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**Lead Exposure, Knowledge, Attitudes and Perceptions, and Effectiveness of a New Hand Cleanser: A Field Study Involving Recreational Firearms Users at Two Shooting Ranges**

Mark Boeniger, Public Health Consultant, 8380 Jakaro Drive, Cincinnati, OH 45255

Susan Puskas, Vice President, Quality, Regulatory Affairs and Human Relations, Medtox Scientific, 402 West County Rd, Saint Paul, MN 55112

ABSTRACT

Firearms are a source of lead (Pb) exposure for millions of recreational and professional users. This study presents results of a field survey that measured lead in hand wipe samples, both quantitatively and qualitatively (using a colorimetric indicator). A new skin cleansing towelette, specially developed for removing toxic metals from the skin, was evaluated for its efficacy to remove lead. Study participants completed questionnaires that measured their knowledge, attitudes and perceptions regarding lead exposure and firearms use, and their perceptions about how the new skin cleanser performed. Following a competitive match, the mean amount of Pb on both hands of all participants was  $595.2 \mu\text{g} \pm 766$ . Following use of the hand cleanser towelette, the mean Pb sampled was  $109.6 \mu\text{g} \pm 87$  ( $n=28$ ,  $p=.003$ ).

Users of non-jacketed ammunition were significantly more exposed than users of jacketed bullets, with a mean exposure of  $964 \pm 866 \mu\text{g Pb}$  ( $n=15$ ) and  $121 \pm 83 \mu\text{g Pb}$  ( $n=14$ ), respectively. Pistol shooters had almost twice the hand exposures as rifle shooters. A colorimetric indicator wipe sampling method for Pb was able to identify amounts greater than about  $140 \mu\text{g Pb}$  per hand wipe.

Overall, on a scale of 1-10, participants desired more information about the amount of Pb exposure received while shooting, mode = 8. The median and mode scores regarding the cleanser's performance were 9 and 10. Most also liked the feel (e.g. gentleness, lather, ease of use) and gave a median and mode score of 8.8 and 10. Fourteen of the respondents had at least at one time had their blood tested for lead. Of these, nine (64%) reported that their results were elevated. Exposure to lead from firearms use warrants additional research on the pathways of exposure, how to best reduce exposure, and education efforts to minimize both personal exposure and the risk of take home transfer.

## INTRODUCTION

Presently, there are between 16,000 and 18,000 firing ranges in the United States. Among the National Rifle Association's 3156 ranges, 30% of those are indoor shooting facilities. The National Shooting Sports Foundation estimates there are 17 million active target shooters in the United States, including 13.8 million rifle shooters and 10.7 million who participate in handgun target shooting.<sup>1</sup> Among law enforcement agencies, there are 88,000 federal and one million state and local officers who are required to train with their firearms regularly. Approximately 18 million Americans purchased a hunting license in 2005.<sup>1</sup> Finally, among regular and reserve military branches there are millions of additional people who regularly train with firearms.

Lead (Pb) is a soft inorganic element that presents an unusually high hazard to health. Unlike most toxic substances, the U.S. Environmental Protection Agency has not been able to assign a no-effects threshold dose for lead, because studies continue to discover adverse health effects at increasingly lower dose levels. Part of the hazard of lead is its ability to accumulate within the body over time, increasing health risks from small but frequent exposures. The Occupational Safety and Health Administration considers a workplace over-exposure to be an average airborne concentration greater than 50 micrograms per cubic meter ( $\mu\text{g}/\text{m}^3$ ) of air, which is equal to a daily maximum allowable amount of about 500 micrograms ( $\mu\text{g}$ ) per day (assuming an inhalation volume of  $\sim 10$  cubic meters of air). The volume of 500  $\mu\text{g}$  of lead is about the size that would cover the nose on an Eisenhower dime.

Persons who use firearms can receive substantial exposures to lead, as reflected by elevated blood-lead levels and clinical symptoms.<sup>2,3,4,5,6,7,8,9</sup> Lead fume is emitted from two sources during conventional firearm use: 1) lead styphnate from the ignition primer, and; 2) elemental lead from the bullet due to heat and friction as it moves down the barrel. Particle sizes are typically between 0.5 to 2  $\mu\text{m}$ , so they are quickly dispersed when the firearm is discharged.<sup>15,10,11</sup> The gases and particles emitted when firing a gun may contain unburned gunpowder compounds (nitrocellulose, nitroglycerin, etc), carbonaceous material, lubricants, nitrates, and several elements. The primer inside the cartridge is likely to contain lead styphnate, barium nitrate, and antimony sulfide compounds. Ammunition construction typically consists of the bullet head (traditionally made of lead), a cartridge filled with gunpowder, and an impact sensitive primer that ignites the powder. During firing, temperatures inside the barrel can approach 2000°F, easily volatilizing lead at the base of the bullet. It has been reported that roughly 80% of the lead emitted when firing comes from the bullet and 20% is due to the primer.<sup>12</sup> Full metal jacketed bullets, despite the name, are not actually completely covered - the base of the bullet is partly to completely uncovered. The purpose of jacketing is to reduce barrel fouling and it can also enhance target penetration. "Total" metal jacketed bullets are now available

where the entire bullet is encapsulated in copper. Conventional ignition primer, which in addition to containing lead, may also contain barium and antimony. Presently, a variety of non-leaded primers are available.<sup>13,14</sup>

Most modern (or gas operated) semi-automatic firearms use the force of expanding propellant gas to eject spent cartridges and to chamber new rounds. Emissions that occur when the breach is opened to eject the spent cartridge, as well as what is emitted from the end of the barrel and gaps in the firing mechanism, may be deposited onto the shooter, a process that is referred to as blowback. That which is deposited onto the shooter is the gun shot residue (GSR).<sup>15</sup> Firearm users exposed to GSR are at risk from airborne and dermal exposures to Pb, with substantial concentrations of Pb deposited on their hands. Handling firearms before and after shooting also increases risks for dermal exposures to GSR. If the hands are not fully decontaminated, firearm users have increased risks for lead exposure through hand-to-mouth contacts which can include consumption of food and beverages, and smoking. Transfer of unseen GSR contamination can also result in lead present inside users automobiles and other surfaces that are frequently touched and contacted by bare skin.

Typically, public health investigations of lead exposures from use of firearms have focused on airborne exposures, without considering skin contamination. Field studies to evaluate interventions have focused primarily on substitution of non-leaded ammunition and ventilation controls. Other interventions such as the effectiveness of hand decontamination to reduce hand-to-mouth transfer, have not been studied. One unpublished report regarding hand contamination with lead found thousands of micrograms of lead after target shooting among college students at a indoor firing range.<sup>16</sup> In that study the levels of lead obtained upon arriving at the shooting range on hand wipe samples varied between 46  $\mu\text{g}$  to 290  $\mu\text{g}$  of lead per wipe. Post shooting hand wipe samples showed wipe concentrations from between 390  $\mu\text{g}$  to 3900  $\mu\text{g}$  of lead (approximately a 10-fold increase).

The most comprehensive research regarding hand Pb deposition and firearms use has come from the forensic field. One study documented the potential for transfer of Pb to police vehicles and other surfaces by persons who may have used firearms.<sup>17</sup> An extensive study of elemental gunshot residue analysis, involving over 1500 test shots and 57 weapons, was reported by Krishnan in 1977.<sup>18</sup> His work focused on the distribution of Pb on the hands and the type of weapon used. Generally, it was found that increasing the caliber increased the Pb deposition on the hands. When rifles were fired, deposition was usually greater on the hand holding the gun, rather than on the trigger hand if bolt-action mechanisms were used, whereas deposition was generally greater on the trigger hand if semi-automatic weapons were used. This is as expected, since with bolt-action rifles, the breach remains closed, whereas with semi-automatic

weapons the breach is temporally open to expel the spent cartridge and replace it with a fresh one. With handguns, lead deposition on the hand grasping the handgun was higher than on the one not holding the gun. Deposition on the back of the hand was not much different from the palmer surface of the grasping hand, presumably because touching any surface of the contaminated firearm caused transfer of the Pb to the skin surface. Krishnan also reported that handling cartridges, whether spent, or when loading, appreciably contaminates the hands with highly variable concentrations of Pb, ranging from the tens of micrograms to over a thousand micrograms, after only one to four shots were fired. Krishnan did not address whether the type of ammunition used might affect Pb deposition.

Another recent study mapped the Pb residues on the hand by taking tape strip samples from the surface of the hand.<sup>19</sup> Samples were collected on the anterior and palmer side on each digit and the main part of the hand that grasped the grip. Samples were taken after a .38 caliber revolver and a .38 semi-automatic pistol, both firing jacketed ammunition, was used. Overall, the entire hand was fairly uniformly contaminated, with only slightly greater amounts found on the thumb and trigger finger. Pb residues were about two times greater when the revolver was used. One, two and four shots were fired and the Pb concentrations on the hand increased with each shot, but not in a linear manner.

Hand wipe samples have been previously collected by others to document Pb on the hands of occupationally exposed workers, and among children living in older housing that has lead-based paint. Normally, persons should not be expected to have detectable amounts of Pb on their hands. Unfortunately, few surveys have previously been performed to document the amount of Pb on the hands of firearm users who typically fire many rounds during a relatively short period. Of concern is that many of these individuals may not be fully aware of the risks of lead exposure due to having contaminated hands, or how to reduce exposure.

Many state health departments now post internet information about the hazards of lead exposure while using firearms.<sup>20</sup> The National Institute for Occupational Safety and Health (NIOSH) has prepared a NIOSH Alert to inform firearm users of the potential hazards and risks from lead in GSR and how exposures can be prevented, including the use of appropriate hand decontamination.<sup>21</sup>

Recently it was revealed that common soap and water is not an effective method of decontaminating skin after lead exposure.<sup>22,23</sup> NIOSH researchers had developed a pre-moistened towelette that has been shown to be an effective method for removing toxic elements from the skin, and this could be especially useful for firearms users who may not have access to facilities with running water. A complimentary development by NIOSH researchers quickly and inexpensively reveals the presence of lead on hands and hard surfaces so the need for decontamination is evident.<sup>22</sup> Used together, these two technologies

identify and remove lead from the skin and other surfaces, and therefore could appreciably reduce firearm users' exposures and the potential for take-home transfer.

The primary goal of this study was to evaluate perceptions and attitudes of firearm users to a novel skin cleanser towelette recently developed by NIOSH researchers. Firearm users (hereafter, "shooters") were chosen for this study as a practical application of such a towelette and because minimal exposure research had been conducted on this potentially large population. A instantaneous, colorimetric lead detection wipe, developed by NIOSH researchers, was used in conjunction with the new skin decontamination method to provide immediate results for the presence of lead. This study reports both objective quantitative measures of performance, as well as subjective measures of knowledge, attitudes, and perceptions (KAPs) measured using a questionnaire.

## METHODS

Two private shooting facilities were recruited for this study near a mid-western city. One was an indoor facility which allowed use of only unjacketed ammunition and handguns. Participants shoot with one hand. The second site was an outdoor range whose members used a variety of handguns and rifles with no restrictions on type of ammunition. Users of pistols generally shot with two hands. All participants were recruited on-site at the time of sampling and provided voluntary written informed consent after the nature of the study was verbally explained to them and they were provided a informational sheet and a detailed informed consent document.

In both situations, the participants in this study shot during competitive matches where the number of shots fired was pre-determined and fixed. This allowed repeat sampling opportunities on the same individuals and between individuals under nearly identical conditions, the only exception possibly being the type of firearm and ammunition used.

To evaluate the new skin cleanser, the cleanser (MEDTOX Scientific, St. Paul, MN) was provided after a shooting match. To sample the amount of Pb on the hands, the participants were provided a pre-moistened towelette (AramSCO Lead Wipes, Thorofare, NJ) and used this to wipe their hands for 30 seconds. This was performed two consecutive times. Samples were placed into lead free centrifuge tubes (Becton Dickenson, Falcon Blue Max™ 50 mL polypropylene, Franklin Lakes, NJ) for storage and transport to the laboratory.

Collection of dermal wipe samples for Pb was previously determined to have a collection efficiency of approximately 65 – 70%.<sup>24</sup> Since two consecutive shooting matches were included, the cleanser was used in only one of the

matches so that it could be compared to the amount of Pb present after a match when the cleanser was not used. The use of the cleanser was provided alternatively to each participant after the first or second match in a random manner to avoid possible bias due to the order in which the cleanser was used. The cleanser towelette was provided to each participant to use on his or her hands for 30 seconds, followed by use of a second towelette with water only that was to be used to remove residual soap from the skin. When possible, hand wipe samples were also collected from participants before they began shooting. 'Before shooting' sampling was conducted simply to document possible contamination upon arrival at the range from handling their firearms, ammunition and, from touching environmental surfaces such as doorknobs etc. at the range. Environmental surface wipe samples were taken to investigate secondary sources of dermal exposure and risk factors for transfers of contamination to skin. The technique used to sample followed the guidelines provided in ASTM Method E 1728-03 for the collection of surface wipe samples for lead.<sup>25</sup>

NIOSH Analytical Method NMAM #9105, (Colorimetric Screening Method for Lead) was used to disclose the presence of Pb collected from hand wipe samples.<sup>26</sup> After collection the wipes were placed on a fresh sheet of wax paper, sprayed with the leaching solution followed by the colorimetric indicator solution. Visualization of the colorimetric change is immediate. NMAM 9105 is known to detect as little as ~15 µg of lead on a wipe.<sup>27</sup> All wipe samples were sent to an AIHA accredited laboratory (MedTox Laboratories, St. Paul, MN) for quantitative analysis using an in-house method based on inductively coupled plasma, mass spectroscopy (ICP-MS) instrumentation.

A non-exposed comparison group, consisting of ten individuals who lived in the same area but who were not known to have potential exposure to Pb, were also asked to provide a hand wipe sample.

### Questionnaire Survey

Two questionnaires were administered as part of this study. An initial one was distributed to all participants in order to document basic demographic information, including gender and age, what type(s) of firearms were used, the kind of ammunition used, and number of rounds expected to be fired. In addition, basic information about each participant's knowledge, attitudes and perceptions (KAP) was requested, focusing on what they knew and thought about lead exposure during firearm use, and what they typically did to avoid exposure. Figure I lists the specific initial questions about KAPs as they were presented in the questionnaire.

A post shooting questionnaire form was administered to some of the participants in order to see if their attitudes and perceptions had changed after having

observed the use of the colorimetric indicator and after using the new hand cleanser. The questions presented in this questionnaire are provided in Figure II.

## RESULTS

### Quantitative Pb Sample Wipes

A total of 29 participants were included from the two shooting facilities in this study. The results of the quantitative hand wipe samples, the colorimetric screening assessment, and the questionnaire responses are provided below.

An initial hand wipe sample was collected from 16 of the participants before shooting began. An assumption was made that participants likely drove their vehicles to the shooting range; touched firearms and shooting box (if used), and likely loaded ammunition before shooting. The mean Pb amount found on these samples was  $165 \mu\text{g} \pm 182$ , minimum  $15 \mu\text{g}$  and maximum  $752 \mu\text{g}$ . These results demonstrate that firearm users do not have to actually fire their weapons in order to become contaminated.

After the matches, the mean loading of Pb on the hands of all participants was  $595.2 \mu\text{g} \pm 766$ . When the hand cleanser towelette was used after a match, it reduced the mean loading to  $109.6 \mu\text{g} \pm 87$ . The difference between the amount of Pb sampled from the hands after using the cleanser towelette, or not using the towelette, are highly statistically significant (paired t-test, 2-tailed,  $n=28$ ,  $p=.003$ ).

The amount of Pb sampled from the hands of shooters using jacketed ammunition was considerably less than when using non-jacketed ammunition. Jacketed ammunition users had only  $121 \pm 83 \mu\text{g}$  Pb ( $n=14$ ) before the cleanser was used, while firing non-jacketed ammunition resulted in a mean sampled amount of  $964 \pm 866 \mu\text{g}$  Pb ( $n=15$ ). Lead loadings in non-jacketed ammunition users ranged from 159 to 3487  $\mu\text{g}$  Pb. The difference between the two group means was highly statistically significant (independent group t-test, 2-tailed,  $p < .001$ ). Considering the jacketed and non-jacketed groups separately regarding the efficacy of the cleanser towelette, use of the cleanser resulted in a 58% and 81% reduction in Pb sampled from the hands, respectively. The amount of lead removed by the cleanser in both cases were statistically significantly different from the hands that were not cleaned (paired t-test, 2-tailed,  $p=.0012$  and  $p=.0024$ , respectively). The data for these four groups are provided in Table 1 and depicted graphically as a percentile box plot in Figure 3.

Differences in the amount of Pb found on the hands of rifle shooters and pistol shooters using jacketed ammunition were also compared. The mean loading of

Pb found on the rifle shooters hands was  $85 \pm 66 \mu\text{g Pb}$  ( $n=6$ ), while the loading detected on the pistol shooters hands was  $148 \pm 88 \mu\text{g Pb}$  ( $n=8$ ). Though the amount found on pistol shooters' hands was greater, this difference was not statistically different in this small group sample comparison (independent group t-test, equal variance, 2-tailed  $p=.152$ )

### Environmental wipe samples

Surface wipe samples identified many environmental sources of lead that could contaminate participants' hands, shoes, and clothing and contribute to transferring the lead to their vehicles and homes. Wipe samples from the tops of shoes recovered 97, 207, and 147  $\mu\text{g Pb}$ . In the indoor facility, the mean floor concentration was  $2947 \pm 762 \mu\text{g Pb}$  per square foot ( $n=3$ ). Metal door knobs within the facility were contaminated with  $94 \pm 39 \mu\text{g Pb}$  ( $n=3$ ). A draw handle and handle to a refrigerator in a kitchen area had 158 and 377  $\mu\text{g Pb}$ , respectively. A single wipe taken on a ledge within a gun box contained 3235  $\mu\text{g Pb}$ . Wipes of the grips on two automatic pistols were in a range of 474 – 1223  $\mu\text{g Pb}$  ( $n=2$ ).

Eight of nine field blanks were below the limit of detection ( $<2.0 \mu\text{g}$ ) except for one (2.5  $\mu\text{g}$ ).<sup>a</sup> Handwipe samples collected from 10 non-shooters (individuals living in the community) were all below the limit of detection.

### Qualitative Colorimetric Indicator

The colorimetric screening method disclosed whether lead was present on the hand wipe samples. Use of the method was intended to be teaching tool to allow participants to see that there was lead on their hands after shooting, and that the lead was removed after using the cleansing towelette. Notably less Pb was detected on hand wipe samples collected from participants using jacketed ammunition compared to non-jacketed. The limit of identification for Pb-containing GRS was approximately 140  $\mu\text{g}$ , while the mean amount quantified on the sampling wipes from shooters using jacketed ammunition was 121  $\mu\text{g}$ . In addition, wipes that clearly showed red coloration – indicating the presence of lead, seemed to have less color saturation than what was previously observed in laboratory-prepared samples with pure forms of lead. Color photographs of some of these samples, along with the amount of Pb quantitatively determined by laboratory analysis, are shown in Figure 4.

### Questionnaires

Twenty-nine initial questionnaires were completed. The questionnaires administered to the participants provided valuable information about the

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<sup>a</sup> In retrospect, the one blank above the LOD was prepared downwind of the shooting site.

individuals and the type of firearm and ammunition used, and the amount of shooting conducted. It was possible to assess whether there were possible differences in the magnitude of hand contamination related to firearm and ammunition, as well as other factors.

Semi-automatic pistols were used by 25 of the participants, while rifles were used by six. The types of ammunition used included lead round nose, 14; lead wadcutter, 5; full metal jacket, 12; and jacketed hollow point, 3. Most of the participants practiced shooting between 1 and 8 times per month. Only three practiced shooting more than this. During these practice sessions, the average duration spent at the facility was 145 minutes (range 60 to 300 minutes) but not all of the time was spent shooting.

Regarding knowledge and perceptions about lead exposure during firearm use, all but one individual indicated on the questionnaire that they were aware that using firearms could expose them to lead. On a scale of 1 thru 10, the most common rating (mode) on how informed they felt about the health hazards of lead exposure was 10, with a median of 8. Regarding concerns about exposure to Pb during firearm use, the median and mode ratings were 5 and 10. Most were interested in learning more about ways of avoiding exposures with median and mode ratings of 8 and 10. The most common sources of information cited as to where they were most likely to have received information about lead exposures were magazine articles (41% of respondents, presumably in gun-related publications) and from other firearm users (48% of respondents). Other sources of information cited included newspapers, television and the internet.

Fourteen respondents reported having their blood tested for lead at least at once. Nine of 14 (64%) reported being told their blood lead levels (BLL's) were elevated. Respondents were not asked which BLL health-based criteria (e.g., OSHA or USPHS) resulted in a determination of an elevated BLL, because it was assumed that the respondents would not be familiar with the specifics of these criteria.

Regarding the respondents' practices to avoid exposure to lead, 66% indicated that they never eat afterwards without first washing their hands, while 28% indicated that they did sometimes, and 2 indicated that they almost always eat afterwards without first washing. As to when they were more likely to clean their hands after shooting, 41% reported that this was typically performed immediately after shooting (while at the facility), 45% reported that washing was performed within an hour of leaving, and 14% reported that they typically washed more than an hour afterwards. Twenty-six (90%) of the respondents reported that they typically used common soap and water to wash their hands, while five used only moistened towelettes, such as baby wipes, or both soap and water and towelettes. Most of the respondents were non-smokers (86%) but those that did smoke indicated that they sometimes smoked at the practice

range. Twenty-one respondents (72%) wear the same shoes that they wore at the shooting range that they wear to go home, while eight only sometimes do. Eighteen (62%) always wear the same clothes home as they wore at the shooting range, while 10 (34%) reported that they sometimes do, and only one reported that they never do. Twenty-four respondents (83%) reported that they never wear gloves while cleaning their firearm, while three reported sometimes wearing gloves and two almost always wearing gloves. Gloves made of rubber or plastic were chosen if gloves were worn.

The colorimetric indicator wipe was demonstrated to 13 shooters using unjacketed ammunition in the indoor range. A second questionnaire was given to these participants. The colorimetric method indicated that there was substantial lead present on the hands after shooting, as well as all environmental surfaces investigated in the range (Table 1). The colorimetric method was also used among several outdoor shooters, but it was quickly apparent that little hand contamination was present, so a decision was made to discontinue its use since it would not reveal to the participants (in this scenario) how effective the hand cleanser worked. The use of fully jacketed ammunition was likely the reason for this, as a few of the outdoor shooters who did use unjacketed ammunition produced a colorimetric reaction on their hand wipe samples.

Comparing the initial questionnaire results with the post questionnaire results after the colorimetric indicator was demonstrated to 13 indoor shooting range participants showed a generally positive effect of increasing their level of concern about their exposure to lead while shooting. The median and mode responses initially and afterwards were 5 and 10 versus 7 and 10 (Wilcoxon's Signed Rank Test,  $p=.094$ ). Most of these participants indicated a high appreciation of the colorimetric indicator with a median and mode score of 10. However, when asked after the colorimetric indicator was used how interested these participants were to learn more about ways to avoid exposure to lead, median and mode scores before and after were as follows: 8 and 10 versus 9 and 10 (Wilcoxon's Signed Rank Test,  $p=.206$ ).

When the same 13 participants saw the differences in lead on their hands, as demonstrated by the colorimetric indicator, the majority thought that the hand cleanser towelette performed well. The median and mode scores regarding the cleansers performance were 9 and 10. Most also liked the feel (e.g. gentleness, lather, ease of use) and gave a median and mode score of 8.8 and 10.

## DISCUSSION

There is a scarcity of research regarding the public health hazards and risks of Pb exposure during firearms use. In the Krishnan study, and the indoor college range survey mentioned previously, hand contamination amounts were

comparable to the present surveys results.<sup>16,18</sup> In these surveys, a hand rinse method with dilute acid, or moistened towelettes, were used for sampling, respectively, and might have similar sampling recoveries from the skin surface as the method used in the present study.

While participants in the present study used a wide variety of handguns, it was not feasible to conduct a more detailed analysis of the exposure data and correlation with caliber or specific type of hand gun. Future studies could look at the affect of gun caliber and ammunition type and other possible aspects that could affect personal Pb exposure, where these details are systematically assessed. While future investigations may produce additional recommendations to reduce exposures to Pb from GSR, it is clear that effective skin decontamination is a critical, yet not well adopted behavior of recreational shooters.

The colorimetric reagent used in this study, while most sensitive to lead, can also produce a colorimetric reaction to cadmium, barium, nickel, strontium, silver, mercury and calcium.<sup>28</sup> However, the amount of these elements necessary to produce a visible colorimetric reaction is typically much greater than for Pb, and the color hue produced is also typically different than for lead. Cadmium and nickel are the strongest positive interferences, but the specificity of sodium rhodizonate to Pb is about 10,000 times greater.<sup>28</sup> Some potential negative interferences have also been identified, including sodium, potassium, chlorine, iron and tin, but these also need to be present in high concentrations. If these elements are present, they can attenuate the color reaction formed with Pb.

The sensitivity of NMAM 9105 to detect Pb on the hand wipe samples was less than previously documented in the laboratory using pure forms of Pb where approximately 15 µg/wipe could be identified. The colorimetric method nonetheless is a valuable tool in detecting skin contamination from Pb and making risk-based decision to protect public health. In this investigation, the apparent limit of identification was approximately 140 µg Pb/wipe. The exact reason for the lower sensitivity is not definitely known, but most likely is due to the presence of other chemicals, or the form of Pb present that could reduce its solubility in the weak acid leaching solution that is applied. Information regarding the form of Pb present in gunshot residues was not found in the literature. If it were simple Pb metal or Pb oxide, sensitivity should be high, but if it were an organo-Pb compound, this could inhibit proper coupling of the colorimetric reagent molecule with an ionic Pb atom that is needed to form the color complex.

There are no health-based exposure criteria for dermal contamination of lead on skin (hands), however, comparisons can be made to the time weighted average inhalation dose limit mandated by the Occupational Safety and Health Administration (OSHA). The OSHA Permissible Exposure Limit (PEL) is 50 µg/m<sup>3</sup>,

for an 8 hour day of work, and if multiplied by the amount of air typically inhaled per work shift ( $10\text{m}^3$ ), dose would be  $500\ \mu\text{g}$  of Pb per day. The OSHA PEL is intended to protect adult workers who might be exposed daily during a 5-day work week for a 40 year working life. Therefore, the ability to detect a minimum of  $\sim 140\ \mu\text{g}$  or more of Pb on the hands might be a practical tool that indicates a hazard from hand contamination and the necessity for adequate decontamination to prevent hand-to-mouth exposures, without being overly sensitive.

Research studies have shown a strong relationship between contaminated hands and body burden for Pb and other toxic elements among workers in various occupations.<sup>29,30</sup> The fact that thousands of micrograms of lead can quickly accumulate on the hands of firearm users has been demonstrated by this study. Risks for Pb exposures to firearm users vis-à-vis transfer of Pb to food, cigarettes, and the mouth is real. In comparison to inhalation exposure that might be received while shooting, hand-to-mouth transfer may predominate. An upper range estimate of the air concentrations of Pb experienced when shooting is between  $112 - 238\ \mu\text{g}/\text{m}^3$ .<sup>31</sup> A shooter, engaged in mild physical activity, might breath roughly  $1.2\ \text{m}^3$  of air in an hour. Even if there was complete retention and absorption of these unusual exposure concentrations, the exposure to Pb via inhalation while shooting could easily be surpassed by the much greater amounts found on the hands.

Personal exposure to lead and transfer to other items can be limited by the use of traditional approaches that include substitution, engineering controls, or administrative hygienic practices. Lead-free shot (for shotguns) has been a federal requirement for waterfowl hunting for more than two decades. These lead-free pellets are made with either bismuth, tungsten, nickel, iron, or a combination of these. Lead-free cartridge bullets are also available for both rifles and handguns. These are typically made of copper. Increased fouling of the gun bore by non-lead bullets may be a more frequent occurrence than with Pb bullets. In all cases, Pb-free ammunition is also more expensive than traditional ammunition.

Engineering controls can be applied to the design of indoor range facilities. These include the provision of well designed ventilation systems for removing contaminated air and replacing it with fresh air. However, because of the close proximity of the users' face and hands to the firearm, and the high velocity of the expelled emissions from the firearm when discharged, effective reduction of personal exposure through engineering designs can be limited and the costs of installing and operating such engineering controls can be considerable.

Administrative hygienic controls of exposure are traditionally the least preferred, because of greater dependence upon the persons exposed, but may be the only available, least expensive, and most practical approach to preventing exposure to toxic materials. There are numerous approaches available to control personal

and secondary transfer of Pb to other surfaces and people. Frequent cleaning of indoor facilities by HEPA vacuuming and wet washing of surfaces, use of sticky floor mats to remove tracked out Pb from the bottoms of shoes, and not wearing the same clothing and shoes worn at the firing range when in a vehicle or home are some possible measures. Wearing tight fitting rubber or plastic gloves while shooting and preparing ammunition could eliminate considerable hand contamination. Finally, effective decontamination of the hands before eating is an important requirement if this likely route of intake of Pb is to be prevented.

The decontamination cleanser that was field tested in this study was designed by researchers at the Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health (CDC\NIOSH) to remove Pb and other toxic metals through the processes of surfaction, chelation, pH adjustment, and mechanical removal.<sup>22</sup> Design and components of the decontamination system were chosen considering safety for the skin and the environment. In-vitro skin penetration testing found that the active ingredients have no effect on the penetration of Pb through human skin, but that common soap and water can increase penetration by up to 8-fold.<sup>32</sup> That study also suggested that the residence of Pb on the skin, if not removed promptly, could contribute to increased body burden and elevated blood concentrations over time.

The effectiveness of the skin cleaner to remove Pb from the hands was less in this field study than when tested in laboratory studies.<sup>33</sup> In laboratory testing, the skin cleanser components were evaluated individually and in various combinations to determine efficacy. Two configurations were tested with and without using a rinsing step (under running water). The rinsing step was determined to be beneficial to remove residual surfactant along with residual Pb. Using a rinsing step, a 99.5% reduction of Pb was seen after 3000 µg was applied to the skin. When a water rinse was not used, removal was reduced to 97%.

In this study, the objective was to measure the effectiveness of the cleanser without a rinsing step. With the exception of indoor shooting ranges, persons using outdoor ranges (or when hunting) generally do not have running water available for hand decontamination. By extension, workers - as at construction sites for example, may also not have running water nearby. To remove residual surfactants left on the skin surface by the cleanser towelette, a second towelette was provided that was wetted only with water. In retrospect, probably too much water was used to moisten the second towelette and this simply diluted the surfactant, but did not completely remove it. A dryer towelette would probably be superior in sorbing and removing the surfactant and chelated Pb, along with any residual Pb from the skin surface. Current efforts to refine this modification are in progress.

Based on the questionnaire responses, there is a real need for improved education among firearm users regarding their potential exposure to Pb and how to limit their personal exposure as well as how to minimize exposure of others, by avoiding take home transfer. The need for such improved education was reflected in the high proportion of elevated blood lead concentrations reported by these participants. If this proportion of elevated blood lead, as seen in this small survey, is at all representative of the general firearms using community, the total number of affected individuals in the United States could be substantial. Although this present study focused on recreational firearm shooters, the need for good personal hygiene practices, which includes use of an effective decontamination cleanser, is applicable to the prevention of exposure to Pb in many trades and for those whose hobbies expose them to Pb.

## CONCLUSIONS

This study affirms that using firearms is a source of lead exposure and results in appreciable loading of Pb on the hands of the user. Skin contamination should not be disregarded as a inconsequential public health hazard, due to the potential for hand-to-mouth transfer, percutaneous absorption, and take-home transfer. Use of a novel skin cleanser was effective in removing lead from the skin, and was rated favorably by the participants in this study. The use of a colorimetric screening technique for detecting the presence of lead was useful for showing firearm users whether lead was present and of the need for decontamination or other interventions. The large population of firearm users in the U.S. warrants that risk-based emphasis be placed on education and prevention of lead exposures.

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