entire study period from a pre-training mean of 0.49 μmol/L to 1.27 μmol/L at the end of the study (Table 3). The FEP levels for the nine trainees who had blood drawn about six weeks after completion of training all showed a decrease from the May 3 level, dropping from a mean of 1.53 μmol/L to 1.23 μmol/L.

Air lead concentrations for each occupied booth are

TABLE 2—Amount of Time the Law Enforcement Trainees Spent in the Firing Range and the Approximate Number of Rounds Fired, per Time Period

Time Period	Number of Days	Mean Total Time (hours)	Range	Mean Time per Session (minutes)	Range	Rounds Fired
1. (February 3–March 2)	6	7.2	7.0–7.6	72	33–120	900
2. (March 3–March 30)	5	2.6	2.5–2.7	39	12–78	300
3. (March 31–May 3)	6	4.1	4.1–4.1	41	3–121	550

TABLE 3—Free Erythrocyte Protoporphyrin Levels of Law Enforcement Trainees, μmol/L, Colorado, 1987

	Date Sample Was Taken				
Trainee	1/29/87	3/03/87	3/31/87	5/03/87	(6/10–6/18)
1	0.35	0.46	0.37	0.44	0.37
2	0.60	1.43	2.53	2.21	
3	0.62	0.66	0.92	1.12	0.90
4	0.34	0.48	0.62	0.64	
5	0.39	0.97	1.91	2.11	1.74
6	0.62	0.81	1.08	1.24	1.01
7	0.43	0.48	0.92	1.03	
8	0.37	0.51	0.81	0.94	0.87
9	0.35	0.37	0.48	0.48	
10	0.60	0.62	0.96	1.04	
11	0.35	0.50	0.94	1.35	
12	0.55	0.58	0.89	0.69	
13	0.76	no data	no data	1.84	1.56
14	0.67	1.04	2.16	2.66	1.93
15	0.46	0.66	0.76	0.80	0.64
16	0.34	0.35	0.43	0.48	
17	0.48	1.29	2.81	2.60	2.07
Mean	0.49	0.70	1.16	1.27	1.23
Median	0.46	0.60	0.92	1.00	1.01

Mean change 1/29–3/03 = 0.21 μmol/L
Mean change 3/03–3/31 = 0.46 μmol/L
Mean change 3/31–5/03 = 0.11 μmol/L
Mean change 1/29–5/03 = 0.79 μmol/L

shown in Table 4. Final adjustments to the ventilation system completed on March 9 probably contributed to the large decrease in the amount of airborne lead to which each person was exposed, as evidenced when comparing concentrations from the March 3 sampling with those from March 31 sampling. The data also show that the different booths on the range had very different air lead concentrations, both before and after changes were made to the ventilation system. The air lead concentrations in the classroom and control room dropped to below detectable levels after the first adjustment in the ventilation system.

The cumulative exposure to lead was directly related to the change in blood lead in Period 1 (Figure 1). We estimated lead exposure for the subjects not included in this figure by averaging the concentrations for the booths on either side of

TABLE 4—Air Lead Concentrations of Each Occupied Firing Range Booth, 8-hour Time-Weighted Averages in μg/m³, Colorado, 1987

	Date of Sample				
Booth	2/03 am	2/03 pm	3/03 am	3/03 pm	3/31
1	—	—	2917	—	2567
2	—	—	3095	1641	—
3	—	—	1823	994	811
4	2389	2688	3555	3398	837
5	PF	PF	2953	2359	850
6	639	513	1856	1883	553
7	2553	2426	4921	5589	1041
8	—	304	—	—	1006
9	—	—	4207	3269	1540
10	—	—	3706	4114	1875
Mean	1860	1483	3226	2906	1231
Classroom	175	170	<17	<17	<28
Control room	160	175	<17	<17	<23

Dual Image Shooting (March 31) = 205 μg/m³
— = Booth not being used.
PF = Pump failure
OSHA Standard is 50 μg/m³ for an 8-hour time-weighted average.

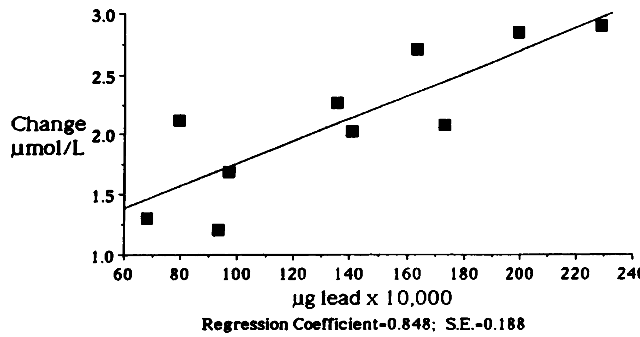

FIGURE 1—Change in Blood Lead Levels of Trainees* by the Cumulative Exposure to Lead in the Firing Range during Period 1 (January 29–March 3, 1987)
***Includes only the 10 trainees with complete data.**

the one with a failed pump, and redid this analysis; the results were very similar.**

Symptoms possibly related to lead exposure were reported by three trainees who complained of having a metallic taste in their mouth throughout most of the training.

The results of the air sampling using alternative ammunition (Table 5) indicated that substantial reductions in airborne lead were obtained through the use of the jacketed bullets. A 97 percent reduction occurred when using the copper-jacketed bullets.

Discussion

All of the blood lead levels collected on March 3, after four weeks of training, were above 1.45 μmol/L, considered elevated for non-occupational exposures; 14 were >1.93 μmol/L, the value at which the Occupational Safety and Health Administration (OSHA) requires active medical surveillance in occupational settings; and four were >2.90 μmol/L, the level at which OSHA requires medical removal from the source of exposure.[14] Even though most of the blood lead levels began to drop after March 3, only two trainees had a blood lead level below 1.45 μmol/L by the end of the study, and eight still had levels >1.93μmol/L.

The decrease in the blood lead levels after March 3 could be attributed to the lower mean time spent on the firing range and amount of ammunition fired by each recruit during March and April, final adjustments to the ventilation system, and five days of "dual-image" training where only one trainee at a time was on the range for a very short period of time and exposed to much lower levels of lead (205 μg/m³ versus an average of over 2,000 μg/m³—Table 4).

**Data available on request to authors.

TABLE 5—Air Lead Levels in μg/m³ Using Different Types of Ammunition, 8-hour Time-Weighted Averages, Colorado, 1987

Booth	Lead Bullets	Nylon-coated Bullets	Copper-jacketed Bullets
6	741.5	52.0	27.8
7	1800.9	82.3	43.7
8	1752.4	no data	30.5
9	1345.8	100.5	70.2
Mean	1410	78.3	43.1
Reduction	—	94.5%	97.0%

While the blood lead levels began to decrease after March 3, the FEP levels continued to increase. At the end of the study, 11 trainees had FEP levels >0.89 μmol/L, a level at which lead poisoning would be considered a more likely cause than iron deficiency anemia, which may also elevate the FEP level.[15–18] The FEP levels decreased for all nine trainees sampled about six weeks after completion of training. However, five still had FEP levels greater than 0.89 μmol/L.

The blood lead level reflects very recent and current lead absorption. It is not an indicator of the total body burden of lead. The FEP can reflect lead absorption over the previous three to four months and is indicative of biological effects on heme synthesis, thus being a better indicator of the total body lead burden.[15,19,20]

The overall mean air lead concentration for all booths before the March 31 sampling was >2,000 $\mu g/m^3$ (Table 4). At this concentration, the OSHA permissible exposure level of 50 $\mu g/m^3$ for an 8-hour time-weighted average[14] was exceeded within 12 minutes of shooting. The mean exposure level determined on March 31, after final adjustments to the ventilation system, was 1,231 $\mu g/m^3$. At this level, the permissible exposure level is exceeded in 20 minutes of shooting. The trainees were on the range a mean of 73 minutes per session in *Period 1*, 39 minutes per session in *Period 2*, and 41 minutes per session in *Period 3* (Table 2), all well above the time limit at which the OSHA permissible exposure level was exceeded given the range's air lead concentrations.

In recent years, the use of handguns has increased rapidly as a recreational activity, resulting in the formation of many gun clubs whose members use indoor firing ranges frequently.[7,8]*** This, in turn, has resulted in the increased construction and use of indoor firing ranges. The NRA and AFA estimate that there are about 800,000 competitive pistol shooters and 70 million privately owned handguns in the United States.*** Two major builders of indoor firing ranges—Detroit Armor and Caswell International—estimated that they have built about 50 public indoor firing ranges each year for the past 5–10 years, with the number increasing each year.*** In addition, the National Institute for Occupational Safety and Health estimates that there are 16,000 to 18,000 indoor firing ranges in the United States.

Interviews conducted with members of shooting clubs in the Denver area, as well as telephone communication with the NRA and the AFA, revealed that pistol club members commonly practice weekly as a group for as much as an hour or two at a time, each shooting approximately 100 to 200 rounds of ammunition each time. Serious competitive shooters reported practicing up to five hours per week shooting about 500 rounds of ammunition per week. If other indoor firing ranges have air lead concentrations similar to those found in this study then, based on our data, frequent users would be at risk for developing elevated blood lead levels and adverse health effects from the lead exposure.

At the very least, users should be made aware by means of conspicuous warning posters that exposure to lead from indoor firing ranges can cause adverse health effects. Improvements of ventilation systems may help to decrease air lead concentrations. However, such measures are extremely difficult and expensive to undertake and often do not alleviate the problem.[6] Another alternative is to limit the amount of exposure a person could receive by determining from air monitoring how long a person could remain on the range per day before the person's exposure exceeded the OSHA standard. While it is not clear whether a high exposure to lead in a short period of time is biologically equal to lower exposure over a longer period of time, this approach to controlling lead exposure has been suggested.[6] For some persons this may be acceptable, but for others, especially members of pistol teams, such a time limit may be unacceptable. Another option that also may not be popular with the public is requiring the use of respirators while using the indoor firing range. A final possibility, and one that may have the most potential, is to use jacketed ammunition, shown in this and other studies to be effective in reducing the air lead level in indoor firing ranges.[6,21]

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