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The Evaluation and Validation of IDenta Corporation's Bullet-hole Testing Kit (BTK)

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The Evaluation and Validation of IDenta Corporation's Bullet-hole Testing Kit (BTK)

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Abstract

Originally developed in 1982, IDenta Corporation's Bullet-hole Testing Kit (BTK) is currently being used around the world in the field of crime scene analysis. IDenta claims the kit can successfully be used to identify a bullet hole and determine its caliber. The kit was used to test 180 holes made by firearms and other non-firearm weapons. Though the statistical analysis of the data shows there is not enough evidence to conclude the BTK is capable of identifying a bullet hole or determining a bullet's caliber, there are additional factors that must be considered. The user's ability to distinguish between true bullet holes and false positives is achieved through additional training and shows the kit as an aid in identifying true bullet holes. Furthermore, further research concerning the kit's ability to determine a bullet's caliber has the potential to support such a claim.

Keywords Bullet-hole Testing Kit, Shooting Reconstruction, Sodium Rhodizonate, Rubeanic Acid

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Introduction

Crime scene analysis boasts a long history. Years of deductive and inductive reasoning applied to physical evidence found at the scene has successfully claimed a place for crime scene analysis in the field of forensic science. An investigator's ability to reconstruct the potential series of events leading up to and during a crime hinges on the ability to correctly identify relevant physical evidence and its role in the scene. Many companies over the years have developed a wide array of products to aid the crime scene investigator in this task.

Shooting scenes are becoming increasingly commonplace. As reported by the Federal Bureau of Investigation (2013), 69 percent of murders, 40 percent of robbery offense and 21.6 percent of aggravated assaults in the United States included the use of a firearm. The need to reconstruction a shooting scene presents itself regularly. Identifying a bullet's path and finding the fired bullet are important fundamental aspects of shooting reconstruction. IDenta Corporation's Bullet-hole Testing Kit (BTK) is a chromophoric (color-producing) test able to detect the presence of lead and copper, two common components in modern ammunition. Through this color change, IDenta claims the ability of the BTK to identify a bullet hole, determine directionality of the bullet when it struck the surface, and estimate the bullet's diameter while in the field, during the initial crime scene investigation (IDenta Corporation).

Within the United States court system, the admissibility of expert scientific evidence and testimony is subject to the requirements established in Daubert v Merrell Dow Pharmaceuticals, Inc. Therefore, an evaluation and validation of IDenta's BTK is necessary before this technique can be applied in the United States and its results used in a court of law.

Background

In a 1923, Mr. James Alphonso Frye was charged and convicted of second-degree murder. Prior to conviction, a systolic blood pressure polygraph was performed on Mr. Frye. This test was based on the belief that a person's systolic blood pressure rises when telling a falsehood. Mr. Frye had 'passed' this exam, and wished for an expert in this technique to testify on his behalf to overturn his conviction. This request was rejected after it was found that this particular type of polygraph examination had not yet been scientifically recognized by the relevant psychological and physiological authorities. This ruling established the Frye test, which requires the principles on which expert testimony is based be generally accepted by the scientific community (Frye v United States).

The Federal Rules of Evidence, Rule 702 specifically, further defined expert testimony and admissibility. It states:

> If scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise, if (1) the testimony is based upon sufficient facts or data, (2) the testimony is the product of reliable principles and methods, and (3) the witness has applied the principles and methods reliably to the facts of the case.

When Merrell Dow Pharmaceuticals, Inc. was sued by the parents of children born with birth defects after the mothers were prescribed and ingested the anti-nausea medication Bendectin, the ideas and guidelines pertaining to expert testimony and the admissibility of theories and techniques was once again revised. The Daubert Standard poses the following questions for the admissibility of techniques or theories in a U.S. courtroom:

- Has the technique or theory been scientifically tested?
- Does the technique or theory have a known or potential error rate?
- Has the technique been subjected to peer review and publication?
- Is the technique or theory subject to standards governing its application?
- Is the technique or theory generally accepted by the relevant scientific community? (SWGGUN ARK)

In order for a product to be used in the forensic science community, and any results collected with that product, and be admissible in a United States court, the previously stated requirements for expert testimony must addressed. For companies outside of the United States, this is not a procedure typically encountered. The request by IDenta to have their Bullet-hole Testing Kit be validated within the United States was made to the University of Central Oklahoma's Forensic Science Institute.

The IDenta Corporation was established by Mr. Yaacov Shoham, the company's CEO, and Mr. Baruch Glattstein, the company's Chief Scientist, of Israel. With many years of experience within the Israeli police force, these two men have developed multiple products for in-the-field detection of illicit drugs and explosives by law enforcement agencies all over the world. Their line of products also includes drug detection kits for the consumer market. IDenta Corporation is currently the sole producer of an in-the-field bullet hole testing kit (IDenta Corporation website; B. Glattstein, personal communication, December 18, 2014). The IDenta

Bullet-hole Testing Kit is already currently available through many American forensic supply retailers.

Literature Review

When the trigger of a firearm is pulled, a sequence of mechanical action occurs that results in the discharging of a cartridge. The striking of the primer results in the ignition of the powder charge held within the cartridge case. This ignition results in a rapid expansion of gases and pressure, which force the bullet down the barrel, as well as creating recoil during the extraction and ejection of the fired cartridge case (Meyers, 1993; Heard, 2008; Hatcher, Jury & Weller, 2006). The ignition of the impact-sensitive primer compound and the gunpowder charge creates not only gases and pressure, but particulates and residues as well. Known as gunshot residue (GSR), partially burned, unburned and the soot from burned gunpowder are expelled from the barrel of the firearm after the bullet. Some residues are deposited on or around the target, while some of these residues are left within the barrel to be transferred to the surface of the subsequently passing bullet. The residues then left on the bullet will typically be transferred to the initial target in what is known as bullet wipe. The Association of Firearm and Toolmark Examiners (AFTE) define bullet wipe as "the discolored area on the immediate periphery of a bullet hole, caused by bullet lubricant, lead, smoke, bore debris or possible jacket material" (AFTE Glossary, 2013, p.140). The presence of bullet wipe is indicative of the passage of a bullet; however, the absence of bullet wipe does not preclude the passage of a bullet. Its presence can be used in reconstructing a shooting scene. This bullet wipe is also capable of containing trace amounts of the bullet's jacketing material. The turbulent journey down the rifled barrel of a firearm will score the surface, allowing for minute particles to be transferred to the target.

Modern ammunition – bullets

Being easily melted and formed, as well as being readily available, has made lead a logical metal for bullet manufacture since the inception of the firearm. However, lead buildup within the barrel created many issues in muzzle-loading firearms. As breech-loading firearms and modern cartridges were developed, this issue was combated with the jacketing of the lead bullet with a cuprous zinc alloy (Walker, 1940). Jacketed ammunition is far more popular with modern shooters and exceedingly common. Lead-only projectiles are still manufactured and used, but to a far lesser degree. In recent years, a trend towards decreasing a shooter's exposure to lead has resulted in changes to bullet design. This includes the creation of the total metal jacket. A traditional full metal jacketed bullet has an exposed lead base. During the firing process, this lead can be vaporized and inhaled as well as be deposited on the firearm's barrel, the target and/or the shooter. To decrease this exposure, the total metal jacket encases the entire bullet, including the base. If the cartridge's priming compound contains lead, vaporous lead is still a risk factor but to a lesser extent (Gulson, Palmer & Bryce, 2002).

Modern ammunition – primers

Smokeless powders have revolutionized the firearms industry. Clean, efficient and cheap, these chemical compounds give shooters the utility needed to project a bullet down a barrel at amazing speeds. However, these smokeless powders are only as good as the primers that ignite them.

Modern smokeless powder primers consist of seven components all with the intention of providing a combustible gas to ignite the propellant. The seven are an initiator, a sensitizer, an oxidizer, fuels, a frictionator, binders and other materials. The initiator is what detonates upon impact of the firing pin, as it is the primary explosive, and heats the mixture to ignite the powder. The most commonly used initiator today is lead styphnate. It is non-corrosive and does not contain mercury. The sensitizer in modern priming mixtures is tetracene, which helps increase the lead styphnate's sensitivity to shock. The oxidizer provides oxygen to the reaction so that the initiator and additional fuels have sufficient oxygen to create as much expanding gases as possible. A commonly used oxidizer is barium nitrate, as it stores well and does not react with other chemicals whether wet or dry. Fuels, such as powdered aluminum, are added to the priming mixture to burn. They use the oxygen provided by the oxidizer to create a longer lasting flame to ensure the propellant is ignited. Antimony sulfide is generally used as it is easily oxidized and very stable. The frictionator is always found in rimfire cartridge primers, but not always in centerfire cartridge primers. This is due to the need for something sharp for the sensitizer and initiator to hit against in order to react rapidly. Ground borosilicate glass is best. Binders, such as gum or starches, help keep the seven components mixed together once they have dried, as they are typically manufactured and placed in the cartridge cases damp.

For centerfire cartridges, a pellet of the wet priming mixture is inserted into the primer cup. The priming mixture and the anvil, "an internal metal component…which the priming mixture is crushed by the firing pin blow" (AFTE Glossary, 2013, p. 7), are separated by a small foil disc and sealed with lacquer. When assembling rimfire primers, a pellet of wet priming mixture is dropped into the mouth of the cartridge case and placed under a spinner bit that rotates at 3500 to 4000 rotations per minute. The bit moves down the cartridge case, spinning the priming mixture into the rim of the case. (Eissler, 1897; Davis, 1943; Remington Factory Tour, 2011).

Chromophoric (color-change) testing in bullet hole detection

With the obvious abundance of lead and copper used in the manufacturing process of modern ammunition, it follows to use the presence of these metals for bullet hole detection. These metals are transferred to the bullet and the bullet's target through multiple means. The lead, barium and antimony typically found in modern primers can be deposited in the gun barrel. As subsequent bullets pass through the barrel, that debris can be deposited on the exterior surface of the bullet. In addition, small amounts of this debris can be blown in front of the bullet, allowing for this transfer to occur even in a freshly cleaned barrel. This same process is true for vaporous lead created by the excessive heat from the gunpowder's ignition melting the exposed lead on the bullet's base (if jacketed), or the bullet itself (if lead-only). Copper is far less malleable and requires much more heat to vaporize than lead and thus is typically seen in far less quantity than lead. Copper residues may be detectable near a bullet hole due to the damaging interaction between the bullet's jacket and the barrel's rifling during the firing process. In addition, the abrasive qualities of the target material can play a role in trace amounts of copper being left on the target (Walker, 1940; Haag, 1981; Haag, 2001).

Some of the methods that have been employed to detect these heavy metals on and around bullet holes include infrared photography, radiography, spectrography and microchemical methods. Each of these methods had their limitations. Radiography equipment was not easily accessible; spectrography required the destruction of the fabric that contained the bullet hole; and with microchemical methods, again the fabric was destroyed as well as needing technical skill to conduct these procedures. In 1940, Walker cites multiple German-written articles discussing experiments for the detection of lead and other heavy metals, but no set procedure or methodology had been established at that time and such methods were even identified as requiring “considerable skill… not quantitative, and do not leave a permanent visible results” (Walker, 1940, p. 505). However, the interest scientists took to bullet hole testing during the first half of the 20th century is apparent.

The first appearance of heavy metal detection research using non-destructive microchemical techniques in the forensic community was in 1980 in an article summarizing a 1976 presentation made by Mr. Mitsumasa Kubota of the National Research Institute of Police Science in Tokyo, Japan, at the annual Association of Firearm and Toolmark Examiners conference. In his presentation, Mr. Kubota describes an experiment he conducted “to determine the composition of the bullet fired from the bore of the weapon” (Kubota, 1980, p. 60). Using filter paper, ammonia solution, sodium rhodizonate and rubeanic acid (also known as dithiooxamide or DTO), Mr. Kubota was able to successfully identify the bullet composition within the bore of a firearm. The procedure he employed allowed for testing with no harm done to the firearm. These same color tests were utilized by Lucien Haag in 1981; however, he applied them directly to the bullet hole to detect the presence of lead and/or copper. Suggested procedures for using sodium rhodizonate and rubeanic acid in the detection of lead and copper, respectively, were subsequently published for use in the forensic laboratory (Lekstrom & Koons, 1986; Dillon, 1990). These same generalized procedures, chemical concentrations and techniques have been adapted to in-field testing by the IDenta Corporation. Additional research has been conducted to expand on these procedures, establish and address their limitations and compare them to newly developed methods (Cole, Ross & Thorpe, 1992; Bonfanti & Gallusser, 1995; Schous, 1999; Kelley & Chu, 2001; Bailey, Swart & Finch, 2007; Jacobson, Swanepoel & Wong, 2010).

Problem Statement

IDenta Corporation's Bullet-hole Testing Kit (BTK) was originally developed in 1982 and is currently being used around the world in the field of crime scene analysis. However, any technique or theory to be used in a United States court must meet the standards for admissibility as outlined in the Daubert v Merrell Dow Pharmaceuticals, Inc. Supreme Court decision. Therefore, in order for any results found or conclusions drawn by using the BTK to be admitted as evidence in a United States court, any capabilities of the kit must be evaluated and validated through empirical research. A systematic validation of the kit and the claims made by IDenta concerning the kit's abilities must be conducted.

Research Questions

IDenta advertises the BTK as capable of "identifying bullet holes caused by many types of bullets, namely lead, full metal jacket (FMJ), total metal jacket (TMJ) bullets, etc.," as well as capable of "assess[ing] the direction from which the bullet was fired" (IDenta Corporation) based on the shape of the colored imaging of the hole, and lastly capable of estimating the diameter of the bullet from the diameter of the colored imaging of the hole. Due to constraints on the number of holes that can be tested, as well as the existence of validated procedures for determining a bullet's direction, IDenta's claims concerning the bullet's direction will not be tested in this research. The remaining claims produce the following hypotheses:

H1: The BTK will identify a bullet hole based on the presence of lead and/or copper visualized by a color change on the test paper.

$H1_0$: The BTK will not identify a bullet hole based on the presence of lead and/or copper visualized by a color change on the test paper.

H2: The BTK will estimate the diameter of the bullet based on the measurement of a visible color change on the test paper.

$H2_0$: The BTK will not estimate the diameter of the bullet.

Limitations

Many metals have a chromophoric reaction with sodium rhodizonate. The procedure set out by Dillon (1990) includes the application of a sodium rhodizonate solution to the suspected area followed by a buffer solution of sodium bitartrate and tartaric acid in distilled water. The color change produced *may* be lead, “but in order to be objective, it must be confirmed in an additional procedure which is chemically specific for lead” (p.252). This is achieved by spraying the suspected area with dilute hydrochloric acid. The BTK does not include hydrochloric acid, so the testing kit is a presumptive test for lead, not a confirmatory test.

Due to the inconsistent nature of lead and copper deposits around bullet holes, the BTK is unable to provide heavy metal data for every hole encountered. The risk of false negatives is possible, potentially leading a crime scene analyst to disregard a suspect hole as being made by a bullet when in fact it was. It must be acknowledged that the lack of color change when using the BTK does not eliminate the hole or defect as being made by the passage of a bullet. There is also a possibility of incorrectly identifying the type of ammunition used to create the bullet hole based on the BTK results. The BTK reacts with metal deposits around the hole. These deposits, called bullet wipe, are attributed to debris left on the bearing surface of the bullet by the firearm’s barrel. Therefore, the BTK results are potentially indicative of the residues in the firearm’s barrel, not the bullet that created the hole (Lekstrom & Koons, 1986).

The modern firearm and the ammunition it uses have not drastically changed for over 100 years. To stand out, manufacturers have begun experimenting with different materials. Not only are copper and lead being used in ammunition, but nickel, aluminum, tin, brass and zinc have found their way into modern ammunition. If present, these metals may mask or enhance the color change used in the BTK. Not all metals and their interactions with the chemical reactions utilized in the sodium rhodizonate test and the rubeanic acid test have been examined or accounted for.

Materials and Methodology

IDenta Corporation's Bullet-hole Testing Kit (BTK)

IDenta advertises their BTK as capable of identifying a bullet hole through the presence of copper (Cu) and/or lead (Pb), determining a bullet's direction based on the bullet hole shape and determining a bullet's caliber based on the diameter of the lead and/or copper reactions.

Figure 1. IDenta Corporation's Bullet-hole Testing Kit (BTK)

The BTK uses a chemical reaction between lead and sodium rhodizonate to provide a color change in order to confirm the presence of lead. This is accomplished with the use of crushable ampoules housed within plastic mini tubes and test paper. The glass ampoule containing acetic acid (labeled '1-Lead Solvent') is crushed. The acetic acid is dropped onto a clean piece of test paper. The test paper is then pressed against the suspect hole for approximately one minute. The breaking of the glass ampoule containing 5 milliliters of deionized water (labeled '2-Lead Reagent') creates a 0.2% aqueous solution with the 10 milligrams of powdered sodium rhodizonate held within the plastic mini tube. This aqueous solution is dropped onto the test paper. If lead is present, a magenta colored ring will appear on the test paper.

This same type of chemical reaction resulting in a color change is used to confirm the presence of copper by an interaction with rubeanic acid. The glass ampoule containing 5 milliliters of 12% ammonium hydroxide solution (labeled ‘3-Copper Solvent’) is crushed. The ammonium hydroxide solution is dropped onto a clean piece of test paper. The test paper is pressed against the suspect hole, as with the lead test. The glass ampoule containing a 1% alcoholic solution of rubeanic acid (labeled ‘4-Copper Reagent’) is crushed and dropped onto the test paper. If copper is present, a green-black colored ring will appear on the test paper (Steinberg, Leist & Tassa, 1984).

Sodium rhodizonate and rubeanic acid are not new chemicals to be used in bullet hole detection and analysis. These chemicals, in their respective concentrations and applications, have been used in the forensic laboratory for many years. However, their utility in the field has been limited. The BTK seeks to bring this chemistry to the field through their compact and portable BTK field kit. The case is 10.4 inches wide, 13.1inches long and 3.33 inches tall. Each kit contains forty ampoules: ten sets of solvent and reagent for lead and ten sets of solvent and reagent for copper. The kit also contains instructions for use, test papers, plastic bags for test paper collection, a ruler, a permanent pen and technician report forms to record observations.

IDenta Corporation donated four (4) Bullet-hole Testing Kit cases for the validation and evaluation of their product within the United States. This provides forty sets of solvent/reagent pairs for lead and forty sets of solvent/reagent pairs for copper, allowing for testing of approximately no more than 200 suspect holes.

Target Materials

As this kit is intended for use in the field, the target materials used simulate items typically found at crime scenes but are difficult to submit or transport to the forensic laboratory. The target materials used in this experiment included a car, sheetrock and vinyl siding. The car, a 2001 Hyundai XG300 4 door sedan, VIN KMHFU45D01A106912, was provided by a local police department. The sheetrock was constructed into 2'x2' square walls by a local university's carpentry shop. The Georgia-Pacific brand vinyl siding was purchased at Lowe's and installed in 4' lengths to two 4'x4' pieces of plywood.

Figure 2. Target Materials (car, sheetrock, vinyl siding)

Ammunition

Three projectile types were used: Aguila brand 22 LR 40 grain lead round nose, Speer brand 9mm Luger 124 grain Gold Dot jacketed hollow point and American Eagle (Federal) brand 40 S&W 180 grain full metal jacket. As the BTK tests specifically for copper and lead, only copper jacketed lead 9mm Luger and 40 S&W bullets were used; and 22 LR bullets of lead only.

Figure 3. Ammunition (22 LR, 9mm Luger, 40 S&W)

Firearms

Each bullet type was fired into each of the three target materials using the following local police department reference firearms: Smith & Wesson 422 model 22 LR pistol, serial number TVC2405 and magazine; Glock 19 model 9mm Luger pistol, serial number FUL066 and magazine; and Glock 22 model 40 S&W pistol, serial number 2ESZ168 and magazine. Before each target material was fired into, the barrel of each firearm was cleaned with a cotton patch and Shooter's Choice Bore Cleaner.

Figure 4. Firearms (22 LR, 9mm Luger, 40 S&W)

Potential False Positives

The sheetrock and vinyl siding were punctured using non-bullet objects, specifically a Phillips head screwdriver and hammer, and Hilti brand DX 36 0.27 Caliber Semi-Automatic Powder Actuated Tools (stud gun), to test for potential false positives and to test the kit's ability to distinguish between bullet holes and non-bullet holes. The car was unable to be punctured with the screwdriver, however defects were created and tested with the screwdriver and hammer. The first stud gun rental broke during the research process after being used to puncture the vinyl siding. Another stud gun rental was obtained the following day and used to puncture the sheetrock and car.

Figure 5. Potential False Positives (screwdriver/hammer, stud gun)

Data Collection

Each target material was shot 12 times with each bullet type. All shots were fired at a distance of approximately 5 feet from the target, and approximately perpendicular to the target, representing the best case scenario. Each target material also had 12 holes created with the screwdriver; and 12 holes created with the Hilti powder actuated tool. This totaled 180 holes for testing.

Each suspect hole was tested for the presence of lead and copper based on the BTK manufacturer’s instructions provided in the case. Prior to testing, each test paper was labeled with a unique identifier explained in the data tables. A photograph with scale was taken after the manufacturer’s instructions were fulfilled.

Data Assessment

A result was considered positive for lead when a magenta color change, however slight, was observed. A result was considered positive for copper when a green-black color change, however slight, was observed. Per the manufacturer's literature, "the test takes 3-4 minutes from the time of sampling until final results are obtained" (IDenta Corporation BTK brochure), thus if a color change was not observed within four minutes of applying the reagent, a negative result was recorded. A positive (1) or negative (0) result was recorded for each test paper in an Excel spreadsheet.

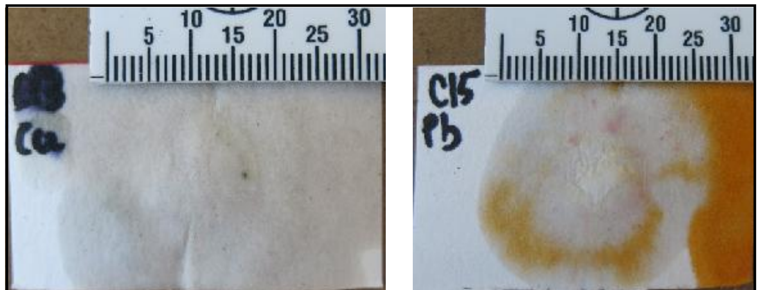


Figure 6. Example of 'slight color change' for copper (left) and lead (right).

The photographs were used to measure the diameter of the color ring to evaluate any correlation between the color ring diameter and the diameter of the bullet (H2). The measurement was only taken if enough of a circle (in the form of a visible color change) was present to measure a diameter. This measurement was recorded and statistically evaluated.

Analysis

Three different targets (car, sheetrock, vinyl siding) and five different weapons (22 LR pistol, 9mm Luger pistol, 40 S&W pistol, screwdriver, stud gun) were considered in this experiment. Twelve shots were fired (or holes punctured in the case of the screwdriver) for each combination of target and weapon. For each hole, the bullet test kit was used to test for the presence of lead and/or copper by observing a color change on a test paper. For the pistols, if a color change was present, the diameter of the hole was also measured. In many of these cases

(25 for lead and 16 for copper) a color change was present, but not enough of the shape was visible to measure the diameter (see Figure 6).

Color Change

1. Statistical Analysis

Logistic regression was used to test for differences in color change with respect to target and/or weapon. The dichotomous response variable, or the color change being a yes or no response, and the need to predict the probability of the color change response, fulfilled the need for logistic regression, versus other statistical procedures, such as analysis of variance. Four different logistic regressions were performed, each with a different dependent variable. The four dependent variables were (1) presence of lead (lead), (2) presence of copper (copper), (3) presence of both lead and copper (both), and (4) presence of either lead or copper (any). The independent variables were target, weapon, and the interaction of target and weapon. If a dependent variable was found to be significantly related to an independent variable, the logistic regression was followed by multiple comparisons with Tukey's adjustment for multiplicity. Summary statistics for color change are presented in Table 1.

Table 1. Number (%) of Test Papers on which a Color Change was Observed

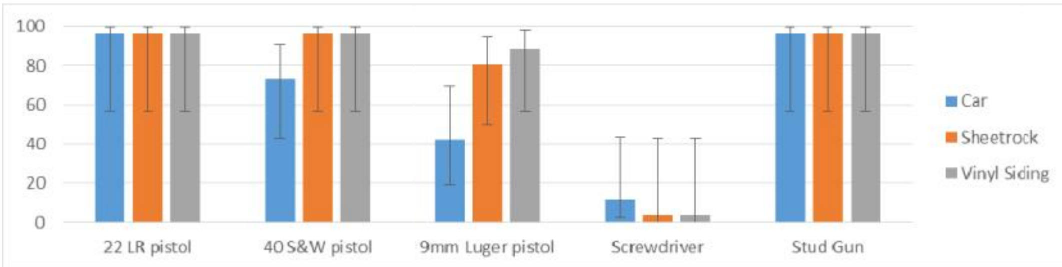
Weapon	**Lead** *n* (%)	**Copper** *n* (%)	**Both** *n* (%)	**Any** *n* (%)
22 LR pistol				
Car	12 (100)	0 (0)	0 (0)	12 (100)
Sheetrock	12 (100)	0 (0)	0 (0)	12 (100)
Vinyl Siding	12 (100)	0 (0)	0 (0)	12 (100)
40 S&W pistol				
Car	9 (75)	3 (25)	3 (25)	9 (75)
Sheetrock	12 (100)	12 (100)	12 (100)	12 (100)
Vinyl Siding	12 (100)	0 (0)	0 (0)	12 (100)
9mm Luger pistol				
Car	5 (42)	6 (50)	2 (17)	9 (75)
Sheetrock	10 (83)	12 (100)	10 (83)	12 (100)
Vinyl Siding	11 (92)	3 (25)	3 (25)	11 (92)
Screwdriver				
Car	1 (8)	0 (0)	0 (0)	1 (8)
Sheetrock	0 (0)	7 (58)	0 (0)	7 (58)
Vinyl Siding	0 (0)	1 (8)	0 (0)	1 (8)
Stud Gun				
Car	12 (100)	2 (17)	2 (17)	12 (100)
Sheetrock	12 (100)	12 (100)	12 (100)	12 (100)
Vinyl Siding	12 (100)	7 (58)	7 (58)	12 (100)

2. Results

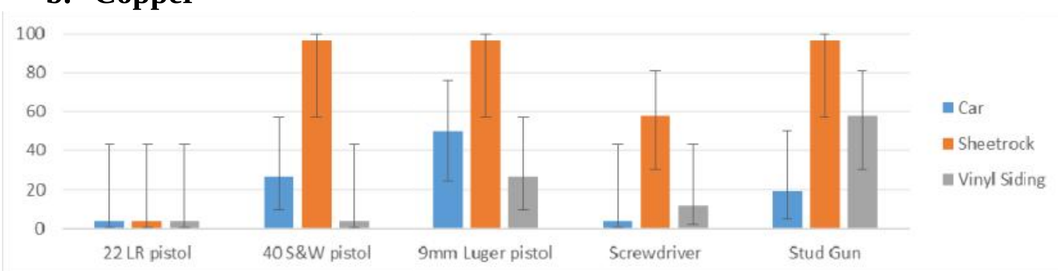
The target*weapon interaction was not significant in any of the models (lead: p=0.6952, copper: p=0.1988, both: p=0.2476, any: p=0.8805). The least squares means (with 95% confidence intervals) of the proportion of test papers on which a color change is observed are displayed in Figure 7.

Figure 7. Least Squares Means (with 95% Confidence Intervals) of the Proportion of Test Papers on which a Color Change was Observed by Target and Weapon

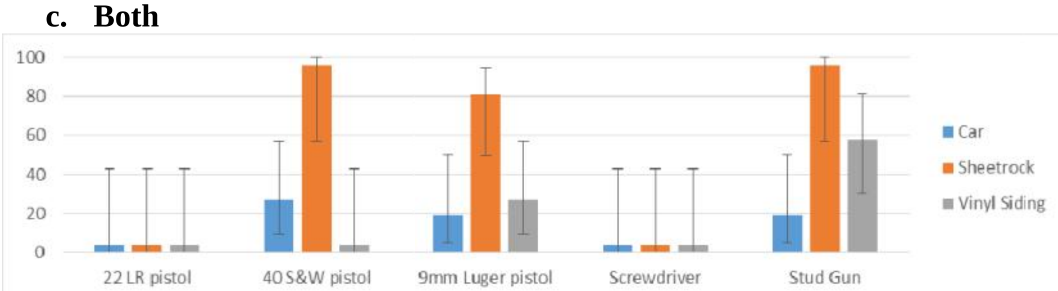
a. Lead



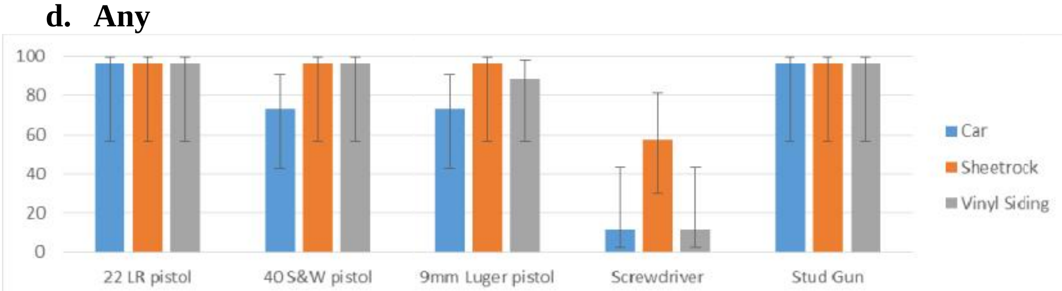
b. Copper



c. Both

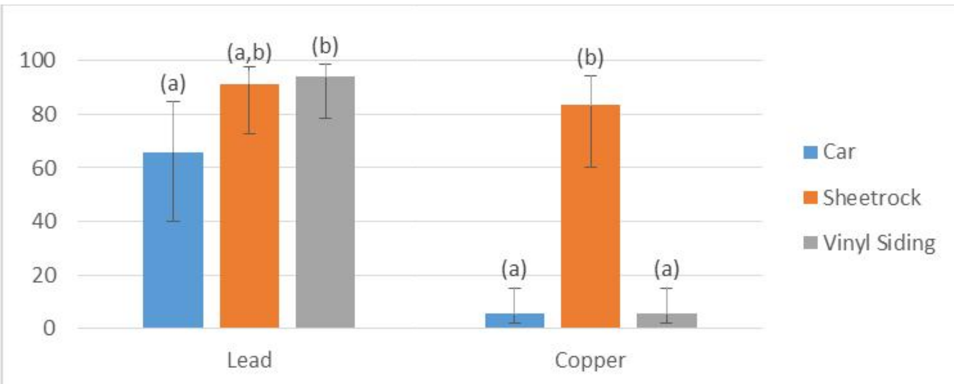


d. Any



Since none of the interaction terms was significant, the interaction terms were removed from the models leaving only the main effects for target and weapon. Both target and weapon were significantly related to the presence of lead and copper (lead: p=0.0126 for target and p<0.0001 for weapon, copper: *p*<0.0001 for target and *p*=0.0001 for weapon). Graphs for target (averaged over weapon) and weapon (averaged over target) are displayed in Figures 8 and 9, respectively.

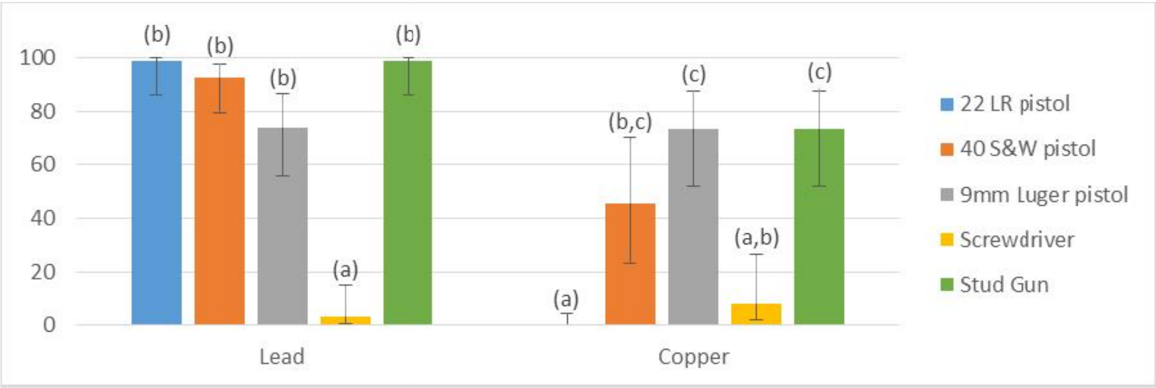
Figure 8. Least Squares Means (with 95% Confidence Intervals) of the Proportion of Test Papers on which a Color Change was Observed by Target.



(a,b) The lsmeans of targets tested for the same element, that are marked with the same letter are not significantly different at the 0.05 level.

In general, the fewest color changes (lead and/or copper) were observed on the car, and the most on the sheetrock. For lead, significantly more color changes were observed on the vinyl siding than on the car; and for copper, significantly more color changes were observed on the sheetrock than on either of the other two targets. There were no other significant differences with respect to target.

Figure 9. Least Squares Means (with 95% Confidence Intervals) of the Proportion of Test Papers on which a Color Change was Observed by Weapon.



(a,b,c) The lsmeans of weapons tested for the same element, that are marked with the same letter are not significantly different at the 0.05 level.

In general, the fewest color changes (lead and/or copper) were observed with the screwdriver and the most with the stud gun. For lead, significantly fewer color changes were observed with the screwdriver than with any of the other weapons. For copper, significantly fewer color changes were observed for the 22 LR pistol than for the 40 S&W pistol, 9mm Luger pistol, and stud gun; and significantly fewer color changes were observed for the screwdriver than for the 9mm Luger pistol and stud gun. There were no other significant differences with respect to weapon.

Diameter:

1. **Statistical Analysis**

Summary statistics and 95% confidence intervals for the mean diameters were computed for each combination of weapon and target for which at least two diameters were measurable. The confidence intervals were then compared to the true diameters of the bullets: 5.715mm for the 22 LR pistol, 10.16mm for the 40 S&W pistol, and 9.017mm for the 9mm Luger pistol. Summary statistics for diameter are presented in Table 2.

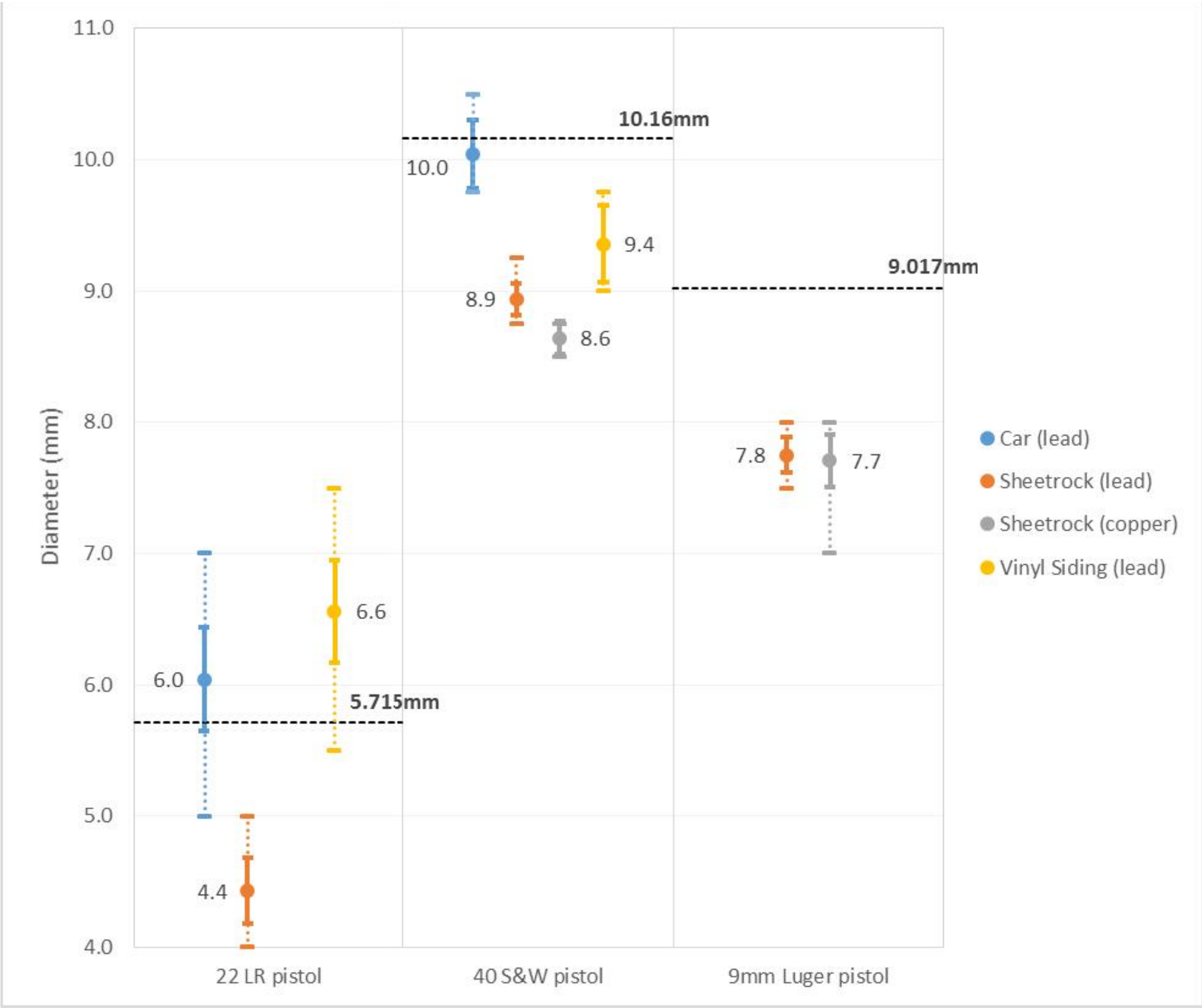
Table 2. Summary Statistics for Diameter (mm)

	Lead			Copper		
Weapon	*n*	mean (sd)	range	*n*	mean (sd)	range
22 LR pistol						
Car	12	6.04 (0.62)	5.00-7.00	0		
Sheetrock	11	4.43 (0.37)	4.00-5.00	0		
Vinyl Siding	12	6.56 (0.61)	5.50-7.50	0		
40 S&W pistol						
Car	6	10.04 (0.25)	9.75-10.50	0		
Sheetrock	12	8.94 (0.19)	8.75-9.25	7	8.64 (0.13)	8.50-8.75
Vinyl Siding	7	9.36 (0.32)	9.00-9.75	0		
9mm Luger pistol						
Car	1	10.75		1	11.00	
Sheetrock	9	7.75 (0.18)	7.50-8.00	12	7.71 (0.32)	7.00-8.00
Vinyl Siding	0			0		

2. Results

The 95% confidence intervals (marked with solid lines) and ranges (marked with dashed lines) for the diameters of each combination of weapon, target, and element are displayed in Figure 10. For each pistol, a reference line marking the true diameter of the bullets is shown on the graph. The confidence intervals for the car (lead) are the only ones that contain the true diameter. In all other cases, except vinyl siding (lead), the confidence intervals underestimate the true diameter. Even though most of the confidence intervals do not contain the true diameters, it does appear that the bullet test kit does a good job of separating the pistols since none of the confidence intervals for one pistol overlap any of the confidence intervals for the other pistols; and none of the ranges overlap if each target is considered separately.

Figure 10. 95% Confidence Intervals (and Ranges) for the Mean Diameters.



Discussion

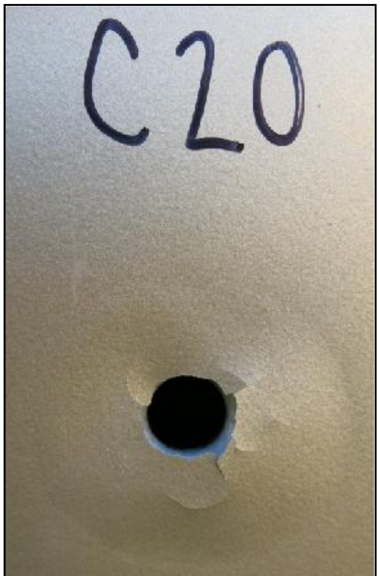


Figure 11. Bullet hole in painted vehicle sheet metal

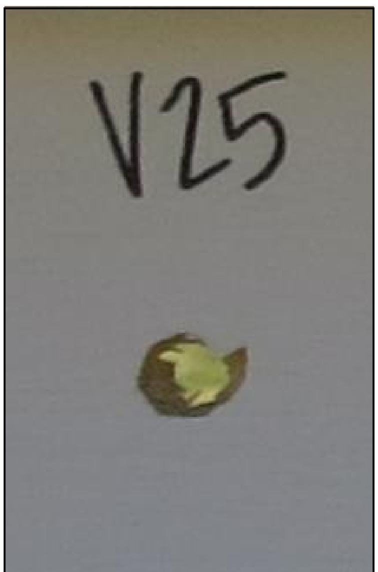


Figure 12. Bullet hole in vinyl siding

The BTK performed in a logical manner with the 22 LR pistol. As this ammunition is lead-only, no copper was detected while lead was detected on every target material. The BTK also performed in an expected manner with the 9mm Luger and 40 S&W pistols. This ammunition had copper-jacketed/lead core bullets as well as lead within the primer, so having both lead and copper detected follows an expected result. When considering the behavior of painted vehicle sheet metal when shot, it is expected that the bullet wipe containing the lead and copper residues is not readily visible or accessible by the BTK's test paper (See Figure 11). The sheet metal curls inward and the paint chips off, as seen in the above photo. The lead and copper residues may have been present on each test hole, however the BTK's method does not account for this and thus some residues may have been missed. The vinyl siding had the same possibility of missed residues due to the cracking and breaking of the plastic. Though the residues were visible, at times they were pushed deep into the hole (See Figure 12).

The screwdriver unexpectedly tested positive for lead or copper on each of the target materials. This is possibly due to contamination from the drawer in which the screwdriver was stored prior to use in this research. The sheetrock was punctured with the screwdriver first, and had the highest positive results;

while the vinyl siding then the car were punctured, each with only one positive result. This supports contamination that was removed during the puncturing of the sheetrock. For any future research, the screwdriver should be wiped down prior to use.

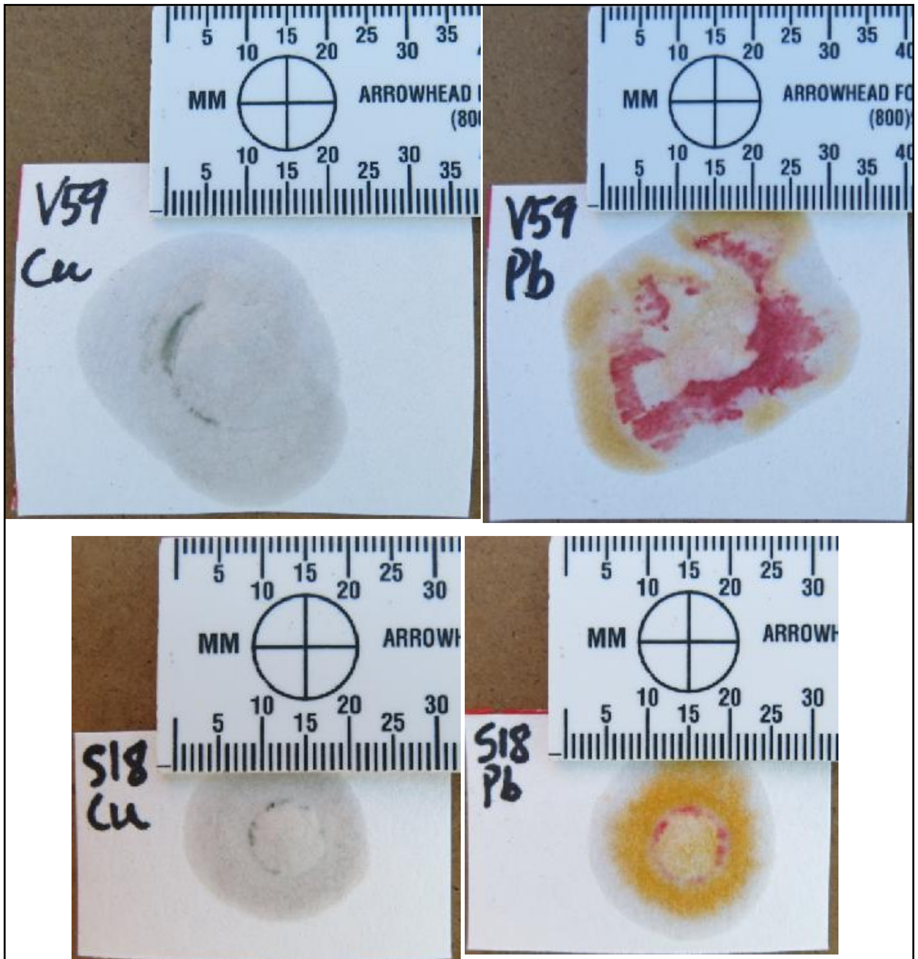


Figure 13. Differences in color change of stud gun versus bullet hole

The stud gun was used as a potential false positive. As the numbers show, the stud gun consistently produced lead and copper residues. If evaluated purely on the statistical analysis, it would appear the stud gun in fact ‘fooled’ the BTK. However, the appearance of the color change was vastly different from the color change seen from a known bullet hole (See Figure 13). If the user is trained, or aware of this possibility, this type of false positive is easily avoided.

Fail to reject $H1_0$: The BTK will not identify a bullet hole based on the presence of lead and/or copper visualized by a color change on the test paper. It was statistically shown that the target*weapon interaction is not significant. Meaning the differences in the weapon results are not dependent on the differences in the material; and the differences in the target results are not dependent on the differences in the weapon. When evaluating by target, the results were similar for some targets, but dissimilar for others. When evaluating by weapon, some results were similar and such results were logical and expected. An example is the similar results for lead residue for the 22 LR, 9mm Luger, 40 S&W and stud gun; while the screwdriver results for lead residue were significantly different. Lead is known to be in 22 LR, 9mm Luger, 40 S&W and stud gun blanks while lead is not a material used to manufacture screwdrivers. However, there was no significant difference between the 40 S&W and the screwdriver when evaluating the presence of copper residues. Copper is known to be in 40 S&W ammunition, but is not a material used to manufacture screwdrivers. Therefore, there is not enough evidence to conclude the BTK identifies a bullet hole based on the presence of lead and/or copper based on a visible color change on the test paper. However, even though the BTK did not successfully eliminate the screwdriver and stud gun in all cases, the addition of visual examination allows for the elimination of both the screwdriver and stud gun.

Fail to reject $H2_0$: The BTK will not estimate the diameter of the bullet. As seen in Figure 4 of the Results, the 95% confidence intervals for the mean of the measured diameter of the color changes for all three calibers used did not contain the true diameter of the caliber except in two cases (22 LR fired into the car and the 40 S&W fired into the car). If looking at the true value of the diameter, a hole made with a 40 S&W bullet could easily be mistaken for a hole made with a 9mm Luger bullet. Therefore, this is not enough evidence to conclude the BTK estimates the diameter of the bullet based on the measurement of a visible color change on the test paper. However, the confidence intervals for different calibers do not overlap. Though these confidence intervals do not contain the true value, the fact that they do not overlap could be enough to establish ranges for the diameters of the different calibers based on the target. These upper and lower bounds could be established with addition research, and then the BTK would likely be capable of estimating the diameter of the bullet.

Conclusions

The use of sodium rhodizonate and rubeanic acid in distance determination analysis is widely accepted. The value of these chemical reactions with lead and copper has been documented many times in both research and casework. This project was undertaken to extend those benefits to in-the-field analysis. Though the statistical analysis of the data shows there is not enough evidence to conclude the BTK is capable of identifying a bullet hole or determining a bullet's caliber, there are additional factors that must be considered.

Identifying a bullet hole. The user's ability to distinguish between true bullet holes and false positives is achieved through additional training. This training must consist of photographs of BTK results from true bullet holes and false positives to show the consistency and narrow color ring typically exhibited by true bullet holes; and photographs of BTK results from false positives to show the sporadic and inconsistent patterns exhibited by other non-firearm defects. A competency test and certificate of completion in a user's training record would support the user's ability to correctly access the BTK results. When a trained user employs the BTK, the kit will prove to be an aid in identifying true bullet holes.

Determining a bullet's caliber. Further research concerning the kit's ability to determine a bullet's caliber has the potential to support such a claim. If BTK results of additional bullet holes of known caliber were measured, upper and lower bounds could be established for each caliber. With enough measurements, statistically significant data would show the kit's ability to predict a bullet's caliber based on the color change observed.

The BTK would be a valuable tool to any crime scene investigator or shooting incident reconstructionist. With proper training and knowledge of the kit's strengths and weaknesses, the BTK would be a valuable addition to any department's or agency's arsenal of tools used in the field. As gun crime is a common occurrence in the United States, having the ability to properly identify true bullet holes can increase productivity and efficiency at crime scenes by allowing one to triage defects at shooting scenes.

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