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The Use of Image Analyzing Software for Muzzle to Target Distance Determination

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Kimberly A. Edwards

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The Use of Image Analyzing Software for Muzzle to Target Distance Determination

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By ______________________________

Name Graduate Advisor

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Name Committee Member

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Name Committee Member

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THE USE OF IMAGE ANALYZING SOFTWARE FOR MUZZLE TO TARGET DISTANCE DETERMINATION

2011

Kimberly A. Edwards

Muzzle to target distance can be an important aspect in criminal investigations. For most distance determination opinions to be of value to an investigation, the range must be stated such that it gives meaningful information and the resulting bracket of muzzle to target distance must also be defended during courtroom testimony. Current measurement tools lead to subjective opinions by examiners. With objective measurements, examiners can provide improved investigative conclusions that may be defended in court with quantifiable data. Due to the rapid advancement in software technology in recent years, the ability exists to analyze targets with more accurate measurements. Currently, test targets are measured by approximate methods which utilize a high degree of subjectivity. This study examined the application of *Image J*, image analyzing software, for use in determining muzzle to target distance. This research examined objective data to include particulate density and Gunshot residue dispersion and carried out a statistical replicate study to determine the number of targets needed at a given distance for each gun and ammunition combination.

One pistol, revolver, rifle and shotgun were selected for this study. Test targets were shot five times at distances of: 4, 8, 12, 16, 20, 24 and 28 inches for the pistol, revolver and rifle, and at distances of: 4, 8, 12 and 16 feet for the shotgun. Visual and chemical examinations were performed on test targets using standard protocol procedures, published through the National Institute of Justice (NIJ) Distance Determination Training Module (2011). The targets were digitally photographed through each step and analyzed using the aforementioned protocol and *Image J*, image analyzing software. Comparisons were made between the National Institute of Justice model and *Image J*. Data were obtained and reported using the image analyzing software for particulate count and GSR dispersion.

DEFINTION OF TERMS

(As defined in AFTE GLOSSARY 5th Edition) (Association of Firearm and Toolmark Examiners, 2010)

Ammunition – The material fired in and from any weapon. One or more loaded cartridges consisting of a primed case, propellant, and with one or more projectiles.

Bullet – A non-spherical projectile for use in a rifled barrel and sometimes contained within a sabot.

Bullet wipe – The discolored area on the immediate periphery of a bullet hole, caused by bullet lubricant, lead, smoke, bore debris or possible jacket material.

Cartridge Case – The container for all the other components which comprise a cartridge.

Gushot Residues – The total residues resulting from the discharge of a firearm. It includes both gunpowder and primer residues, plus metallic residues from projectiles, fouling, etc.

Modified Griess Test – A version of the original Griess test in which alpha naphthol is used in place of Marshall's reagent as a result of reported carcinogenic qualities of Marshall's reagent.

Muzzle – The end of a firearm barrel from which the bullet or shot emerges.

Nitrites – A chemical component of black and smokeless gunpowder.

Primer – The ignition component of a cartridge.

Projectile – An object propelled by the force of rapidly burning gases or other means.

Sodium Rhodizonate Test – A method of detecting primer and lead bullet residue.

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Chapter 1

Introduction

In the United States, firearm injury accounts for approximately 31,000 deaths yearly (CDC, 2009). In 2009, the FBI's Uniform Crime Report stated there were 13,636 homicides (Federal Bureau of Investigation, 2009). Of those homicides 67% were committed with a firearm. According to the *National Suicide Statistics at a Glance* report, between 2002-2006 half of all suicides involved a firearm (CDC, 2009). According to the Centers of Disease Control and Prevention (2010) between the years of 1979 and 2007 unintentional firearm injuries remained either the second or third leading cause of injury death in the United States.

Firearm examiners support investigations of gunshot injuries by providing meaningful investigative leads as to answering questions of muzzle to target distance. For most distance determination opinions to be of value to an investigation, the range must be stated such that it gives meaningful information and the resulting bracket of muzzle to target distance must also be defended during courtroom testimony.

Background

When a firearm is discharged it ejects many components from the muzzle to include: partially burned and unburned gunpowder, lead, barium, antimony and other metallic components from the primer compound, propellant powder and bullet, for pistols, revolvers or rifles or pellets or slugs in shotguns. Firearms can also eject these components from other openings such as the cylinder gap in a revolver. These residues expelled from the firearm are collectively referred to as gunshot residue (GSR). GSR is expelled from the firearm at a high velocity in the shape of a cone and renders an irregular, elliptical-type pattern onto a target (see *figures 1 & 2*).

Figure 1. Cone-shaped GSR deposition

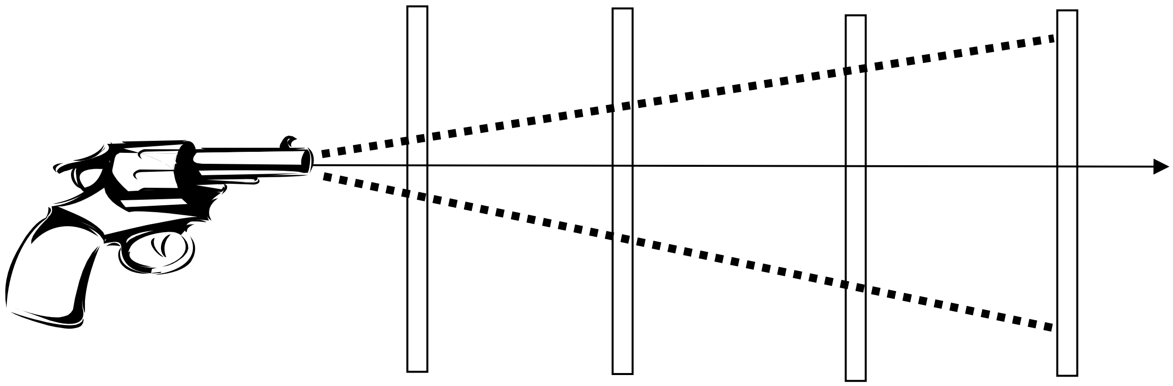
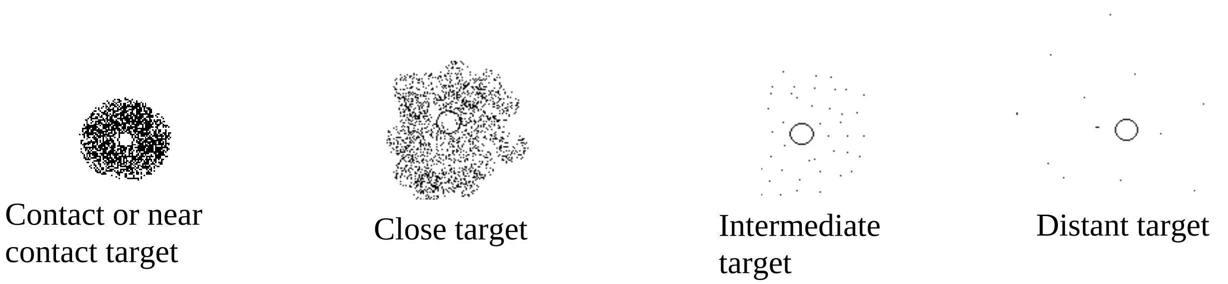


Figure 2. Basic gunshot deposition patterns at varying ranges



Residue patterns can be reproduced and therefore have evidentiary value. Some residues are visible and others require chemical treatment in order to visualize. It is the reproducibility of gunshot depositions and/or patterns that make approximating distance possible. Utilizing the submitted weapon and ammunition to test fire targets at varying distances, examiners can reproduce test targets with patterns similar to the evidence target for comparison purposes to determine the approximate range of muzzle to target distance.

Problem Statement

Currently, many firearm units within crime laboratories are reconsidering providing distance determinations due to problems associated with determining a meaningful range of distances and the problem of defending that opinion during testimony. Current methodologies used by firearm examiners in the field have been met with disapproval from the National Academy of Science (NAS) (2009) due to a lack of statistical and empirical foundations.

Utilizing acetate target overlays to find the measurements of GSR dispersion are subjective in nature and not the most accurate method of measurement. As in any science, difficulties arise from utilizing outdated or invalid measuring tools. Acetate overlays represent only approximate measurements during examination and analysis of GSR patterns. GSR patterns, while they can appear circular, take on an irregular shape and contain several minute particles. Manually counting each particle is not a very practical use of an examiner's time given the volume of casework most agencies maintain. The rings imprinted onto the acetate overlay are circles, yet many patterns can be elliptical in shape and may be concentrated to one side of a bullet hole or another. Approximate measurements preclude the ability for examiners to provide more objective opinions. With more precise, objective measurements, examiners can provide distance determination analyses that can be defended in court with quantifiable data.

Due to the rapid advancement in software technology in recent years, the ability exists to analyze GSR dispersion on targets with more accurate measurements that were previously measured by approximate methods. With image analyzing software, it is now feasible to obtain more precision in measurements of GSR dispersion, nitrite dispersion, lead dispersion, a visible particulate count and more. Examiners can zoom in to the image without damaging valuable evidence or producing cross-contamination. Using these precise measurements, examiners can compare evidence and test targets with accuracy and obtain quantifiable data that would allow for more objective conclusions and determine brackets of distance with improved credibility. The examiner also obtains data and images for use in courtroom testimony and as a permanent digital record for the examiner's case file.

Purpose of the Research

A correlation of particulate density on a target and muzzle to target distance has been demonstrated to be an important measure in comparing test targets to evidence targets in distance determination studies (Stone, et. al. 1984, Nichols, 1998a, Nichols, 2004). However, particulate counting has been viewed by examiners as a tedious necessity. In his article *Gunshot Residue Review*, Nichols (2004) states that the criteria for GSR pattern descriptions should be consistent, objective and definable. However, at this time, there are no standard criteria for particulate density measurements. Currently, the tools available to examiners are limited in their usefulness in extracting objective data from targets. This study examined the application of *Image J*, image analyzing software, for use in analyzing targets for determining muzzle to target distance with objective criteria. This research also looked at defining objective criteria for particulate density and examined how to identify the number of replicate test targets needed for a representative average at each distance of a gun and ammunition combination for statistical significance.

Research Questions

Three questions were addressed in this study: 1) Can objective data be obtained using image analyzing software? 2) Can particulate density be objectively measured? 3) How many replicates are needed at any given distance with a particular gun and ammunition combination?

Chapter 2

Literature Review

Gunshot patterning is defined as “the spatial distribution of gunpowder residues deposited upon a surface” (Nichols, 2004). Several studies were conducted to determine the variables that have an effect on GSR dispersion on targets. Barnes and Helson (1974) suggest that there are ten factors which have the largest effect on residue patterns: muzzle to target distance, barrel length of gun, propellant burning rate, propellant type, caliber, muzzle to target angle, target material, primer propellant charge and weapon type. Other studies indicate additional factors that also influence GSR patterns as well; which include type of projectile, environmental influences, and evidence handling (Bonfanti & Gallusser, 1995; Dillon, 1990; Rathman 1990).

GSR patterns are formed from all the components that comprise a cartridge case, but particularly the primer and gunpowder. Priming compounds are chemical mixtures produced to ignite the gunpowder when subjected to significant pressure, such as when the firing pin strikes the primer. Vaporous residues from the primer are deposited onto a target, depending on the distance, in a characteristic manner for a specific ammunition. Different primer types also produce different burning rates. Primers basically consist of an explosive, oxidizer, frictionator and fuel. Chemical tests used in distance determination detect specific elements present in the primer compounds, specifically lead, barium, and antimony. With the exception of lead-free primers, all primers utilize lead styphnate as the explosive. Barium nitrate is generally used as an oxidizer and antimony sulfide is used as a fuel and frictionator (Nichols, 2004).

Gunpowder is manufactured in varying shapes, sizes, and chemical mixtures. These different gunpowder types vary according to caliber and ballistic performance desired. Smokeless gunpowder contains nitrocellulose, which is produced by the chemical process of nitration. During the firing of a cartridge, not all gunpowder is burned, resulting in the deposition of nitrites during the combustion of smokeless gunpowder that leaves unburned and partially burned gunpowder. These nitrites are detectable through chemical testing and their patterns made visible. Smokeless gunpowder of the same manufacturer and formulation will produce characteristic patterning (Nichols, 2004).

Propellant type has several factors which, collectively, impact GSR dispersion onto targets. These are: powder type (black powder or smokeless powder), grain geometry, chemical composition of propellant, charge weight and combustion rate (Barnes & Helson, 1974). Smokeless powders (or nitrocellulose based powders) are seen in modern ammunition and come in three types: single base, double base, and cordite. As virtually all firearms today use smokeless powder that is the powder type that was used in this study. Grain geometry is the actual structure of the propellant powder flakes and influences the rate of burn in gunpowder. Barnes and Helson (1974) studied the properties various shaped gunpowder and found flake powders produced wider patterns and ball powder traveled the furthest and produced a darker carbonaceous pattern. The drop off rate for ball powder was approximately 6-8 feet further than the other types of propellant powders they reviewed. Nichols (1998a) studied three propellant types: flattened ball, flake, and disc powders. He found marked variability in powder diameters among the different propellant types. He states in his study that different geometries of powders vary in the distances they travel and in their dispersion onto targets. Confirming what Barnes and Helson found, Nichols (1998a, c) also found that flake powders tended to disperse in a wider pattern than the flattened ball or the disc powders and that flake powder traveled the shortest distance of the three types studied, which would be indicative of a quicker burning powder. Nichols (1998a, c) also found that flattened ball powder consistently had more definable patterns out to greater distances, produced diameters less consistent with each other and traveled the furthest of the three powder types.

Barnes and Helson (1974) test-fired a 35 year old lot of ammunition. What they discovered was the GSR dispersion was darker and more distinct and the particulate count was 3-5 times greater for the older ammunition than for the newer ammunition. Therefore, date of manufacture can be a factor in

GSR dispersion as well. They further found that the two most causal factors in GSR dispersion among propellant type factors are chemistry and burning rate. Chemistry of ammunition refers to the total composition of the propellant make up, deterrents (to slow burn rate), stabilizers (to extend shelf life), flash inhibitors and other chemical additives. Charge weight is the amount of powder that is loaded into a cartridge. However, there is no mention in the Barnes and Helson (1974) study as to which types of propellants or how many types were actually included in their study, how each reacted, or what the specific results were of each type. Burn rates are broken down into three categories: slow, medium and fast burning powders. Powders which burn more slowly will leave a denser, visible powder pattern than a fast burning powder due to the amount of unburned powder still present at the time GSR impacts the target. Veitch (1981) conducted a study in which he used five different brands of ammunition. The results of that study indicated, that of the differences in commercial brands, two of the different brands produced markedly more burned and unburned powder around the bullet hole, which he contributes to an inefficient burn rate of the powder. However, Veitch (1981) also states that while the other three had lesser amounts of the visible burned and unburned powder, all five brands produced patterns of equal distribution. Results also indicated that the amount of propellant powder loaded into a round of ammunition had a considerable affect on GSR distribution. When propellant was reloaded at only 75% and 50% of the original charge weight and shot at the same distances, patterns showed less burned and unburned powder to be present. It appeared as if the targets, which were shot with the reduced charge weights, were shot from a greater distance than they actually were. Nichols (1998a) concludes, in his study, *Effects of Ammunition on .25 Auto Caliber Gunshot Deposition*, that it is sufficient to use ammunition in which manufacturer, caliber, cartridge type and powder type are similar. Nichols reasserts in his discussion the importance of using the same ammunition when recreating an actual shooting.

Additionally, research has shown that the type of projectile has an effect on GSR dispersion (Veitch 1981). Projectiles can be jacketed, semi-jacketed or unjacketed (plain lead); with varying configurations as well, such as hollow point, and round nose. According to Walker (1940), a smoke halo consists of mainly metallic dust. This was confirmed in Veitch's study (1981) when he found that jacketed bullets displayed virtually no smoke halo when compared to unjacketed bullets. Using jacketed bullets, Veitch (1981) found that on the first shot, from a recently cleaned firearm, there was minimal GSR dispersion. However, on the second and third shots, there was an increase in the amount of GSR found on the target. After the third shot, there was minimal increase in the amount of powder dispersion. After cleaning the bore again, Veitch (1981) then loaded the test firearm with ammunition containing (unjacketed) lead round nose bullets to foul the barrel. He then loaded the same test firearm with the jacketed bullet ammunition once more. What he found was that a distinct smoke halo and partially burned gunpowder were both deposited on the target. By the third and fourth rounds of the jacketed ammunition, the smoke halo had disappeared but the density and amount of powder residue remained the same. Veitch (1981) explained this as a "cleaning" effect on the bore of a firearm due to the change from lead bullets to jacketed bullets.

When considering factors related to GSR dispersion, firearms and their components are an important factor to consider. Variables studied pertaining directly to firearms and their components that have an effect on GSR distribution are barrel length, caliber and weapon type. Studies have shown that a longer barrel length on a firearm will produce tighter patterns and less particulate count (Barnes & Helson, 1974; Nichols, 1998b). Conversely, a shorter barrel will produce a wider pattern with more particulate. In fact, Nichols (1998c) states that barrel length had the highest discriminatory power of the variables he studied, making the most distinct impact on GSR distribution.

Caliber also plays a significant role in appearance of GSR dispersion. According to research conducted by Barnes and Helson (1974) and Nichols (1998c), caliber of firearm affects size and characteristics of GSR dispersion onto targets. Higher caliber firearms leave a larger pattern on targets and smaller caliber firearms tended to deposit smaller GSR patterns (Barnes & Helson, 1974).

The different weapon types include revolvers, pistols, rifles and shotguns. Powder dispersion will vary depending upon the weapon type used. As stated previously, longer barreled firearms such as rifles will create smaller, tighter patterns. Shotguns loaded with pellet ammunition will potentially produce a pattern containing several holes (depending on the muzzle-to-target distance) in the target; at closer distances shotguns tend to leave a very large opening where the projectiles penetrate the target. Revolvers release GSR residues from the cylinder gap in a distinct pattern on targets are close distances.

Hodges (2008) studied same make and model firearm and differing ammunition. He found that ammunition is an important factor in accurately recreating GSR patterns, confirming studies previously on ammunition and GSR patterns. Hodges (2008) study is noteworthy in that he was able to provide statistical analysis to support previous assertions that cautioned examiners to utilize the same ammunition as the suspect ammunition. In the second part of his study, Hodges (2008) also found no statistical difference in GSR dispersion utilizing the same make and model, 40 caliber, Glock Model 27 pistols.

Other elements impacting GSR dispersion are: distance, target material, atmospheric conditions, and evidence handling. The further a shooter is from a target the larger and less dense the particulate pattern is likely to be (Barnes & Helson, 1974: Nichols, 1998c). Barnes and Helson (1974) state that distance was the most important factor in determining GSR patterns. At closer ranges, regardless of caliber of firearm, targets will display similar features such as petaloid patterns and carbonaceous film. This petaloid pattern is composed of the carbonaceous and other small particulate that resembles the overlapping petals of a flower (Barnes & Helson, 1974). It occurs at distances of approximately 10 inches or less and its presence on a target is significant for performing distance determinations because the examiner can infer that the maximum muzzle to target distance will be no further than approximately 10 – 11 inches.

Target material can be a factor in how the GSR dispersion appears. Nichols (1998b) studied five different target materials cotton, acetate, denim, fleece, and blotter paper. Using pistols in his study, Nichols (1998b) found that the rougher textured fabrics, such as cotton, denim, and fleece retain more of a smoke gradient whereas smoother textures did not. Nichols (1998b) also found that looser weave fabrics such as cotton and fleece showed greater penetration of powder particles. The tighter weave fabrics such as denim, acetate and blotter paper failed to show this type of reaction. In rifles, it appeared that type of fabric, however, did not make a difference in the GSR display (Nichols, 1998b).

Studies have indicated that rough evidence handling and environmental factors can diminish powder density found on targets as well (Dillon, 1990; Rathman, 1990). Atmospheric conditions can cause GSR dispersion to appear abnormal. High winds or precipitation may diminish GSR before it reaches the target, thereby reducing the amount available for distance determination testing (Nichols, 1990). Due to their water solubility, nitrites can degrade in times of precipitation, high temperatures, and humidity (Bonfanti & Gallusser, 1995). Emergency personnel, while taking measures to preserve life, may handle victim clothing brusquely thereby diminishing the density of the GSR pattern (Dillon, 1990). In their research, Bonfanti and Gallusser (1995) studied the effects of humidity, snow, running water, and stagnant water on GSR dispersion. They found that all conditions tested resulted in the loss of some GSR, with snow resulting in the least amount lost and stagnant water with the most GSR lost (Bonfanti & Gallusser, 1995).

In 1993, due to a Supreme Court ruling, changes were made in the admissibility of expert testimony (*Daubert v. Merrell Dow Pharmaceuticals, Inc*. 509 U.S. 579, 113 S. Ct. 2786, 125 L. Ed. 2D 496, United States Supreme Court). This ruling replaced the dated *Frye* standard where it was assumed that unsound methodologies in professional testimony would be discovered through vigorous cross-examination (*Frye v United States*, 293 F. 1013, 1014 D.C. Cir. 1923). According to the *Daubert* ruling, judges are now tasked with the determination of the admissibility of expert testimony based on several criteria. The five questions a judge must ask in determining the admissibility of expert testimony are: has the technique, used to obtain the results, been scientifically validated, has the method been peer reviewed, is there an established error rate, are there established protocols for the technique and were they applied in this situation, and finally has the technique gained acceptance in the relevant scientific community (*Daubert v. Merrell Dow Pharmaceuticals, Inc*. 509 U.S. 579, 113 S. Ct. 2786, 125 L. Ed. 2D 496, United States Supreme Court)? Also, according to Daubert, if there is too great an analytical gap between the data and an examiner's opinion, their conclusion may also be inadmissible (*Daubert v. Merrell Dow Pharmaceuticals, Inc*. 509 U.S. 579, 113 S. Ct. 2786, 125 L. Ed. 2D 496, United States Supreme Court). The Daubert ruling has changed the way expert testimony is evaluated and more emphasis is placed on the scientific validity of the methodology used by experts to reach their conclusions. This has caused momentum in the field of firearm and toolmark analysis toward methodologies that are based more on quantitative data, which is more objective, rather than a reliance on qualitative data, which is more subjective. The discipline of firearm and toolmark examinations was recently criticized by a committee from the NAS in a report they published in 2009 for not having adequate statistical and empirical foundations.

However, examiners face many obstacles in the advancement of objective data using the standard protocol (Dillon, 1990; SWGGUN, 2011). To begin, quantitative data from approximate measurements are unreliable. Researchers have attempted to obtain quantifiable data but are limited by available tools. In several studies, conducted to determine expectations regarding gunpowder deposition, Nichols (1998a,b) evaluated test targets using these criteria: (1) presence of smoke, (2) presence of smoke and smoke gradient (2=smoke and gradient, 1=presence of smoke/no gradient, and 0=no smoke and no gradient) (3) powder pattern diameter, (4) density and distribution of the powder within the pattern, and (5) the maximum distance at which significant powder was deposited on the target (Nichols, 1998a, b). The presence of smoke and a smoke gradient would most likely be considered objective in nature; however, density and distribution of powder patterns still utilizes a more subjective opinion. Measurements of the powder patterns were made using an acetate overlay target out to 3 inches, in half inch increments, creating 6 circular zones. Nichols (1998a, b) estimated the number of particles in each zone and gave the target a rating based on the estimated number of particles within the zone (0 = less than 5 particles, 1 = 5-24 particles, 2 = 25-49 particles, 3 = 50-74 particles, 4 = 75-99 particles, and 5 = 100 and more particles). The diameters were measured such that 90-95% of the powder particles were contained in the circle while centered on the entrance hole. This technique was based on a similar technique used by Stone et al (1984). While this methodology was an improved attempt to quantify the data, it still lacked accuracy due to the limitations of the measuring tools. The examiner is estimating particle counts and is limited to what can be visualized on the target without magnification. He also makes conjectures about density and distribution of the powder rather than setting a standard density measurement area. Using 90-95% of the powder particles is an inconsistent method of measuring. The use of terms such as “dense”, “medium” and “light” are subjective in nature as well.

Another obstacle discovered in reviewing the literature, was the lack of a standard number of replicate test targets which an examiner must produce at each distance in order to obtain an accurate average deposit of GSR for a particular gun and ammunition combination. All studies reviewed contained varying numbers of replicates with no reason given by the researcher for choosing the number of replicates produced. Neither the Scientific Working Group on Firearms (SWGGUN, 2011) nor National Institute of Justice (Dillon, 2011) guidelines indicate any specific number of repetitions or formula to identify how many replicates are needed for accurate distance determination analysis. This is a problem because the examiner relies on the test targets produced to be an average representation of the gun and ammunition combination. Statistical analysis is needed in order to determine the number of repetitions required.

The process for determining muzzle to target distance was first published by Dillon (1990) and is considered to be the basis for the standard protocol in performing distance determination examinations today. SWGGUN (2011) and the National Institute of Justice (Dillon, 2011) have established general guidelines for the examination of targets for distance determination. According to these guidelines, to perform a distance determination, examiners conduct visual/microscopic and chemical examinations of the GSR found on the evidence garment. For the visual and microscopic examination, the examiner checks for physical indications consistent with the discharge of a firearm and the passage of a bullet. In addition, an examiner will make a detailed description of the evidence garment's appearance. Elements suggesting the discharge of a firearm include: vaporous lead, metallic particulate and presence of unburned or partially burned gunpowder. Indications of the passage of a bullet, that would be noted, on the evidence garment include a hole in the garment and a visible ring around the hole (bullet wipe). Physical effects noted on an evidence garment would be: ripping or tearing of an area of the garment, burning or singeing of the cloth and heavy vaporous lead (smoke). Should any of these indications be present on an evidence garment this may be indicative of a close contact shot (Barnes & Helson, 1974). After obtaining a full description of the location on the evidence garment that these indications were present, measurements are then taken of the unprocessed, evidence garment. The diameter of this visible pattern of unburned and partially burned gunpowder is measured utilizing a clear, target-style overlay standard. Secondly, a particulate count is conducted on the evidence garment. In their *Guidelines for Gunshot Residue Distance Determinations*, SWGGUN (2011), states that a laboratory should have policies in place stating the protocol firearm examiners are to use in conducting their examinations. While a particulate count is advised, there are no standard procedures for performing a particulate count. Through interviews with different laboratories, the researcher was able to ascertain that particulate counts are generally performed by one of two methods at the current time: (1) viewing the evidence garment under a stereomicroscope and marking the particulate by hand, or (2) individually counting and marking the particulate by laying a clear acetate sheet over the target area of the garment and manually marking the acetate overlay at each particle location. The final process of visual examination, according to SWGGUN (2011) and NIJ guidelines (Dillon, 2011), is measuring the areas of the target that have "light", "medium" and "dense" particulate, with the acetate overlay. After the visual and microscopic examination, the guidelines suggest, chemically specific chromorphic (color producing) tests be utilized. A Modified Griess Test (MGT) is conducted first to detect the presence of nitrite compounds not visible, even during microscopic examination, that result from unburned or partially burned gunpowder on an evidence garment. After the MGT is performed the nitrite compounds will create a visible Orange Azo Dye pattern of varying intensities. Darker coloring indicates a larger concentration of nitrite particles and lighter results indicate fewer nitrites. As a target is further from the gun, fewer nitrites are deposited onto a target. Items noted after performing a MGT include density, location, and diameter of the pattern of nitrites around a suspected bullet hole. These nitrite depositions are important to record because a pattern of nitrite deposits around a suspected bullet hole can possibly be reproduced using the suspect weapon and ammunition (Dillon, 1990). The term "drop off" is used by examiners to indicate the maximum distance which nitrites from a firearm are able to reach the intended target and the nitrites "drop off" before impacting the target. The first distance, at which there is a consistent absence of nitrites on test targets, will indicate the drop off rate for that particular weapon. This is important as it can indicate to the examiner the maximum distance at which the target will contain nitrites.

The second chemical test performed is a Sodium Rhodizonate Test (SRT) which detects lead residues from vaporous lead, particulate lead, and bullet wipe. The presence of vaporous lead and bullet wipe is generally characteristic of a close range shot and is quite significant in distance determination as the examiner can possibly reproduce this vaporous lead smoke, utilizing the suspect weapon and ammunition, to assist in determining muzzle to target distance. Generally, the closer a gun was to the target, the darker the results of the chemical test will be due to the larger amount of lead that is reaching the target. As the target is further away from the muzzle, less of the vaporous lead is reaching the target and "drop-off" will occur. Again, a maximum distance at which the vaporous lead is deposited may be important information to the examiner. However, examiners are looking only at the vaporous lead; the presence of particulate lead is random and is created by several non-reproducible variables such as barrel fouling and bullet fragmentation (Dillon, 1990).

After the evidence garment is processed the suspect ammunition and weapon are then used in combination to test fire targets at known distances. At this time there is no standard protocol for the number of shots at each distance an examiner must produce for an accurate examination. Research indicates that diameter of overall GSR dispersion, particulate density, color, and diameter of chemical test results are significant factors in comparing test targets for distance determination (Nichols, 1998a). Previous studies have shown that particulate density correlates well to the distance at which a gun was shot (Stone, et. al. 1984, Nichols, 1998a). However, labels of "dense", "medium", and "light" particulate are still subjective and acetate overlays to measure diameters are only approximate measurements. The known targets are also examined both visually and chemically in the same manner as the unknown target. Examiners will compare the results of the visual examination and chemical tests from the unknown target to the results of the test fire targets to determine which known distance pattern best matches the unknown target. A range or bracket of muzzle to target distance is then determined from this process.

Most of the time shotguns use multiple projectiles (pellets) instead of a single projectile. These projectiles are expelled from the muzzle of the shotgun and stay together for a while and then begin to spread out at further distances. The farther the muzzle to target distance, the larger the pellet pattern produced on a target. For this reason, shotgun targets are examined differently. Targets shot with a shotgun are examined using a visual examination only; no chemical testing is usually performed (Dillon, 1990). The general appearance of an evidence target is documented and the resulting diameter of the overall pellet pattern is measured using the acetate overlay. Test targets are shot at varying distances as mentioned above, and the diameters of the resulting pellet patterns are measured as well. These diameters of the overall pattern are compared to the evidence target resulting in an approximate muzzle to target distance range.

Image Analyzing Software

Image J is an image analyzing, open source, software application written in JavaScript. Originally produced by the National Institutes of Health (NIH), this image analyzing software has been tested and applied for use in many disciplines (Rasband, 1997-2009). Applications include: several areas of microscopy to include measuring strands of DNA, biotechnology, and medical imaging. *Image J* is also capable of being spatially calibrated so that more accurate measurements are practical. This software accepts many data types and file formats and can be performed using all major operating systems to include Microsoft Windows and Linux. *Image J* is capable of assisting in analyzing digital images by: measuring area, mean, and standard deviation, lengths, and angles. There are image enhancing capabilities to this software as well. These capabilities do not change photographs, but enhance the image to facilitate better viewing. These capabilities include: smoothing, sharpening, edge detection, interactive brightness, contrast adjustments, and color changing capabilities, improving the quality of images that were hard to visualize previously. *Image J* will allow the user to crop, scale, resize, rotate or flip images horizontally or vertically. Users can add text, arrows, rectangles, ellipses or polygons to images which can be useful for labeling or highlighting areas of interest thus allowing the user to create graphical displays. This software contains a zoom feature (1:32 to 32:1) and ability to scroll images. This magnification tool is a more efficient and uncomplicated way to view small particulate and does not require a microscope. All analysis and processing functions work at any magnification factor. Macros and plug-ins are available for this software rendering it capable of being customized to the end-user's specifications (Rasband, 1997-2009). Most agencies are on a fixed budget and it is not feasible for them to obtain expensive software. *Image J* is free and requires no licensing. *Image J* is easy to use and has a free tutorial available on the website.

There are several other benefits to using digital images and software. These benefits include storing digital images that have been transferred easily and efficiently. Data images can also be sent to recipients using an email program. These images can also be viewed by other examiners for use in technically reviewing case work. The images can be sent to the reviewing examiner containing the overlay of the area that the examiner, performing the analysis, actually measured. This allows the reviewer to see the same area that was measured and to have the ability to re-measure that same area as well. The resulting measurements can be saved to an Excel spreadsheet which would allow a table of data to be compiled in a usable format to make charts, for adding to case reports and permanently stored as digital files. The resulting measurements can be expanded using decimal places for precise quantification of data. With this tool, more precise data quantification of results is now possible. Overlays of particulate and chemical results can be made from test targets and laid on top of evidence photos for use in comparison without cross-contamination or destroying evidence.

Chapter 3

Research Methodology

The first question examined in this research was: can objective data be obtained from image analyzing software? To obtain objective data, the researcher utilized *Image J*, image analyzing software, to measure: particulate count, diameter of particulate density, and the area of the entire pattern. Using a scaled digital photograph of the target in *Image J*, all particulate was selected and numbered. A measurement function was performed in *Image J* to give the number of particulate. Using the total number of particulate, the number of particulate needed at 50% and 80% were calculated. An elliptical tool was utilized to enclose the area that encompasses the amount of particulate needed in the smallest shape. The elliptical area was then set as an overlay and the diameter was measured across the center of the ellipse, using a line drawing tool and measure function in *Image J*. Then, using an Excel spreadsheet and the data obtained in *Image J*, a mean, range and standard deviation were calculated.

The second question was: Can particulate density be objectively measured? Using the total number of particulate, the number of particulate needed at 50% and 80% were calculated. That number of particulate was then enclosed in an ellipse in the same manner as stated previously. The diameters of the resulting ellipses were measured using the line segment and measure function in Image J. Then, a measurement of the overall area and diameter of was made in the same manner, encompassing the entire pattern.

The third question examined was: how many replicates are needed, at each distance for an average representation of each gun and ammunition combination? There are currently no established protocols for identifying the number of replicate targets for statistical comparisons in distance determination. The researcher utilized a 95% and a 90% confidence level to calculate confidence intervals to assist in determining what measurements would fall into a particular distance. Five repetitions were produced at each distance with each gun and ammunition combination. The results of these test targets were used to help calculate the information needed for the confidence interval. The mean of the diameters, the standard deviation and a measure of the difference between targets were used to help calculate confidence intervals. A second statistical formula was utilized to calculate the number of repetitions needed at each distance for statistical significance.

Procedure for Collecting Data

One revolver, pistol, rifle and shotgun were selected for this study. The revolver utilized for this study was a Smith & Wesson®, LadySmith, .38 Special caliber, serial number CDJ3277 (*figure 3*). This double action revolver has a 1.87" conventionally rifled barrel, five round capacity, and weighs 14.5 oz.

Figure 3. 38 Special (caliber), Smith & Wesson®, LadySmith revolver, serial number CDJ3277 utilized, in this research

The pistol chosen for this study was a Glock Safe Action Pistol©, model 26, 9x19mm Parabellum caliber, serial number EMG550 (*figure 4)*. The Glock© 26 is a subcompact, short recoil-operated locked breech, centerfire, semi-automatic pistol. This pistol has a hammer-forged barrel, which is polygonally rifled. The pistol has a 10 round capacity, fed through a box magazine, a barrel length of 3.46" and weighs 19.8 oz.

Figure 4. 9mm (caliber), Glock© 26 semi-automatic pistol, serial number EMG550, utilized in this research

The rifle selected was a .22 long rifle (caliber) Remington® model 121 "Fieldmaster", serial number 10160 (*figure 5*). This rimfire rifle has a 14 round capacity fed through a tubular magazine. It is pump-action and has a 25 inch conventionally rifled barrel.

Figure 5. .22 long rifle (caliber), Remington® Model 121, "Fieldmaster" pump-action rifle, serial number 10160, utilized in this research

The shotgun utilized was a Remington 870™ Express© 20 gauge, serial number RS87558A (*figure 6*). It utilizes pump action and has a 20" barrel, modified Rem™ Choke and can chamber both 2 ¾ or 3" shotshells. This shotgun has a five shot capacity which if fed from an internal magazine.

Figure 6. 20 gauge Remington 870 ™ Express©, pump-action shotgun, serial number RS87558A, utilized in this research

Ammunition, used in this research, was purchased at a local discount retail store. The following types of ammunition were chosen:

- .38 special caliber Remington® "ShurShot" 130 grain, centerfire, full metal jacket (FMJ) with a copper jacketed projectile and brass cartridge case.
- 9mm Luger caliber Federal® "Champion" 115 gain, centerfire, full metal jacket (FMJ) with a copper jacketed projectile and brass cartridge case.
- .22 long rifle, Remington® "Thunderbolt" 40 grain, rimfire, full metal jacket (FMJ) with lead projectile and brass cartridge case.
- 20 gauge, Remington® "ShurShot" Target Loads number 7 ½ shot with plastic shotshell, 2 ½ dram equivalent, 2 ¾ inch, ⅞ ounce shot.

All firearms and ammunition selected for this study was chosen based on its availability to the general public.

White, heavy 100% cotton twill fabric was chosen for the pistol, revolver and rifle targets, in order to yield the best results on both visual and chemical examinations (Nichols, 1998). Results on the chemically specific chromorphic color tests show results more readily on the white, twill fabric due to its light color. The tighter weave of this fabric is conducive for holding in GSR particles. Test targets were made by cutting rectangles of the white twill jean fabric and attaching the rectangles to a cardboard backing. Shotguns are processed using visual examinations only. Therefore, shotgun targets were shot on BenchKote® paper targets to yield better results on pellet patterns. All targets were labeled with caliber and distance. All test firing was conducted on an indoor range to control for environmental variables that may affect GSR patterns. All guns were thoroughly cleaned prior to use in order to minimize particulate deposition from previous uses.

Test targets for the pistol, revolver and rifle were shot five times each at distances of: 4, 8, 12, 16, 20, 24 and 28 inches. Shotgun test targets were obtained at 4, 8, 12 and 16 feet. When all test targets were obtained, the unprocessed targets were immediately photographed.

Worksheets were designed to document targets at each distance for each gun. The worksheet contained the visual and chemical examinations for each distance, for both the standard procedure and the Image J analysis, for each gun type. All test targets were obtained and processed utilizing the standard distance determination examination procedure that is in current use (SWGGUN, 2011 & Dillon, 2011). Information recorded during visual examination (as they applied to the target) using standard protocol, were: approximate diameter of “light” particulate, “dense” particulate, the overall particulate or pellet pattern, and the approximate diameter of the smoke rings at “heavy” and “light”. Measurements obtained during visual examination, with Image J, and recorded on the worksheet, included: total particulate count, diameter of the density of particulate at 50% and 80% of total particulate, the diameter of the overall GSR pattern and the area of the overall pattern. For the Modified Griess Test, information recorded for the standard protocol was the approximate diameter of the total orange Azo dye pattern and how light to dark it appeared. Information documented on the Modified Griess test for Image J included a color code for the results of the test, the diameter and area for the total pattern of orange Azo dye. For the standard protocol, information recorded for the Sodium Rhodizonate test included the approximate diameters for the color results in areas of “light”, “medium” and “dark” for each pattern. Information recorded for Image J were a color code for the results of the test, the diameter of “light”, “medium” and “dark” purple test results, total area and diameter of entire pattern of chemical results (*examples 1 and 2*).

Example 1. Distance worksheet - 8” distance measured using overlay standard.

Distance Determination Worksheet

Examiner: Kimberly Edwards
Date: 5-20-11
Test Material: white, twill jean
Method of Analysis: standard
Distance for Test Fires: 8 inches
Ammunition: Remington, 22 Thunderbolt, high velocity 22LR, RN
Weapon: Remington Fieldmaster pump-action rifle, serial no. 10160

Shot #	Visual Exam	Modified Griess Test	Sodium Rhodizonate Test
1	Dense particulate out to ~1”, heavy smoke out to ~1”, light particulate to ~2”	Very light scattered orange out to ~8”	Dark purple to ~1”, medium purple out to ~2”, light purple out to ~4”
2	Dense particulate out to ~2”, heavy smoke ring out to ~1”, light particulate to ~2”	Very light scattered orange out to ~4”	Dark purple to ~1”, medium purple out to ~2”, light purple out to ~4”
3	Dense particulate out to ~1”, light particulate out to ~2”, heavy smoke ring out to ~1”, light smoke to ~2”	Very light scattered orange out to ~4”	Dark purple ~2”, med-light purple out to ~4”
4	Dense particulate out to ~1”, light particulate out to ~2”, heavy smoke ring out to ~1”, light smoke to ~2”	Very light scattered orange out to ~8”	Dark purple to ~1”, medium purple out to ~2”, light purple out to ~4”
5	Dense particulate out to ~1”, light particulate out to ~2”, heavy smoke ring out to ~1”, light smoke to ~2”	Very light scattered orange out to ~8”	Dark purple to ~1”, medium purple out to ~2”, medium-light purple out to ~5”

Example 2. Distance worksheet- 8” distance measured in Image J.

Distance Determination Worksheet

Examiner: Kimberly Edwards
Date: 6-9-11
Test Material: White twill jean
Method of Analysis: Image J
Distance for Test Fires: 8 inches
Ammunition: Remington, 22 Thunderbolt, high velocity 22LR, RN
Weapon: Remington Fieldmaster pump-action rifle, serial no. 10160

Shot #	Visual Exam	Modified Griess Test	Sodium Rhodizonate Test
1	Total particulate count: 48; 50% of particulate out to 0.80”, 80% of particulate out to 1.06”, 100% of particulate out to 1.95”, area: 3.19”^{2}	Color code=1 Diameter of total orange color: 1.36”, area: 1.42”^{2}	Color code = 3; Area of darkest color: 0.59”, diameter out to: 0.81”,area of medium color: 1.96, diameter out to:1.58”, total area: 6.70, total diameter out to: 2.93”
2	Total particulate count: 43; 50% of particulate out to 0.80”, 80% of particulate out to 1.33”, 100% of particulate out to 2.08”, area: 3.50”^{2}	Color code=2 Diameter of total orange color: 2.04”, area: 2.87”^{2}	Color code = 3; total area: 6.77, total diameter out to: 2.93”
3	Total particulate count: 42; 50% of particulate out to 0.68”, 80% of particulate out to 1.16”, 100% of particulate out to 1.91”, area: 2.39”^{2}	Color code=2 Diameter of total orange color: 1.58”, area: 2.04”^{2}	Color code = 3;Area of darkest color: 0.628, diameter out to: 0.91”,area of medium color: 1.58, diameter out to:1.39”, total area:20.02”^{2}, total diameter out to: 4.96”
4	Total particulate count: 44; 50% of particulate out to 0.82”, 80% of particulate out to 1.16”, 100% of particulate out to 1.88”, area: 2.29”^{2}	Color code=1 Diameter of total orange color: 1.70”, area: 2.25”^{2}	Color code = 3; total area: 14.30”^{2}, total diameter out to: 4.21”
5	Total particulate count: 43; 50% of particulate out to 0.79”, 80% of particulate out to 1.25”, 100% of particulate out to 1.95”, area: 2.33” ^{2}	Color code=3 Diameter of total orange color: 9.02”, area: 68.17”^{2}	Color code = 3; Area of darkest color: 0.80, diameter out to: 1.05”,area of medium color: 5.00”, diameter out to:2.45”, total area: 13.73”^{2}, total diameter out to: 3.98”

Procedure for Obtaining Measurements

After all the test targets were shot, targets were then immediately photographed. A Nikon D-60 digital camera with a standard 35mm lens and a Nikon SB-900 speedlight was used to obtain all photographs. The image was checked, after each photograph taken, to ensure a clear, in-focus image was obtained. Each photograph contained the same standard forensic scale placed beside the pattern, in order to calibrate the scale in the software program.

Initially, the standard protocol was used for each target and all measurements were obtained using the acetate overlay. All measurements were recorded in inches. The first step was to look at the particulate pattern and identify the areas of “light” and “dense” particulate. Then, the approximate diameter of the areas of “light” and “dark”, as well as the overall GSR pattern were documented on the worksheet. To chemically process the targets, a Modified Griess Test was used to detect the presence of nitrites and also a Sodium Rhodizonate Test to detect the presence of vaporous lead residues. First, the Modified Griess test was performed on the target. A digital photograph was obtained of the test target directly after processing. Measurements were then taken of the approximate diameter of the overall resulting color and a description of “light”, “medium” or “dark” was documented onto the worksheet. The Sodium Rhodizonate test was performed next. The results of that test were photographed. The areas of “light”, “medium” and “dark” color were identified and their approximate diameters measured and documented onto the worksheet as well.

Next, the targets were analyzed using *Image J* measurements. The first step in measuring the targets was to set the scale for the current photograph. This was accomplished by using the zoom feature and zooming in on the scale in the photograph. A line segment was drawn with the line segment tool from the top to the bottom of the 1 inch mark. Then, from the “analyze menu”, set scale was selected. This tool automatically places the number of pixels equal to the line segment. The length of measurement is entered along with the unit of measurement. Next, a grid overlay was placed on top of the unprocessed image by selecting “grid overlay” from the plug-ins, analyze menus. This grid was utilized in order to aid in identifying particulate. The multi-point selection tool was used to conduct a grid search, marking the particulate in each square. The multi-point selection tool allows the user to select and mark multiple items and labels those items with a number. The magnification function was utilized during particulate identification so that the visible particulate could be seen with better clarity. The zoom feature was set at 200% during the identification of the particulate. A marker for the particulate was centered directly on the item. After the particulate were all identified, a measurement function was performed to find the total number of particulate marked; this number was then used to find the measurements for particulate density. Particulate density was set such that the area containing 50% of the total particulate was substituted for the label “dense” and 80% of the total particulate for “medium” to standardize all measurements. The measurement for density was calculated by taking the total number of particulate on a particular target, and determining the number of particulate needed at 50% and 80%. Then the “elliptical tool” was used in *Image J* to find the elliptical area that encompassed that amount of particulate needed in the smallest shape. The elliptical area was then set as an overlay and the diameter was measured across the center of the ellipse. There were three measurements for the particulate density: the diameter of the particulate out to 50% of the total particulate (dense), 80% of the total particulate (medium) and 100% of the particulate. When obtaining the counts for 50% and 80% of the particulate for a target, if the resulting number contained a decimal; this number was then rounded to the nearest whole number in order to encompass the total amount into the selection properly. In addition, if during measuring a pattern at 100%, that pattern had a single particulate that was further than 1 inch from the main pattern it was considered an outlier and eliminated from the measurement in each instance.

To measure the color pattern for the Modified Griess Test, in Image J, an elliptical selection was made that encompassed the entire orange Azo dye pattern and set as an overlay. The diameter of the overlay was then measured and recorded onto the worksheet. This process was similar for the Sodium Rhodizonate Test, however if the pattern contained areas of dark, medium or light purple, multiple measurements were made of each diameter and documented. In addition to these measurements a color code was assigned to each target for both chemical results. To obtain this color code all targets of a particular gun, were compared to one another and placed in ordered from lightest to darkest. All targets for one gun were compared over all distances and each color code was based on the overall darkest to overall lightest. Those colors set the upper and lower ends of the scale. Then a color code was assigned to each target so that the results could be graphed and drop off could potentially be identified. The color codes were: 0=no color, 1=lightest color, 2=medium color and 3=darkest color. This measurement is subjective but utilized in order to minimize the level of subjectivity entered into the study. When this data was placed into a graph format one could see if drop-off was had occurred for each gun type and if so at what distance, on both the measurements for nitrites and lead.

After all data were collected from the Image J measurements and documented on the worksheets, the data were compiled into an Excel spreadsheet. Calculations were then made of the average for the diameters of particulate dispersion at 50%, 80% and 100% of particulate density at each distance for each gun type. The mean for diameters of chemical results at each distance were calculated in Excel as well. Using the measurements obtained in Image J, calculations were performed in Excel to find the mean and standard deviation of all replicates, based on the average diameter measurements, at one distance and these measurements were used to establish a formula to determine how many replicates would be needed at each distance given a gun and ammunition combination at each distance. A standard confidence interval, utilizing a 95% confidence level, was used to estimate the number of targets needed for each gun and ammunition combination at each distance.

Chapter 4

Analysis of the Data

Research Question 1: Can objective data be obtained using image analyzing software?

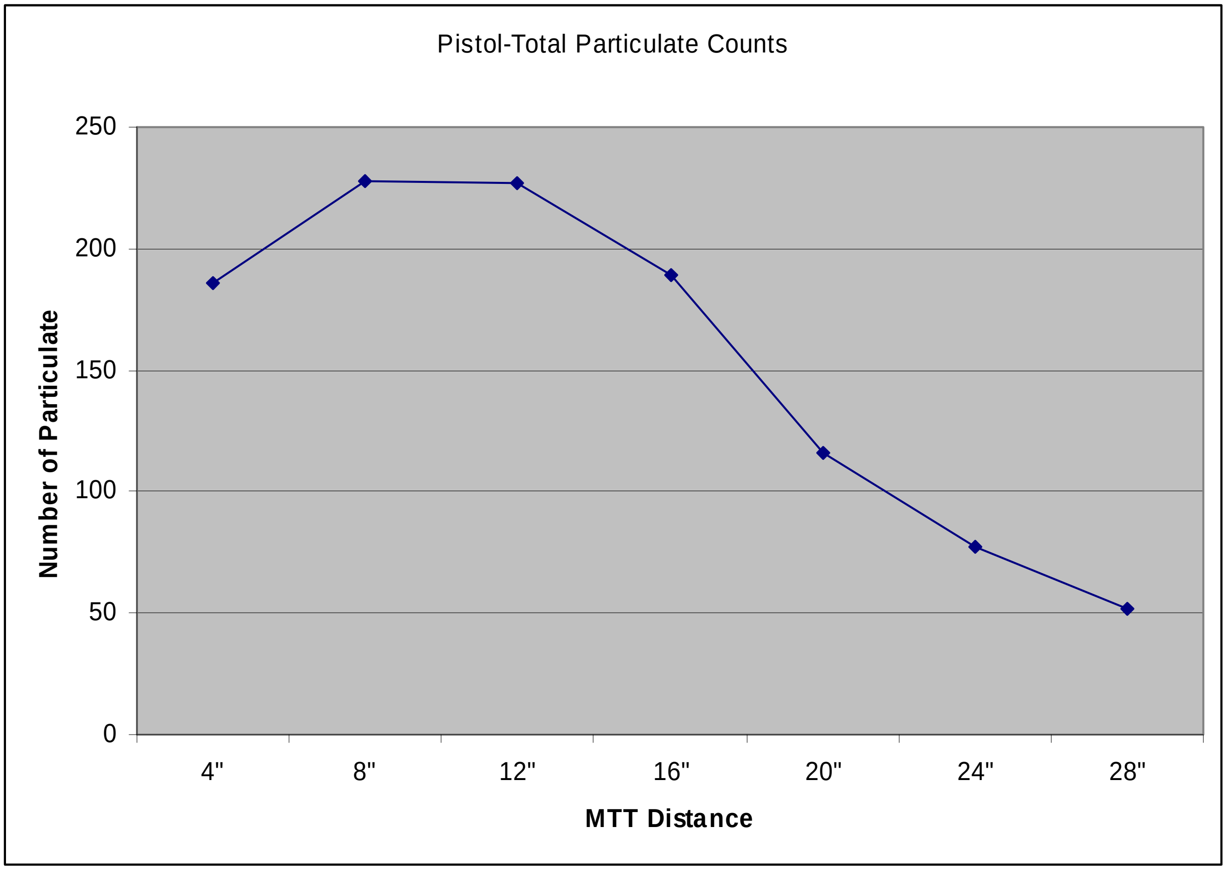
Objective data can be obtained using image analyzing software (*Image J*). Accurate measurements of particulate, diameter, and area were obtained using this software. In addition, using these measurements other objective measurements were possible, such as area, location of particulate. These additional measurements may correlate with muzzle to target distance, but require further study to determine their usefulness.

Total particulate counts are one part of the analysis process when determining muzzle to target distance. Particulate counts for the pistol show that total particulate increased until 8 inches then overall particulate declined steadily after 12 inches, with a sharp decrease after 16 inches (*table 1.0* & *figure 7*). These results indicate where the GSR dispersion becomes increasingly lighter.

Table 1.0. Total particulate counts, at each distance, for the pistol

Total Particulate Counts							
Pistol	4"	8"	12"	16"	20"	24"	28"
shot 1	195	218	223	179	114	74	62
shot 2	190	268	230	184	112	81	45
shot 3	165	257	226	197	95	71	43
shot 4	199	199	234	207	134	82	55
shot 5	180	195	223	180	125	80	55
average	186	227	227	189	116	78	52

Figure 7. Mean total particulate counts for the pistol at all distances



With the measurements that were obtained in *Image J*, a mean, standard deviation and range were calculated using an Excel spreadsheet and graphed for the pistol (*tables 2.0-4.0*).

Table 2.0 Summary statistics of particulate density at 50% for pistol

Pistol- diameter of 50% of Particulate (inches)			
Distance	Mean	Std. Dev.	Range
4"	0.97	0.21	0.78-1.27
8"	1.52	0.29	1.09-1.78
12"	2.66	0.31	2.26-3.03
16"	3.33	0.32	2.89-3.50
20"	3.58	0.38	3.11-4.05
24"	4.01	0.33	3.69-4.51
28"	4.72	0.78	3.83-5.89

Table 3.0 Summary statistics of particulate density at 80% for the pistol

Pistol- diameter of 80% of Particulate (inches)			
Distanc e	Mean	Std. Dev.	Range
4"	2.62	0.34	2.26-3.14
8"	3.40	0.70	2.71-4.16
12"	5.24	0.44	4.87-6.00
16"	6.20	0.87	5.70-7.38
20"	7.36	1.03	6.25-8.55
24"	8.82	1.08	7.36-10.39
28"	10.07	1.65	8.76-12.82

Table 4.0 Summary statistics of particulate density at 100% for the pistol

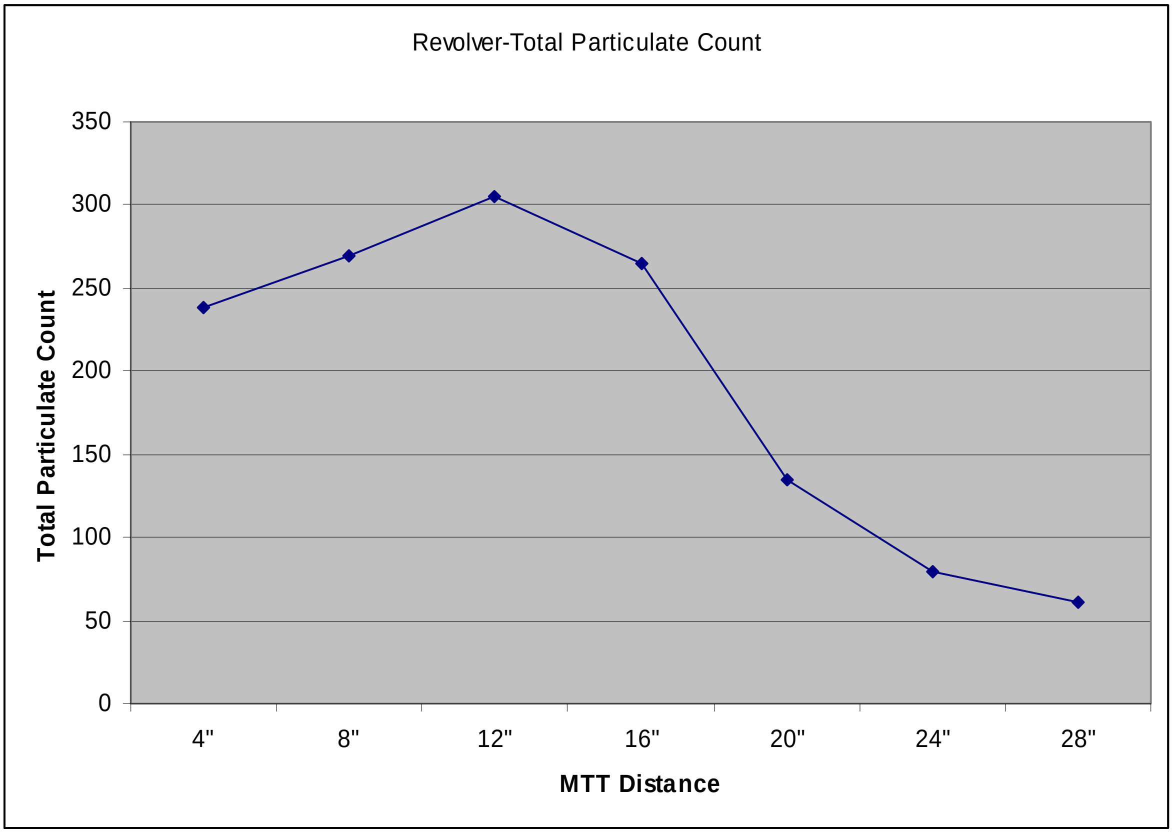
Pistol- diameter of 100% of Particulate (inches)			
Distance	Mean	Std. Dev.	Range
4"	7.45	1.41	6.20-9.18
8"	8.12	1.07	7.06-9.42
12"	9.97	0.79	9.30-11.31
16"	10.92	0.42	10.58-11.42
20"	11.70	0.63	11.07-12.71
24"	12.90	0.96	11.88-14.36
28"	13.61	1.94	11.35-15.67

The average total particulate counts for the revolver indicate that the particulate count increased until 12 inches and then steadily decreased; which means that the GSR dispersion becomes increasingly lighter past the 12 inch muzzle to target distance. (*table 5.0* & *figure 8*). This lighter dispersion is the point where particulate is no longer reaching the target and is more dispersed due to the distance.

Table 5.0. Total particulate counts, at each distance, for the revolver

Total Particulate Counts							
Revolver	4"	8"	12"	16"	20"	24"	28"
shot 1	302	210	278	233	123	100	72
shot 2	230	268	278	227	136	66	100
shot 3	209	233	322	288	127	84	55
shot 4	246	317	330	288	141	75	44
shot 5	207	317	315	288	146	70	32
average	239	269	305	265	135	79	61

Figure 8. Mean total particulate counts for the revolver at all distances



With the measurements that were obtained in *Image J,* a mean, standard deviation and range were calculated using an Excel spreadsheet and graphed for the revolver (*tables 6.0-8.0*).

Table 6.0 Summary statistics of particulate density at 50% for the revolver

Revolver- diameter of 50% of Particulate (inches)			
Distance	Mean	Std. Dev.	Range
4"	1.52	0.12	1.35-1.69
8"	1.99	0.48	1.56-2.55
12"	3.31	0.30	2.94-3.65
16"	3.96	0.66	3.53-5.121
20"	4.45	0.50	3.89-5.19
24"	5.71	0.66	5.13-6.55
28"	6.20	1.07	5.11-7.87

Table 7.0 Summary statistics of the particulate density at 80% for the revolver

Revolver- diameter of 80% of Particulate (inches)			
Distance	Mean	Std. Dev.	Range
4"	2.62	0.34	2.26-3.14
8"	3.40	0.70	2.71-4.16
12"	5.24	0.44	4.87-6.00
16"	6.20	0.87	5.70-7.38
20"	7.36	1.03	6.25-8.55
24"	8.82	1.08	7.36-10.39
28"	10.07	1.65	8.76-12.82

Table 8.0 Summary statistics of the particulate density at 100% for the revolver

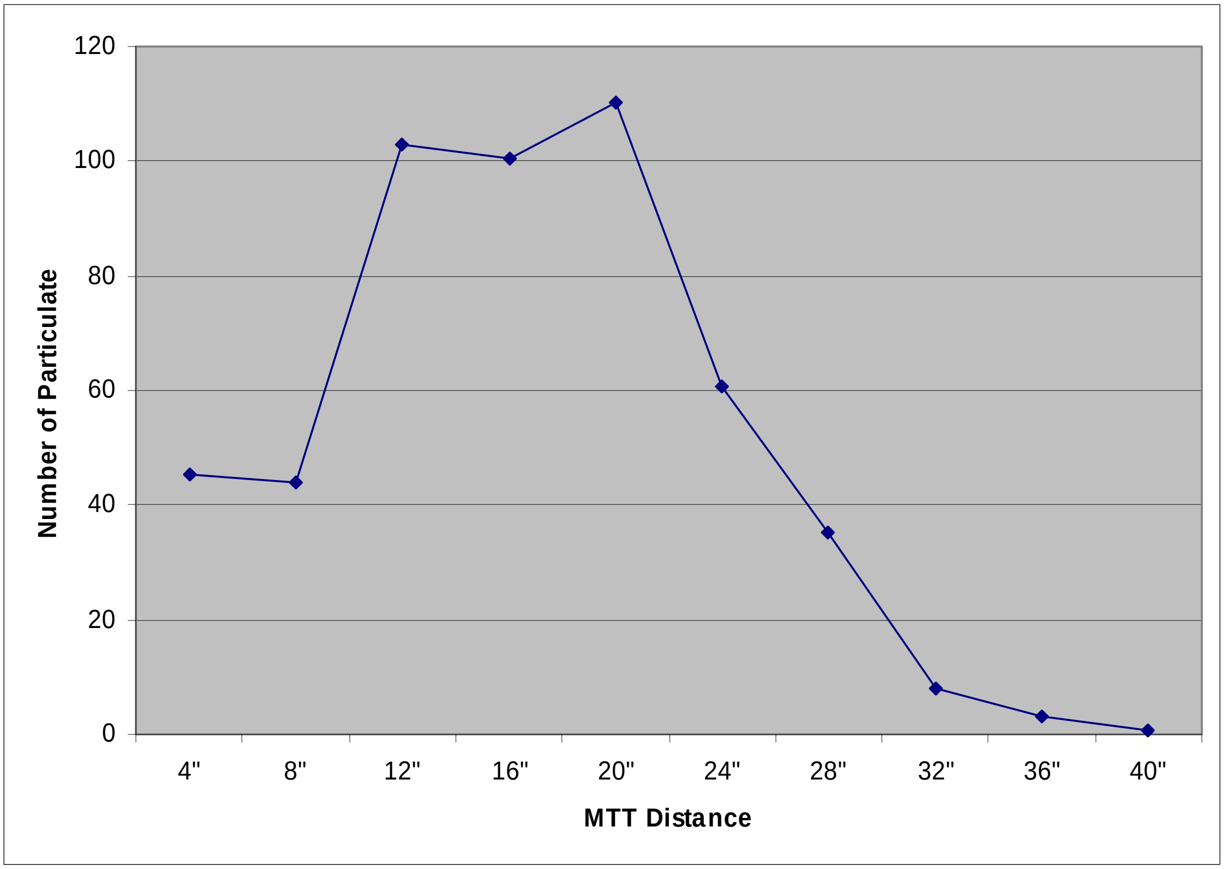
Revolver- diameter of 100% of Particulate (inches)			
Distance	Mean	Std. Dev.	Range
4"	7.45	1.41	6.20-9.18
8"	8.12	1.07	7.06-9.42
12"	9.97	0.79	9.30-11.31
16"	10.92	0.42	10.58-11.42
20"	11.70	0.63	11.07-12.71
24"	12.90	0.96	11.88-14.36
28"	13.61	1.94	11.35-15.67

Total particulate patterns for the rifle have a different pattern than the previous gun types. The results indicate that particulate counts sharply increased after 8 inches and continued to rise until 20 inches where a sharp decrease was observed (*table 9.0* & *figure 9*).

Table 9.0 Total particulate counts, at each distance, for the rifle

Total Particulate Counts									
Rifle	4"	8"	12"	16"	20"	24"	32"	36"	40"
shot 1	45	48	123	106	113	84	6	1	0
shot 2	49	43	82	100	107	54	8	2	0
shot 3	45	42	104	83	118	43	4	3	1
shot 4	43	44	79	89	110	64	10	6	2
shot 5	44	43	126	124	104	59	12	4	0
average	45	44	103	100	110	61	8	3	1

Figure 9. Mean total particulate counts for the rifle at all distances



With the measurements that were obtained in *Image J*, a mean, standard deviation and range were calculated using an Excel spreadsheet and graphed for the rifle (see *tables 10.0-12.0*).

Table 10.0. Summary statistics of the particulate density at 50% for the rifle

Rifle- diameter of 50% of Particulate (inches)			
Distance	Mean	Std. Dev.	Range
4"	0.44	0.07	0.35-0.50
8"	0.78	0.05	0.68-0.82
12"	0.95	0.07	0.91-1.07
16"	1.33	0.14	1.14-1.49
20"	1.67	0.16	1.54-1.95
24"	2.00	0.33	1.59-2.33
28"	2.46	0.24	2.13-2.70

Table 11.0. Summary statistics of the particulate density at 80% for the rifle

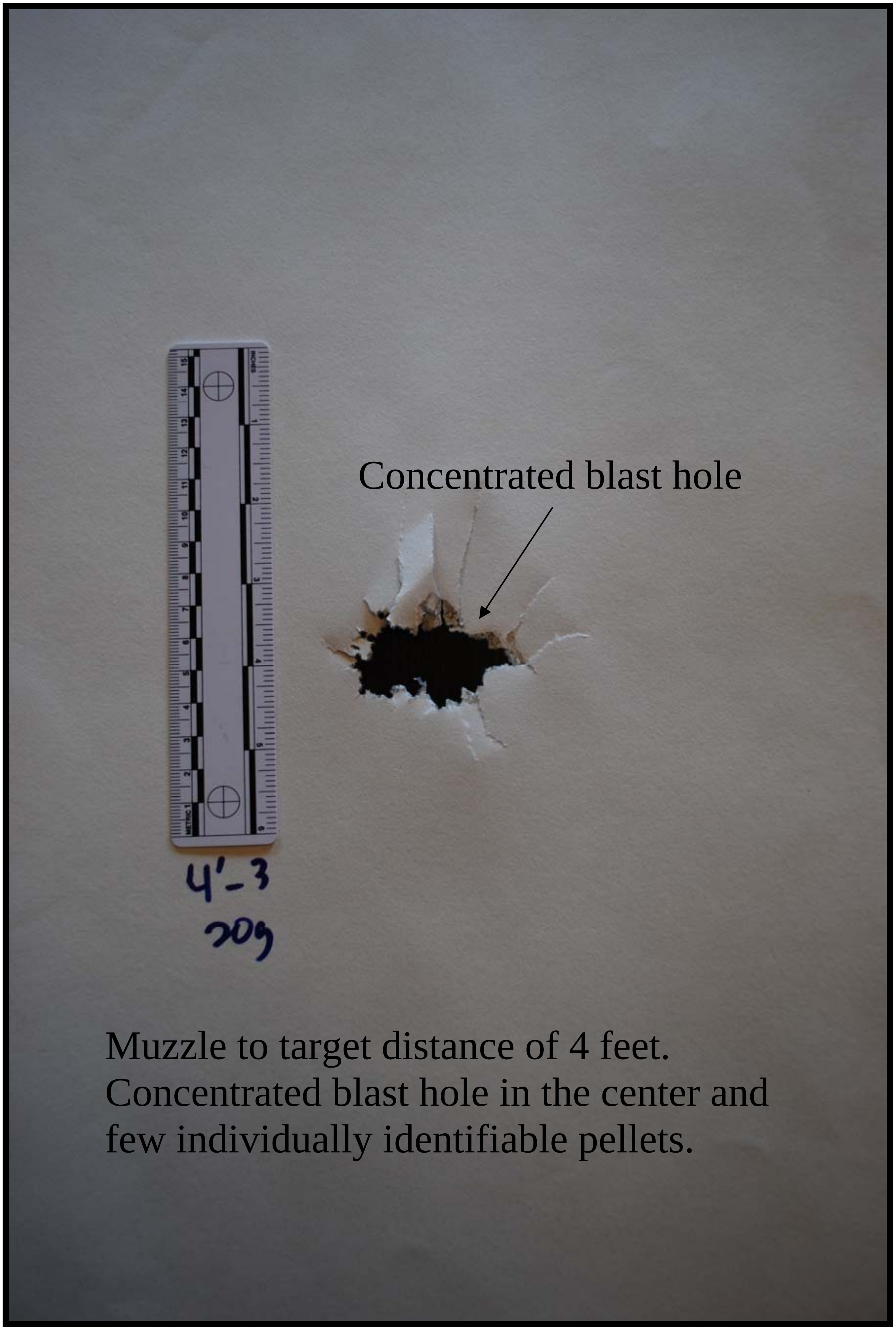
Rifle- diameter of 80% of Particulate (inches)			
Distance	Mean	Std. Dev.	Range
4"	0.68	0.13	.528-.82
8"	1.19	0.10	1.06-1.33
12"	1.37	0.11	1.20-1.52
16"	1.92	0.20	1.58-2.05
20"	2.31	0.18	2.11-2.62
24"	3.32	0.54	2.55-3.95
28"	3.63	0.21	3.45-3.92

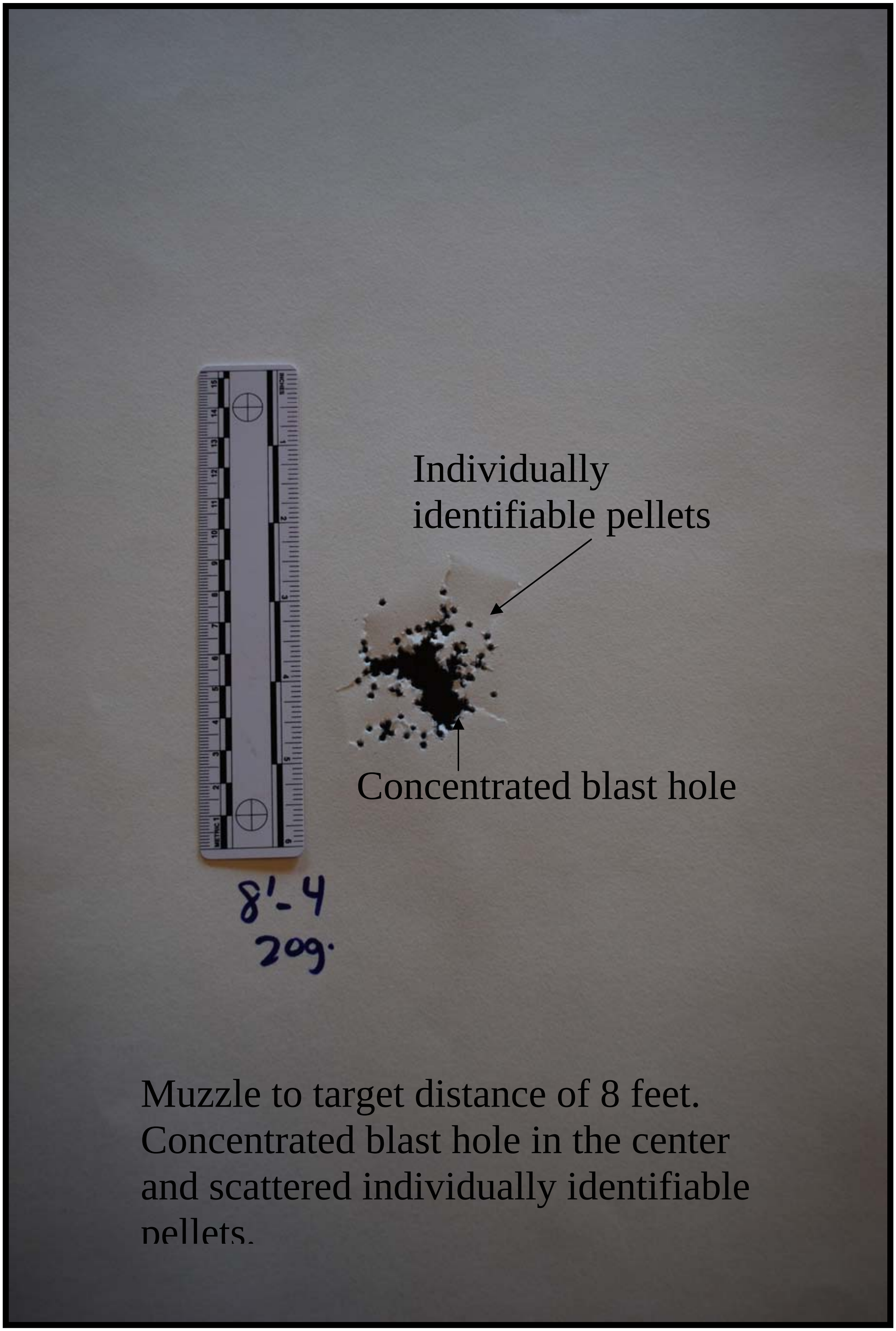
Table 12.0. Summary statistics of the particulate density at 100% for the rifle

Rifle- diameter of 100% of Particulate (inches)			
Distance	Mean	Std. Dev.	Range
4"	1.02	0.08	.89-1.09
8"	1.95	0.08	1.87-2.08
12"	2.62	0.15	2.48-2.86
16"	3.88	0.32	3.75-4.30
20"	4.10	0.48	3.71-4.90
24"	5.74	1.41	4.28-8.07
28"	6.86	2.10	5.29-10.55

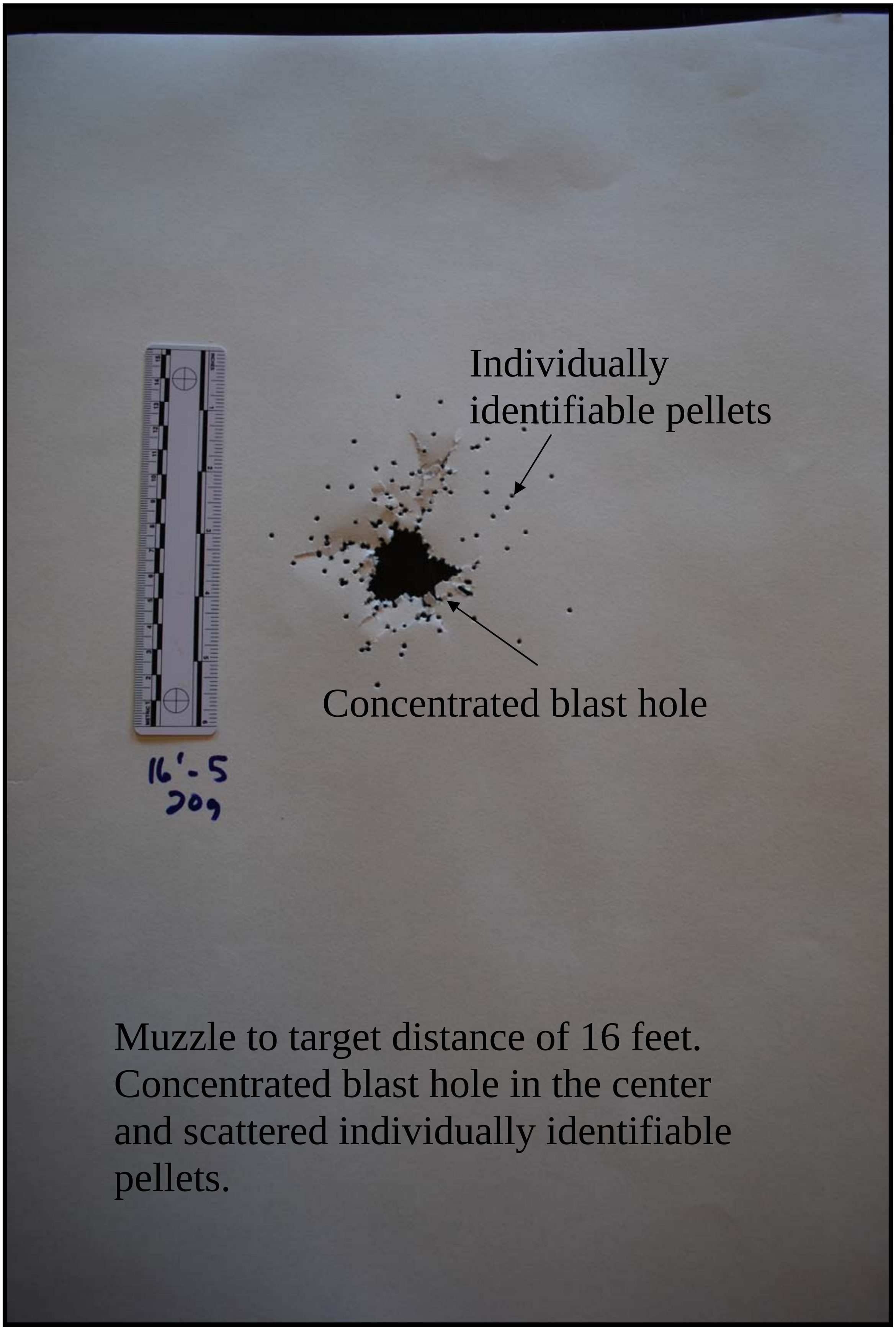
Shotgun targets will consist of an area at which, most of the pellets will strike a target in one grouping. This is referred to, in this study, as a concentrated blast hole. This concentrated blast hole can be surrounded by individually identifiable pellets on a target that are individually counted by examiners (see *figure 10*). To measure shotgun targets, examiners will count individually identifiable pellets on the target and measure the diameter of the resulting overall pellet pattern. Data from this study demonstrate that the pellet patterns, for this shotgun and ammunition combination, increased steadily with distance as do the number of individually identifiable pellets (see *table 13.0* & *figure 11*).

Figure 10. Examples of individually identifiable pellets and concentrated blast hole





Muzzle to target distance of 8 feet. Concentrated blast hole in the center and scattered individually identifiable pellets.

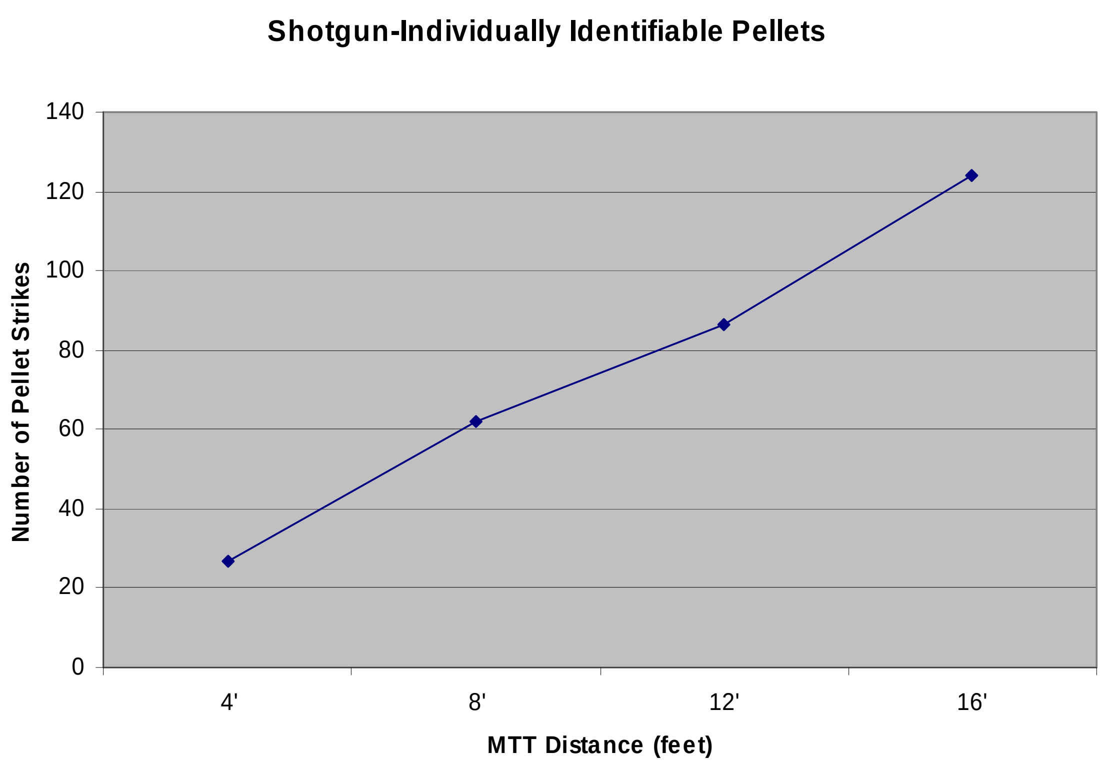


Muzzle to target distance of 16 feet. Concentrated blast hole in the center and scattered individually identifiable pellets.

Table 13.0. Total individually identifiable pellets on target at each distance for shotgun

Individually Identifiable Pellets				
Shotgun	4'	8'	12'	16'
shot 1	23	72	83	117
shot 2	34	56	91	139
shot 3	19	55	89	122
shot 4	34	68	80	129
shot 5	25	59	89	114
average	27	62	86	124

Figure 11. Mean total pellet strikes for the shotgun at all distances



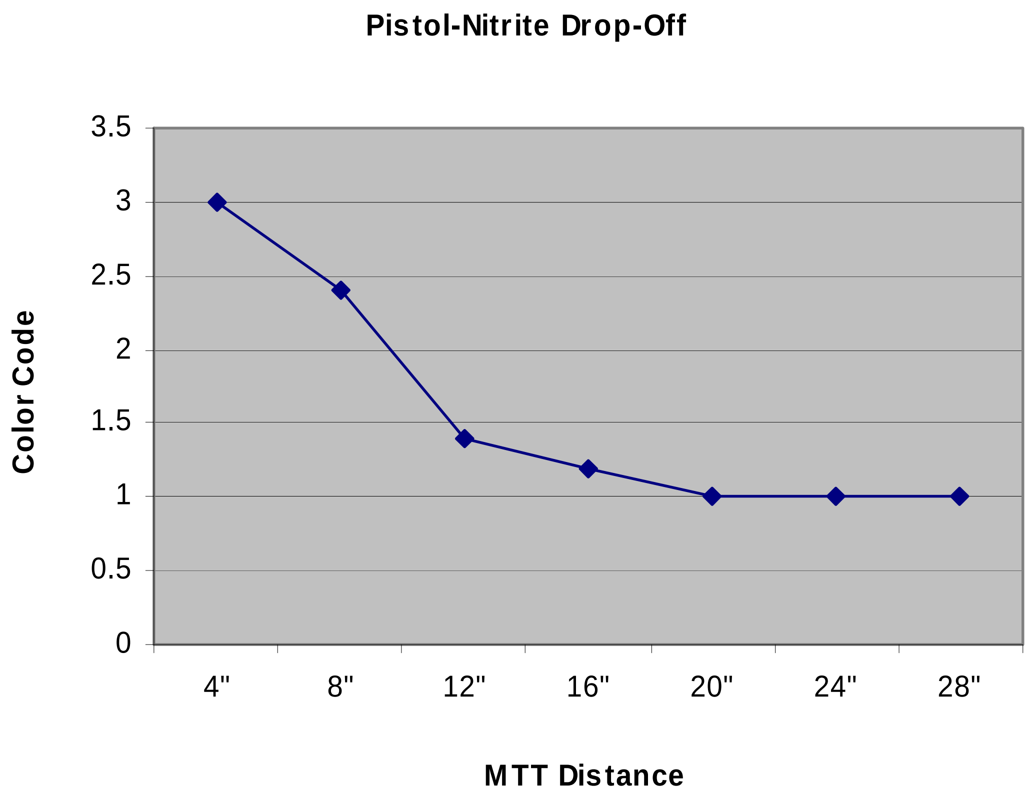
With the measurements that were obtained in *Image J*, a mean, standard deviation and range were calculated using an Excel spreadsheet and graphed for the shotgun (*table 14.0*).

Table 14.0 Summary statistics for the shotgun

Shotgun-Summary Stats, Overall Diameter			
Distance	Mean	Std. Dev.	Range
4'	1.49	0.21	1.17-1.77
8'	2.55	0.62	1.83-3.55
12'	3.96	0.23	3.61-4.25
16'	5.22	0.59	4.55-6.06

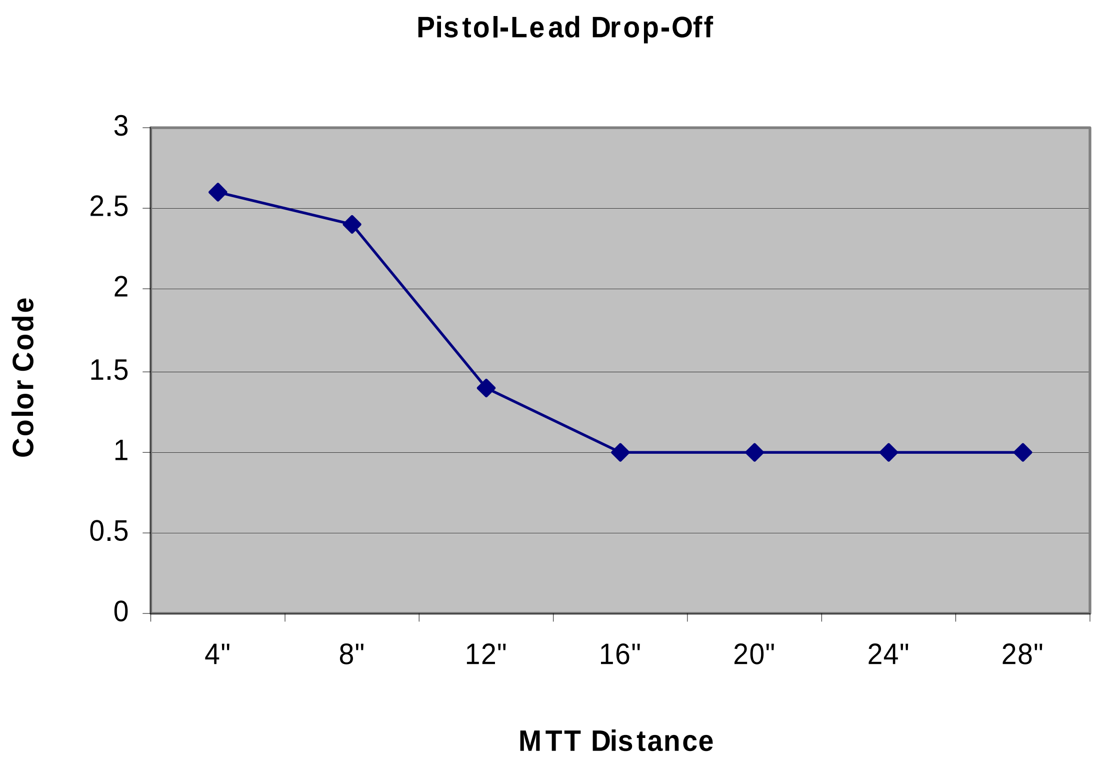
Measurements for chemical tests were not as objective as the previous measurements; however, subjectivity was minimized by assigning a color code to each target. Results on chemical tests required a subjective opinion as to intensity of color. Color codes (0-3) were assigned to each target based on color results from the Modified Griess Test and then the average of these color codes were averaged for all targets at the same distance. All targets shot using the pistol and the 9mm ammunition combination were compared at the same time and a color code was assigned based on the intensity of the color compared to the other targets. Nitrite results for the pistol and ammunition combination indicated that the nitrites dropped off between 16 and 20 feet (*figure 12*).

Figure 12. Nitrite drop-off rate for the pistol



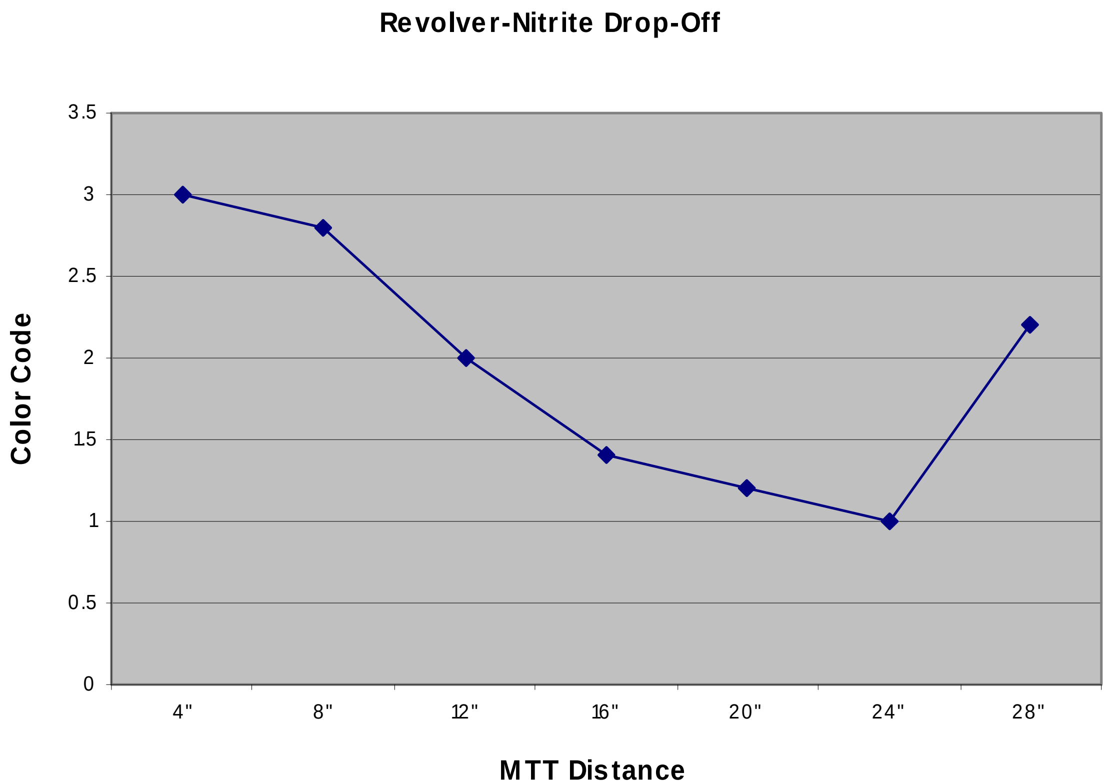
The same scoring system used for the Modified Griess Test, was utilized for the Sodium Rhodizonate Test results. The color codes were averaged for all targets at the same distance. Results indicated lead drop-off for the pistol occurred between 12 and 16 feet as indicated by the graph (*figure 13*).

Figure 13. Lead drop-off rate for the pistol



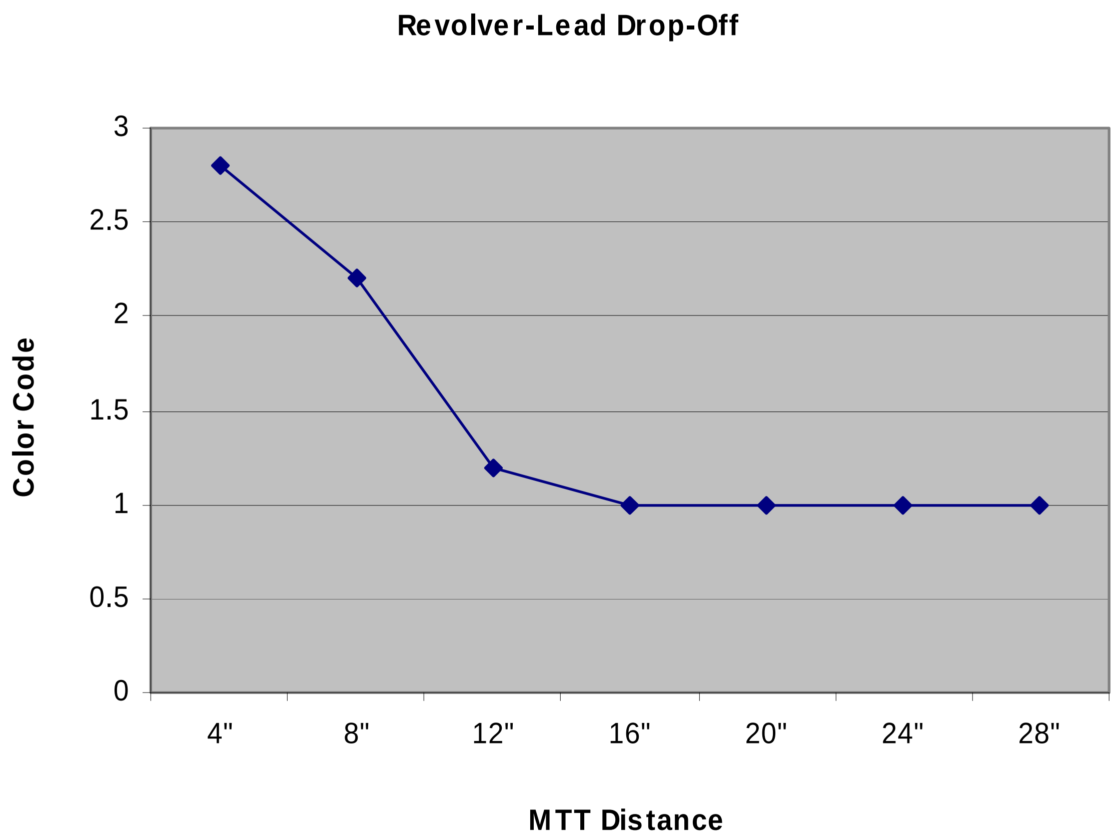
Color codes graphed for the revolver showed a drop-off for nitrites at 20 to 24 inches (see *figure14*).

Figure 14. Nitrite drop-off for the revolver



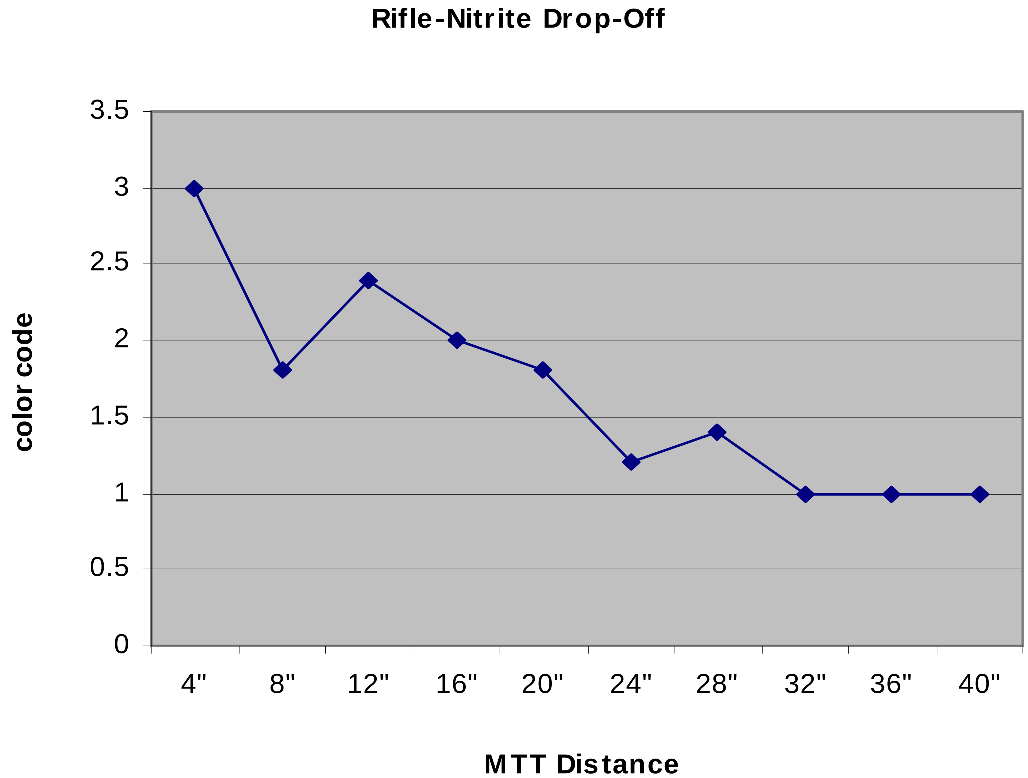
Lead drop-off for the revolver was between 12 and 16 feet (*figure15*).

Figure 15. Lead drop-off for the revolver



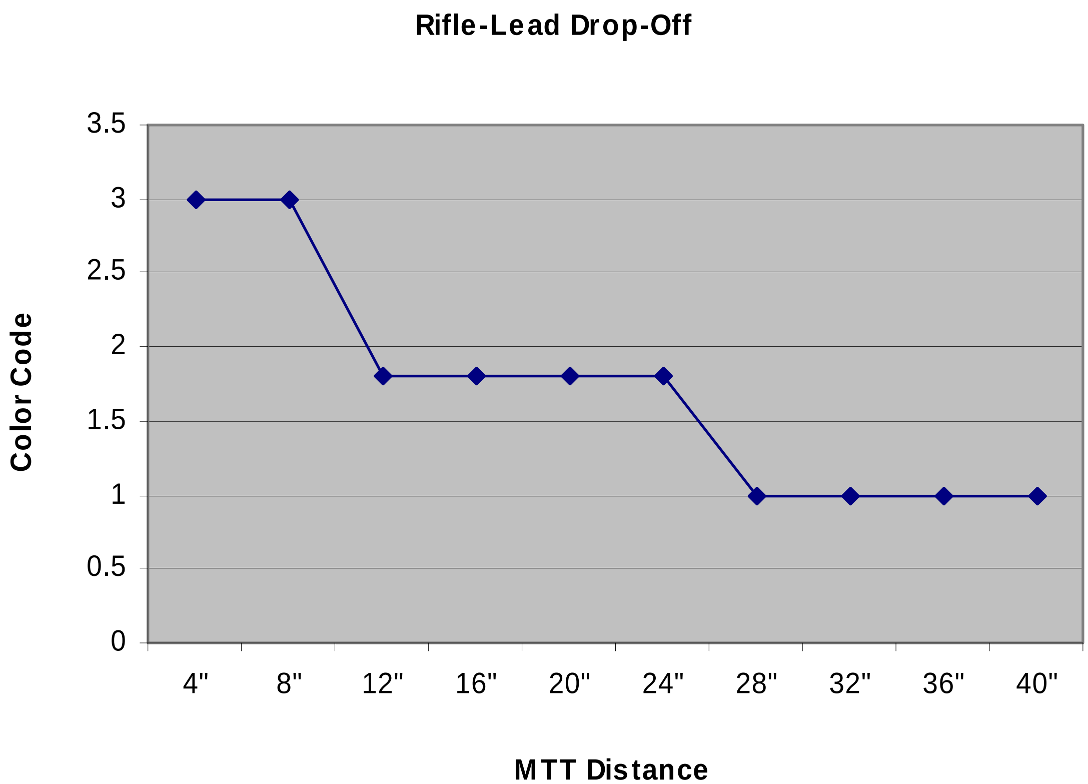
According to the data, nitrite drop-off for the rifle occurred between 28 and 32 inches (*figure16*). It is not uncommon for long guns to have a further drop-off distance than a shorter barreled gun. However, an examiner would need to be cautious in their assessment of the nitrites when comparing to evidence targets because at 4 inches the nitrites are highest, the nitrites declined at 8 inches but increase somewhat at 12 inches before beginning to drop-off slowly.

Figure 16. Nitrite drop-off rate for the rifle



Lead drop-off was a dependable indicator of distance for the rifle (*figure17*). Lead drop-off occurred between 24” and 28” for the rifle.

Figure 17. Lead drop-off for the rifle



Research Question 2: Can particulate density be objectively measured? By using the particulate count measurement in Image J, particulate density could be measured objectively. Parameters were set to measure 50% of the total particulate and 80% of the total particulate and then the overall pattern was measured. This resulted in an actual number of particulate that could be encompassed and measured at each "density". These resulting measurements could then be used to make more accurate comparisons in distance determination studies.

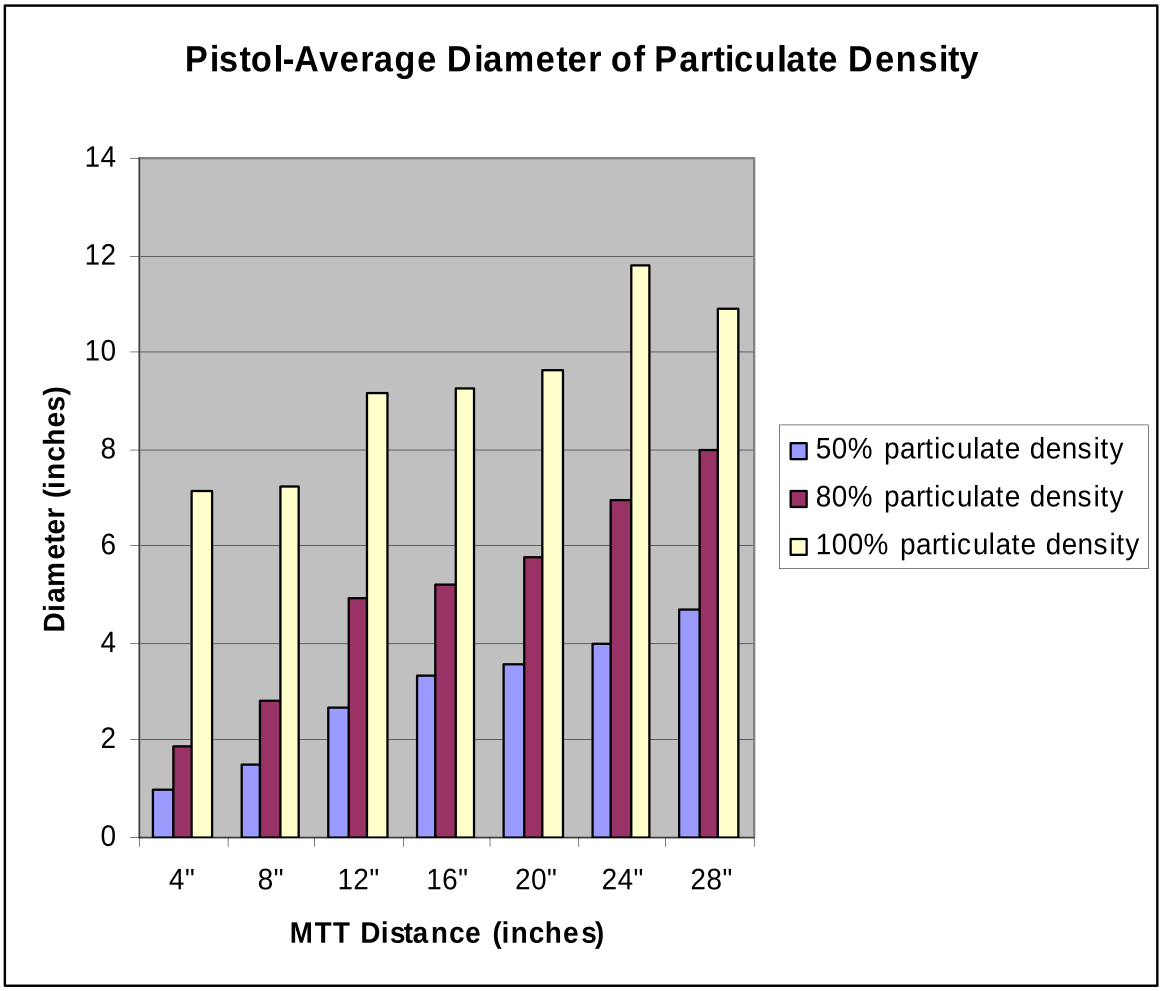
Total particulate was identified and counted. Totals were then calculated for 50% and 80% of the total particulate count and that number of particulate was encompassed in an elliptical area. Measurements were taken of the diameter of the resulting ellipse. An elliptical area encompassed the entire pattern as well, and area and diameter were measured for the entire pattern.

Results indicate that, for the pistol, as the muzzle to target distance increases so too, does the diameter of the overall pattern until 24 inches when the overall GSR pattern begins to decrease. This is due to the lighter dispersion of the particulate and the fact that less particulate is reaching the target at this distance. However, the diameter of the particulate at 50% and 80% continued to increase. The average diameters are one component in comparing test targets to evidence targets to determine the muzzle to target distance (*table 15.0* and *figure 18*).

Table 15.0 Mean diameter of particulate density for the pistol (inches)

Distance	50%	80%	100%
4"	0.97	1.87	7.14
8"	1.52	2.82	7.25
12"	2.66	4.91	9.16
16"	3.33	5.22	9.27
20"	3.58	5.77	9.65
24"	4.01	6.93	11.81
28"	4.72	7.97	10.90

Figure 18. Mean diameter of particulate density for the pistol

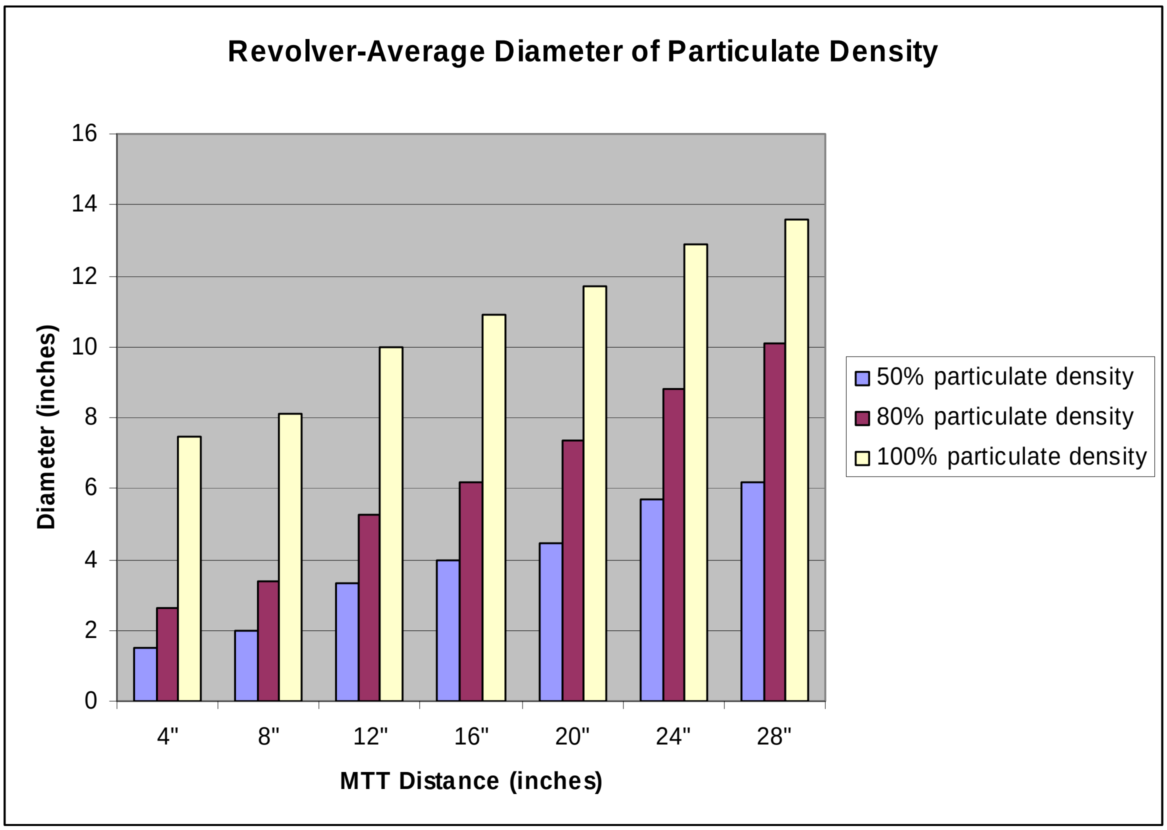


Average diameters for particulate density, for the revolver, showed a steady increase in the diameter, of all particulate densities, for the GSR pattern as the distance increases which indicated that as the distance is increased the particulate is dispersed and lighter due to drop-off and burning of the particulate. These diameters were measured as stated above for the pistol. The average diameters are one component in comparing test targets to evidence targets to determine a muzzle to target distance range (*table 16.0 & figure 19*).

Table 16.0 Mean diameter of particulate density for revolver (inches)

Distance	50%	80%	100%
4"	1.52	2.62	7.45
8"	1.99	3.40	8.12
12"	3.31	5.24	9.97
16"	3.96	6.20	10.92
20"	4.45	7.36	11.70
24"	5.71	8.82	12.90
28"	6.20	10.07	13.61

Figure 19. Mean diameter of particulate density for the revolver

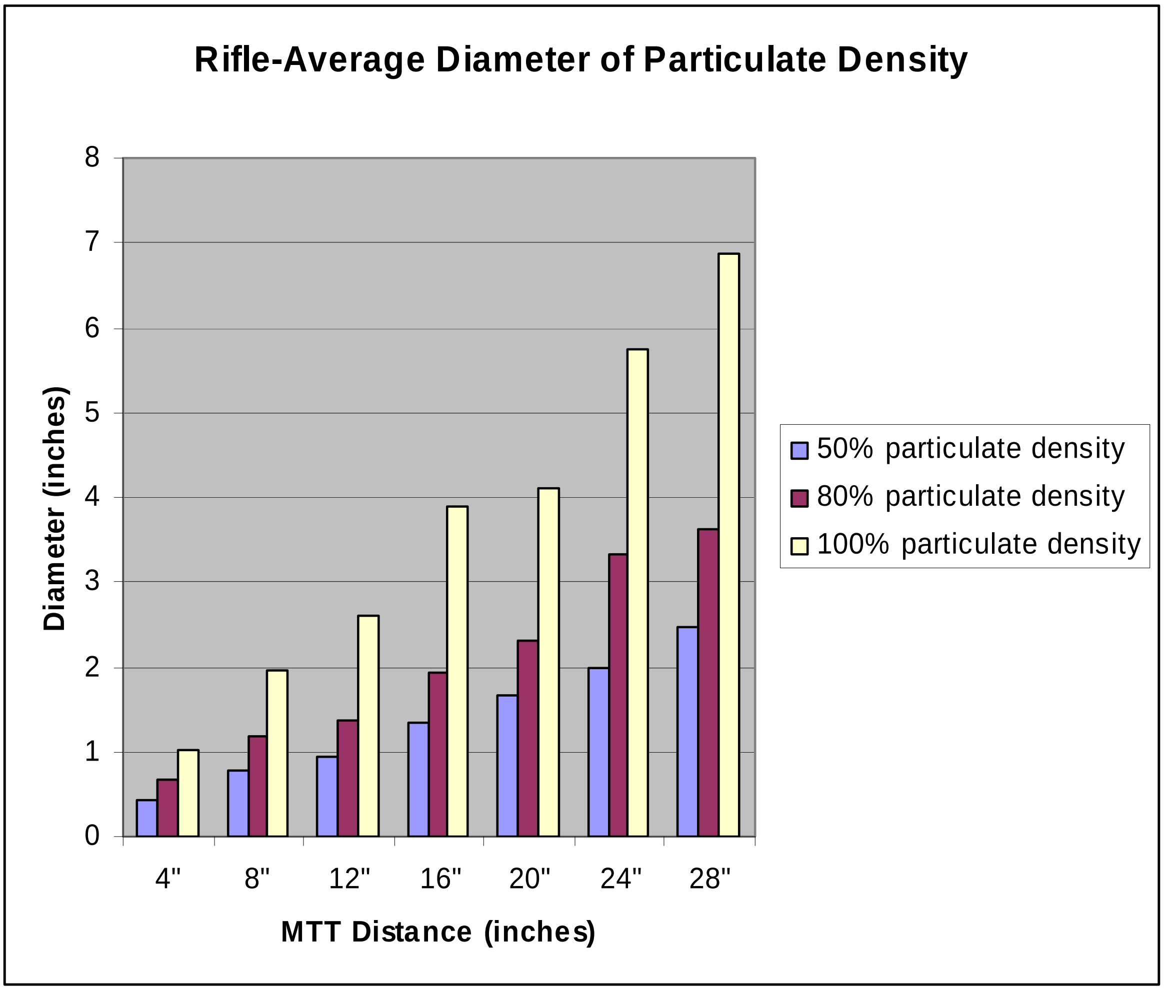


Average diameters for particulate density for the rifle also showed a steady increase in the diameter, at all particulate densities, for the GSR pattern as the distance increases. These diameters were measured the same as the pistol and revolver. As with the revolver, the rifle results indicated that as the distance increased the GSR patterns became lighter and more dispersed. The average diameters are one component in comparing test targets to evidence targets to determine a muzzle to target distance range. Diameters for all particulate densities for the rifle at all distances are listed (*table 17.0* and *figure 20*).

Table 17.0 Mean diameter of particulate density for rifle

Distance	50%	80%	100%
4"	0.44	0.68	1.02
8"	0.78	1.19	1.95
12"	0.95	1.37	2.62
16"	1.33	1.92	3.88
20"	1.67	2.31	4.10
24"	2.00	3.32	5.74
28"	2.46	3.63	6.86

Figure 20. Mean diameter of particulate density at 50%, 80% and 100% for the rifle

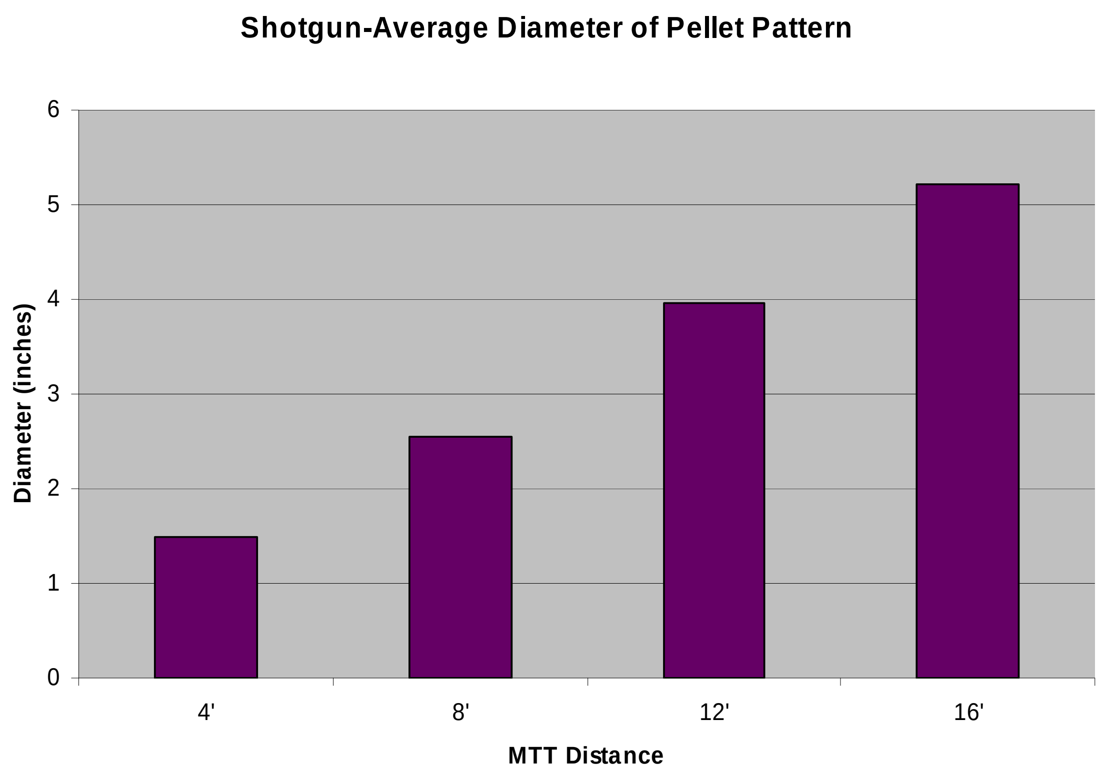


For shotgun targets, the diameter of the overall pellet pattern was measured in Image J, and then averaged over all five test shots. Results of the averages were expressed using an Excel spreadsheet (*table 18.0 & figure 21*). These data demonstrate that as the muzzle to target distance was increased, the total diameter of the pellet pattern continued to increase up to 16 feet.

Table 18.0 Mean diameter of overall pellet pattern for shotgun (inches)

Distance	Diameter
4’	1.49
8’	2.55
12’	3.96
16’	5.22

Figure 21. Average overall diameter of pellet pattern for the shotgun at distances of: 4’, 8’, 12’ and 16’



Research Question 3: How many replicates are needed at any given distance with a particular gun and ammunition combination? By utilizing a univariate inferential one sample z-test, examiners have the ability to estimate the number of targets needed for each gun and ammunition combination at each distance. The formula used to estimate the number of repetitions needed was:

$$(z * \sigma/E)^2$$

Both a 95% and a 90% confidence level were utilized in this study. The z value was determined using the table *Critical Values of the t Distribution* and, in this study, was equal to 2.776 for the 95% confidence level and 2.132 for the 90% confidence level. The σ value is the standard deviation taken from the diameter of the particulate density at each distance. The error rate (E) was calculated by using 5% of the mean.

Upper and lower confidence intervals were calculated for each gun at each distance. The formula utilized for calculating lower and upper confidence intervals was:

$$\bar{x} \pm z * \sigma/\sqrt{n}$$

The value for $\bar{X}$ is the average diameter for particulate density at each distance. The σ value is the standard deviation of the diameters of the particulate density at each distance. The z value was determined using the table *Critical Values of the t Distribution* and, in this study, was equal to 2.776 for a 95% confidence level. Five repetitions were used in this study therefore the square root of five (n) was chosen. These data allow a range that can be used to compare GSR pattern diameters, within a given confidence level, to assist in determining muzzle to target distance.

Pistol

The number of repetitions needed, for this pistol and ammunition combination, was calculated based on the five test targets produced for this study. The table below indicates the number of repetitions needed at each distance for statistical comparison (*table 19.0*).

Table19.0 Replicate data for the pistol at each distance

Distance	Repetitions
4"	16
8"	12
12"	64
16"	8
20"	16
24"	6
28"	41

When confidence intervals were calculated for the semi-automatic pistol, the results indicated some overlap between all distances except between the upper level of 8 inches and the lower interval for 12 inches at 50% particulate density (*table 20.0*). According to these data, using a 90% confidence level, the distances without overlap were: 4 inches to the lower interval of 16 inches at 50% particulate density, 4 inches to the lower interval of 12 inches at 80% particulate density and the upper interval of 8 inches to the lower interval of 12 inches and upper interval of 20 inches to lower interval of 24 inches at 100% particulate density (*table 21.0*).

Table 20.0 Upper and lower confidence intervals for the pistol with a 95% confidence level (highlighted areas indicate where there is no overlap in confidence intervals)

Pistol- Confidence Intervals with a 95% confidence level						
	50% Part. Density		80% Part. Density		100% Part. Density	
Distance	Lower	Upper	Lower	Upper	Lower	Upper
4"	0.71	1.23	1.50	2.24	6.50	7.79
8"	1.15	1.88	2.19	3.46	6.68	7.81
12"	2.28	3.04	4.22	5.60	7.53	10.80
16"	2.92	3.73	4.22	6.21	8.67	9.87
20"	3.10	4.05	5.06	6.47	8.79	10.50
24"	3.59	4.42	5.59	8.27	11.18	12.45
28"	3.75	5.68	7.24	8.71	9.33	12.47

Table 21.0 Upper and lower confidence intervals for the pistol with a 90% confidence level (highlighted areas indicate where there is no overlap in confidence intervals)

Pistol- Confidence Intervals with a 90% confidence level						
	50% Part. Density		80% Part. Density		100% Part. Density	
Distance	Lower	Upper	Lower	Upper	Lower	Upper
4"	0.77	1.17	1.58	2.16	6.65	7.64
8"	1.24	1.80	2.34	3.31	6.81	7.68
12"	2.37	2.95	4.38	5.44	7.91	10.42
16"	3.02	3.64	4.45	5.98	8.81	9.73
20"	3.22	3.94	5.23	6.31	8.99	10.30
24"	3.69	4.33	5.90	7.96	11.33	12.30
28"	3.97	5.46	7.41	8.54	9.69	12.10

Revolver

The number of repetitions needed for this revolver and ammunition combination was calculated based on the five test targets produced for this study. The table indicates how many repetitions are needed at each distance for statistical comparison for the revolver (*table 22.0*).

Table 22.0. Replicate data for the revolver

Distance	Repetitions
4"	111
8"	54
12"	19
16"	5
20"	9
24"	17
28"	62

When confidence intervals were calculated at a 95% confidence level for the revolver, the results indicated that confidence intervals did not overlap between the upper level of 8 inches and the lower interval of 12 inches for 50% particulate density and for the distance between the upper interval of 8 inches and the lower interval of 12 inches at 80% particulate density (*table 23.0*). Using a 90% confidence level, overlap did not occur at 50% particulate density between 8 inches at the upper interval and 12 inches at the lower interval and the upper level of 20 inches and the lower level of 24 inches, at 80% between the upper interval of 8 inches and the lower interval of 12 inches, and at 100% between the upper level of 8 inches and the lower level of 12 inches (*table24.0*).

Table 23.0 Upper and lower confidence intervals for the revolver with a 95% confidence level (highlighted areas indicate where there is no overlap in confidence intervals)

Revolver- Confidence Intervals with a 95% confidence level						
	50% Part. Density		80% Part. Density		100% Part. Density	
Distance	Lower	Upper	Lower	Upper	Lower	Upper
4"	1.37	1.68	2.19	3.04	5.70	9.21
8"	1.40	2.58	2.53	4.28	6.79	9.45
12"	2.95	3.68	4.70	5.79	8.99	10.94
16"	3.13	4.78	5.12	7.28	10.39	11.44
20"	3.83	5.07	6.09	8.64	10.91	12.49
24"	4.89	6.53	7.48	10.15	11.71	14.09
28"	4.87	7.53	8.02	12.12	11.21	16.01

Table 24.0 Upper and lower confidence intervals for the revolver with a 90% confidence level (highlighted areas indicate where there is no overlap in confidence intervals)

Revolver- Confidence Intervals with a 90% confidence level						
	50% Part. Density		80% Part. Density		100% Part. Density	
Distance	lower	upper	lower	upper	lower	upper
4"	1.41	1.64	2.29	2.94	6.11	8.80
8"	1.54	2.44	2.73	4.07	7.10	9.14
12"	3.03	3.60	4.82	5.66	9.22	10.72
16"	3.33	4.59	5.37	7.03	10.52	11.32
20"	3.97	4.93	6.38	8.34	11.10	12.30
24"	5.08	6.34	7.79	9.84	11.98	13.81
28"	5.18	7.22	8.50	11.64	11.76	15.46

Rifle

The number of repetitions needed for this revolver and ammunition combination was calculated based on the five test targets produced for this study. The table indicates how many repetitions are needed at each distance for statistical comparison for the rifle (*table 25.0*).

Table 25.0 Replicate data for the rifle

Distance	Repetitions
4"	20
8"	5
12"	11
16"	21
20"	42
24"	186
28"	290

When confidence intervals were calculated for the rifle, results indicated that confidence interval overlap occurred in at all distances except: 4 inches to upper interval of 16 inches at 50% particulate density, 4 inches to the upper interval of 8 inches and the upper interval of 16 inches to the lower interval of 24 inches at 80% particulate density, and at 4 inches to the lower interval of 16inches at 100% (*table 26.0*). It can be stated, with a 95% confidence level, for data where intervals do not overlap, that if the diameter of the pattern falls within that range the muzzle to target distance for the evidence is at that particular distance. When using a 90% confidence level, overlap did not occur at 4 inches to the upper interval of 20 inches for 50% particulate density, 4 inches to the lower interval of 8 inches and the upper interval of 12 inches to the lower interval of 24 inches at 80% and 4 inches to the lower interval of 16 inches at 100% (*table 27.0*).

Table 26.0 Upper and lower confidence intervals for the rifle with a 95% confidence level (highlighted areas indicate where there is no overlap in confidence intervals)

Rifle- Confidence Intervals with a 95% confidence level						
	50% Part. Density		80% Part. Density		100% Part. Density	
Distance	lower	upper	lower	upper	lower	upper
4"	0.35	0.53	0.52	0.83	0.91	1.12
8"	0.71	0.85	1.06	1.32	1.85	2.05
12"	0.87	1.03	1.23	1.52	2.43	2.81
16"	1.15	1.51	1.68	2.17	3.49	4.28
20"	1.47	1.87	2.08	2.54	3.51	4.70
24"	1.59	2.40	2.65	3.99	3.99	7.49
28"	2.17	2.75	3.36	3.89	4.25	9.47

Table 27.0 Upper and lower confidence intervals for the rifle with a 90% confidence level (highlighted areas indicate where there is no overlap in confidence intervals)

Rifle- Confidence Intervals with a 90% confidence level						
	50% Part. Density		80% Part. Density		100% Part. Density	
Distance	lower	upper	lower	upper	lower	upper
4"	0.37	0.51	0.56	0.80	0.94	1.09
8"	0.73	0.83	1.09	1.29	1.88	2.03
12"	0.88	1.01	1.27	1.48	2.47	2.76
16"	1.19	1.47	1.74	2.11	3.58	4.18
20"	1.52	1.83	2.14	2.49	3.65	4.56
24"	1.69	2.31	2.81	3.83	4.39	7.08
28"	2.24	2.69	3.42	3.83	4.86	8.87

Shotgun

The number of repetitions needed for this revolver and ammunition combination was calculated based on the five test targets produced for this study. The table indicates how many repetitions are needed at each distance for statistical comparison for the shotgun (*table 28.0*).

Table 28.0 Replicate data for the shotgun

Distance	Repetitions
4'	1
8'	6
12'	1
16'	7

After confidence intervals were calculated for the shotgun, results indicated there was no overlap at any distance (*table 29.0*). These data suggests that if the overall diameter of the evidence target is within the lower to upper measurements it can be stated, with 95% confidence that the evidence target was shot at that particular distance.

Table 29.0 Upper and lower confidence intervals for shotgun with a 95% confidence level (highlighted areas indicate where there is no overlap in confidence intervals)

Shotgun- confidence intervals, 95%		
Distance	lower	upper
4'	1.23	1.75
8'	1.77	3.32
12'	3.67	4.25
16'	4.49	5.95

Chapter 5

Discussion

Currently, the tools available to examiners are limited in their usefulness in extracting objective data from targets. This study examined the application of *Image J*, image analyzing software, for use in analyzing targets for determining muzzle to target distance measurements focusing on objective criteria. This research also aimed to define objective criteria for particulate density and examined the number of replicate test targets needed for a representative average at distances when utilizing specific gun and ammunition combinations. Using all these measurements in combination, an examiner can better correlate an evidence target to a distance range.

The first question asked in this study was: can objective data be obtained from image analyzing software? Using Image J, image analyzing software, accurate measurements of particulate count, diameters of particulate density, and area were obtained. These objective measurements led to the ability to calculate more objective information for comparison as well as the ability to graph results. By using digital images in combination with image analyzing software it was possible to obtain not only the data one can measure manually already, but obtain the same type of data with much more accuracy. Furthermore, objective measurements were accomplished in Image J to include more ways to measure targets that are not possible using the overlay, such as area. With the measurements obtained in Image J mean, standard deviation, range and confidence intervals were found using an Excel spreadsheet. Graphs were created in Excel as well using the resulting data. Using image analyzing software allowed the comparison of chemical color results over all distances at one time. The color code measurement for the drop-off graphs called for a subjective opinion, however it did result in the identification of lead drop-off for each gun tested and drop-off of nitrites for the pistol. In addition the graphs were useful for indicating the fact that drop-off had not yet occurred for the rifle, suggesting that nitrites may not be the best indicator of distance for that gun and ammunition combination. The graph also indicated that the revolver was prone to build up of GSR and may deposit this build-up at further distances; this may lead to the conclusion that nitrites were not the best indicator of distance for this revolver. The color coding was possible only with digital photographs of targets because chemical results from the Modified suggesting Griess test are masked by the Sodium Rhodizonate test and the results from the both tests fade, sometimes rather quickly, as was the case with the Glock© Model 27. This pistol showed very little lead residue on chemical tests and faded almost immediately, possibly because it was a newer, cleaner gun with little particulate build-up.

The second question asked was: can particulate density be objectively measured? Studies have shown particulate density to reliably correlate to distance at which a target was shot (Stone, et. al. 1984, Nichols, 1998a). The researcher chose areas of 50% and 80% to represent areas of particulate dispersion. By obtaining particulate counts in Image J, the number of particulate needed for areas of 50% and 80% could be accurately calculated and measured for the pistol, revolver and rifle. By using these measurements an examiner can obtain an overall view of how GSR is dispersed onto a pattern. For example, when comparing the particulate density of the pistol, at 4 inches, 50% of the particulate fit into an ellipse whose diameter measured, on average, .098 inches when compared at 28 inches, at 50% of the particulate, the diameter measured, on average, 4.77 inches. This would suggest that the overall pattern for the 4 inch target was more “dense” and the target at 28 inches more “light” overall. With actual numbers to compare, examiners are not providing a subjective view of how the GSR on the target was dispersed; rather the numbers are an objective measurement as to how “dense” or “light” a GSR pattern appeared. When examiners measure shotgun targets, they measure the overall pattern of pellet strikes. For the shotgun, the data from this study indicated that the pellet pattern diameters continued to increase as the muzzle to target distance increased and that there was no overlap in the measurement of diameter of the overall pellet pattern giving examiners a range of measurements that can be correlated to an evidence target.

The third question asked was: how many replicates are needed at any given distance with a particular gun and ammunition combination? By identifying the number of repetitions needed to show statistically significant averages for test targets and completing that number of repetitions needed at those particular distances, the resulting data could be compared to evidence targets with statistical significance. However, as data from this study suggest, it may not always be feasible for a laboratory to produce the number of test targets necessary. Therefore, confidence intervals may be the more practical method to state results objectively and with a set level of confidence. These confidence intervals can be used to assist in comparing GSR dispersion patterns with more objectivity while still giving the necessary statistical information. Results on confidence intervals indicate that, for the pistol, revolver and rifle there was still some overlap at both the 95% and 90% confidence levels. The shotgun results indicated, for that particular shotgun and ammunition combination, five repetitions were sufficient at all distances to compare with a confidence level of 95%. The ranges listed for confidence intervals on each gun type coincide with information that summary data provides in relation to overlap. Examiners may have to increase numbers of repetitions for distance determination based on the performance of a particular gun and ammunition combination; however utilizing confidence intervals, the number of repetitions required may be decreased compared to using the calculation to find the actual number of targets needed for statistical comparison. Using either of these methods provides an objective, standard measurement applicable to all targets.

Limitations

The basic version of Image J was utilized for this study. There are macros and plug-ins available to enhance, automate, and add to the existing capabilities of the software; however no additions were incorporated into this study. Another limitation was that Image J had no identifiable capability to discern color intensities. Therefore color codes were assigned to each target in order to minimize the subjectivity in the results. This coding system was utilized to encode what was visually seen in order to assist in the objective analysis. While still somewhat subjective this was a meaningful standard applied to this portion of the research and may continue to be viewed as a limitation.

The researcher also observed, while using the standard overlay cross contamination and contact with target surfaces which included GSR and various chemicals from testing occurred; this cross-contamination of the targets if not consistently wiped down after each use, may be considered a harsh limitation if not controlled. Another problem was the acetate overlay measurement was limited to the size of a piece of 8.5”x11” piece of paper; this caused problems obtaining proper measurements on targets where the particulate, nitrites or lead exceeded those measurements. In addition, when viewing shotgun targets, for the standard method of measurement, it was difficult to count the individually identifiable pellets without aid. It was observed that the numbers of pellet strikes counted for the standard measurement were much lower in number than those counted in Image J. Finally, when chemically processing the targets for the revolver, the results on nitrites showed an increase in the intensity of the color at 28 inches. This was an anomaly and possibly due to a build up of nitrites in the revolver or a ventilation system issue at the indoor range specifically for the last five test targets.

Recommendations for Future Research

An area for future research would be to examine a software program that could discern color intensity for use on chemical results. While this study used a color scale to minimize subjectivity a software program that could calculate differences in color intensities would be a good addition to this body of research. One area that could be explored more fully is the lack of lead results of the Glock© pistol. During testing for the presence of lead, the results of the Sodium Rhodizonate test were light and faded rapidly. The Glock© pistols could be compared as a group or to other polygonal rifled pistols. Another possible area for future research could be the study of the numerous measurements available in Image J. This study utilized only those measurements that have, previously, been shown to correlate with test fires at similar distances. However, due to the various other measurements now available through the use of image analyzing software, such as area, not previously available to examiners, a study as to how these other measurements correlate with test targets fired at similar distances could be an area for future research. This study utilized plain white targets on either twill jean or BenchKote®. Future research would be beneficial to determining objective measurements, utilizing image analyzing software, on different colors, patterns and types of fabrics or using infared photos of patterned and colored fabrics. In addition, research to examine utilizing the results of this study to further identify the difference in measurements between the standard methodology and the *Image J* methodology in order to determine if the numbers are statistically significant. In addition, a study on the internal validity of these measurements at each distance could also be very useful as well. This would assist with the validation of the software directly for the purposes of this study and measurements performed in this research. Finally, future research should include developing a cohesive model, based on this current study utilizing image analyzing software, which could be universally applicable to all laboratories.

Conclusion

Each gun and ammunition combination studied created patterns of GSR that are distinctive for only that combination at particular distances. Therefore measurements must be made on a case by case basis for each combination as necessary. Based on the results of this study, some measurements were better indicators of distance and other measurements may not be as reliable an indicator for distance comparison. In the study, results indicated that chemical results of nitrite and lead were reliable indicators of distance for the pistol. Nitrites for the pistol reliably dropped-off between 16 and 20 inches, while lead drop-off was steady between 12 and 16 inches. However, for the revolver nitrites increased at 28 inches due to the build up of nitrites while shooting which may cause unreliable results at closer or further distances. Lead for the revolver however, was a more reliable indicator of distance due to the consistent drop-off of lead between 12 and 16 inches. Results from graphs showed that nitrites for the rifle had not yet dropped-off at 28 inches and further test targets were needed to determine where drop-off occurred. Test targets were then shot at 32, 36 and 40 inches. Drop-off of nitrites, for the rifle, occurred between 28 and 32 inches. The lead drop-off for the rifle was reliably seen between 24 and 28 inches indicating that it was a reliable indicator of distance for the rifle.

By looking at total particulate count, particulate density, and results from chemical testing of nitrites and lead, examiners can get an overall representation of how a gun and ammunition combination function at varying distances. By locating areas that are more reliable indicators of distance for a particular gun and ammunition, examiners can better correlate evidence targets with reliable indicators of distance from test targets. Then, comparisons can be made to evidence targets using: individual particulate count, measures of particulate density with confidence intervals and color coding from chemical results, with better accuracy, to assist in determining proximity of muzzle to target distance.

Qualified firearm examiners will always be needed to perform examinations accurately and provide conclusions based on their knowledge and experience. Current software technology can assist examiners in analyzing GSR dispersion more objectively; thereby determining distance brackets that are meaningful and accurate. The goal of providing investigators information should be pursued and opinions of distance determination should be supported by objective data. The findings of this study may also benefit firearms examiners during their testimony, as an expert witness in court cases, by assisting opinions of distance determination to be based on objective measurements, providing quantitative evidence for their conclusions, as well as a constructing graphics for demonstrative aids in order to better educate their juries. And finally, this research will build upon the existing empirical knowledge, in general for the firearm and toolmark examiner’s community and assist in the movement toward more objective methods of analysis.

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