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Bullet-Weapon Determination on Highly Deformed Bullets (HDB): A Digital Device and a Mathematical Formula Method

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Abstract

During drive-by shooting, police barricade, or armed bank robbery incidents, bullets hitting from a right angle onto a hard surface (car metal, concrete, or brick walls) usually turn into highly deformed bullets (HDB) on the ground due to the heavy impact. From the perspective of forensic practice, these HDBs bear little information due to the fact that there is only one or two rifling's (lands/grooves) usable on the HDBs for the firearm examination. While the number of rifling is one of the standards or criteria for a bullet-weapon determination, an HDB with only one or two visible lands or grooves renders it little evidential value for identification. With a quasi-experimental design and a purposive sampling, two pairs of highly deformed jacked bullets (9 mm and .30) and one pair of highly deformed lead bullet (.38) were selected for testing and calculating. Using a palm-sized digital device, the study proposes a new mathematical formula that allows calculating the number of rifling on HDBs fired from pistols or revolvers. This new approach is able to provide a real-time method of determining the number of rifling's on the HDBs to improve crime scene investigations as well as later lab work for bullet-weapon identification.

Keywords: Forensic science • Crime scene investigations • Bullet-weapon identification • Highly deformed bullets • Mathematical formula of calculating the number of rifling • Real-time digital measurement

Introduction

The majority of bullets found on crime scenes are often not in sufficient good condition to permit a direct bullet—weapon determination with necessary accuracy. When a drive-by-shooting, barricade shooting, or mass shooting incident occurs, quite often highly deformed bullets (HDBs) are found at the crime scene because the bullet hit a hard surface from or close to a right angle. The resulting shape of the bullet is largely dependent on the ratio between the impact angle (incidental) and the critical angle of the bullet [1]. These bullets often turn out to be unusable because the bullet bears only one or two lands/ grooves, making the total number of the riflings (lands/grooves) undetermined, which can be used as one of the criteria for a bullet-weapon determination. Although the phenomena of ricocheted bullets have been investigated in details [2-6], few researches can be found in the literature review on determining the number of riflings (lands/grooves) on highly deformed bullet (HDB). The scarce inquiry of the subject is due to three chief difficulties: (1) Only one or two lands/ grooves on an HDB; (2) A portable field device is needed to measure the land/ groove width on the HDB; (3) A mathematical calculation method is needed for a scientific determination. Using a palm-sized digital device, a quasi-experimental test was conducted with a mathematical formula for the number of riflings (the number of lands/grooves). As a result, the total number of riflings can be calculated by a real-time and digital measurement in the field for a bullet-weapon determination.

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Materials and Methods

Current examination criteria

Currently, there are different criteria or standards used by different firearms examiners to determine if a bullet was fired from a particular firearm involved in a criminal incident. While the more criteria used, the higher confidence level can be achieved, the following ten criteria are most commonly employed and recognized for a bullet—weapon determination: (1) The caliber specific rule (a weapon must fire a specific caliber of ammunition); (2) Type of rifling (rectangular vs polygonal); (3) Direction of rifling (clockwise vs counter clockwise); (4) Land width and groove width; (5) Ratio between land width and groove width (1:1, 1:2, or 1:3); (6) Striations; (7) Frontal mark of rifling (beginning portion of the land/groove); (8) Rifling pitch (the length of one complete resolution of the rifling); (9) Rifling angle (the angle between the rifling and an imaginary horizontal line); and (10) Number of riflings (lands/ grooves) [7].

Out of the ten criteria, it is believed that there is a mathematical correlation between the land/groove width as (5) mentioned above and the number of rifling as (10) mentioned above, which can be used as one of the factors for a bullet—weapon determination. Expressed differently, if the total number of riflings (e.g. 4, 5, 6, 7, or 8) can be calculated on an HDB, it then can be used to compared between the total number of riflings of the bullet found at the scene and the number of riflings from the test bullet, thus determining if the bullet was fired from a particular weapon as one of the factors.

Two recent reports

In 2009, the National Research Council issued a report (The NRC Report) and challenged that current forensic methods, except for nuclear DNA analysis, are less reliable and consistent to identify a specific individual or source due to a lack of quantifiable measurements [8]. In 2016, The President's Council of Advisors on Science and Technology (The PCAST Report) recommended further actions to strengthen forensic science and promote its more rigorous use in the courtroom, again challenging that pattern-matching forensic procedures are less scientific due to its lack of standardization and computerization [9]. While the two reports have received mixed feedback and responses in the forensic science community, a digital measurement and a mathematical calculation does seem to be a better direction or at least an improvement towards a more scientific and quantifiable direction for the firearms examination.

Research design

This quasi-experimental study was carried out to calculate the number of riflings from several highly deformed bullets (each with only one intact land and one groove) using a palm-sized digital device and with a mathematical formula. In essence, the research design was based on four related mathematical questions: (1) What is the mathematical correlation between the circumference and its equal units (rifling) on a fired bullet? (2) What is the mathematical correlation between one unit of rifling and the total number of riflings on a fired bullet? (3) Is there a device that can measure the one unit of rifling on a highly deformed bullet in the field or in the lab? (4) Is there a mathematical formula to calculate the number of riflings based on the diameter and one unit of rifling on a fired bullet? If the four questions can be answered in a field operation, the total number of riflings can be then calculated and used as one of the comparison criteria for a bullet—weapon determination.

Mathematical principles

According to the mathematical relationship among the diameter, the π (Pi = 3.14), and the circumference, the following mathematical inference can be made and calculated:

a. Given Mathematical Principle: Circumference = Diameter × π (Pi=3.14)

b. One Unit of Rifling Width = Land Width + Groove Width (Equal Number of Both)

c. If Diameter × π (Pi) ÷ One Unit of Rifling (One Land Width + One Groove Width) = Number of Rifling

In reality, the diameter is not difficult to know from three sources: a. caliber cased on the fired casing bottom (.40 or 9 mm) at the scene, b. measuring the bottom of the bullet, if possible, or c. from the weapon discovered (the caliber specific rule).

d. The Proposed Mathematical Formula for the Calculation:

Diameter (or the known caliber) × π (Pi=3.14, as a Constant)

———————————————————— ≈ Estimated Number of Rifling

One Unit of Rifling (One Land Width + One Groove Width to be measured)

A crime scene scenario

At a drive-by shooting scene, a bullet was found that has hit a concrete driveway from a right angle and has become a highly deformed bullet (HDB). The HDB has only one visible intact land and groove due to the right-angle trajectory. However, both the crime scene investigation team and later the lab technicians would like to know the total number of riflings for a bullet—weapon determination because the rifling number can be used as one of the critical factors for the determination.

Sampling procedure

For a quasi-experimental study, the caliber variation for common pistols and revolvers should guide the purposive sampling procedure for this project. A review of the past shooting experiments from the author's firearm database indicates the following findings: (1) There are ten common calibers for pistols and revolvers; (2) The pistol caliber consists of .45, .40, .30 (a foreign made), 9 mm, .25, and .22; (3) The database of revolvers comprises the following: .44, .38, .357, and .22.

From the preliminary screening, three observations were noted. First, the calibers of both pistols and revolvers can be divided into three categories. The larger calibers (.45~.40) all have six lands and grooves without any variations. Second, the small calibers (.25~.22) all have six lands and groove without any exception. Finally, only the medium calibers (.30~.38) shows some variations of riling numbers. Therefore, the medium category of calibers becomes the focus of this study.

The Quasi-experimental test

Based on the scenario described above, a quasi-experimental test [10] was conducted and designed to simulate a real shooting scene, in this case, in an outdoor shooting range. Two medium caliber handguns were chosen due to their caliber variation observed from the prescreening examinations under a purposive sampling method [10]. First, a pistol (9 mm, fully metal jacketed) was fired five times from a close to a right-angle onto a piece of concrete inside a big bucket with a cover and a highly deformed jacketed bulleted was selected as Sample Bullet One. The criterion for the selection required that at least one intact land width and one groove width was visible at the bottom of the bullet. Another intact bullet was also retrieved from the same pistol from several telephone books that were bounded together and soaked with water as Control Sample One. The control sample was collected as a ground truth comparison or a positive control.

Next, a revolver (.38) was used to fire five cartridges (lead bullets) from a close to a right-angle onto a piece of car metal inside a big bucket with a cover and a highly deformed lead bullet was randomly selected as Sample Bullet Two. Again, the criterion for the selection required that at least one intact land width and one groove width was visible at the bottom of the bullet. Similarly, the revolver was used to fire a cartridge into several telephone books that had been bound together and soaked with water for retrieving an intact bullet as Control Sample Two for a ground truth comparison or a positive control.

Due to the limitations of availability and variation, a purposive sampling was employed to obtain a highly deformed jacketed bullet (Sample Bullet Three) and one control bullet (Control Sample Three) from the pistol (.30, a foreign made pistol). However, both were collected from a donation for the study, not from an actual shooting.

To summarize the three sample pairs: Pair one: One highly deformed jacketed bullet (HDJB) from a concrete by a 9 mm pistol was selected as Sample Bullet One and one intact fired bullet retrieved from dampened telephone books by the same 9 mm pistol as Control Sample One; Pair two: one highly deformed lead bullet from a car metal by a revolver (.38) was selected as Sample Bullet Two and one intact lead bullet from wet telephone books by the revolver (.38) as Control Sample Two; Pair three: One highly deformed jacketed bullet from a .30 pistol (foreign made) as Sample Bull Three and an intact bullet from the same pistol as Control Sample Three were obtained from a donor's collection.

Results and Discussion

Once the three pairs of bullets were selected and placed in order on the ground, each pair of highly deformed (jacketed) bullet was examined, measured, and recorded to get each unit of rifling using a digital scope (palm-sized) on the spot, which simulated a crime scene investigation. While Figure 1 shows the three highly deformed bullets before the measuring, Figures 2, 4 and 6 display the actual images of the measured rifling (the land width and the groove width) of the three HDB samples. Figures 3, 5 and 7 portray the actual images of the measured rifling (the land width and the groove width) of the three control samples (intact) for a ground truth comparison. Each bullet was examined, measured, recorded, and calculated in approximately ten minutes. The digital device presented each image on a laptop (connecting via a USB cable), and the measurement was a real-time display, suggesting a practical implication for crime scene investigations. Then, three types of data were recorded and input into the formula for calculation: (1) the land width (LW), (2) the groove width (WG), and (3) the measured diameter at the bottom of the highly deformed (jacketed) bullets.

Following the proposed formula discussed earlier, the three estimated numbers of riflings on the three highly deformed bullets were calculated. Using the caliber or the diameter of the three positive control samples from the three pairs, the author also measured the bottoms of the three intact sample bullets with a digital caliper for verification. After each diameter multiplies the Pi (3.14) and then divides by the sum of the one land width and one groove width, the

Figure 1. Three highly deformed bullets: sample one of a highly deformed jacketed bullet from a pistol (9 mm, right). Sample two of a highly dformed lead bullet from a revolver (.38, middle), and sample three of a highly deformed jacketed bullet from a foreign made pistol (.30, left).

Figure 2. Sample bullet one of a highly deformed jacketed bullet fired by a pistol (9 mm) with the digitally measured land width = 3.12 mm (dl1, right) and the digitally measured groove width =1.39 mm (dlo, left).

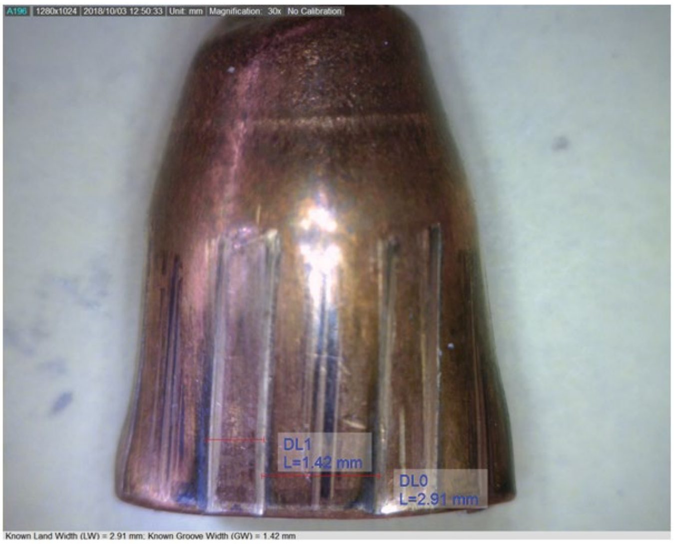

Figure 3. Control sample one fired by a pistol (9 mm) with the digitally measured land width =2.91 mm (dlo, right) and the digitally measured groove width = 1.42 mm (dl1, left).

result was the estimated total number of the riflings for the highly deformed (jacketed) bullets. The following table reports the comparison results (Table 1).

Figure 4. Sample bullet two of a highly deformed lead bullet fired by a revolver (.38) with the digitally measured land width = 0.10 inch (dl1, left) and the digitally measured groove width = 0.11 inch (dlo, right).

Figure 5. Control sample two (intact) by by a .38 with the digitally measured land width = 0.10 inch (dl1, left) and the digitally measured groove width = 0.11 inch (dlo, right).

Figure 6. Sample bullet three of a highly deformed jacketed bullet fired from a foreign made pistol (3.0) with the digitally measured land width = 0.15 (dlo, right), the digitally measured groove width = 0.05 inch (dl1, left), and the known diameter = .30 inch from the fired casing.

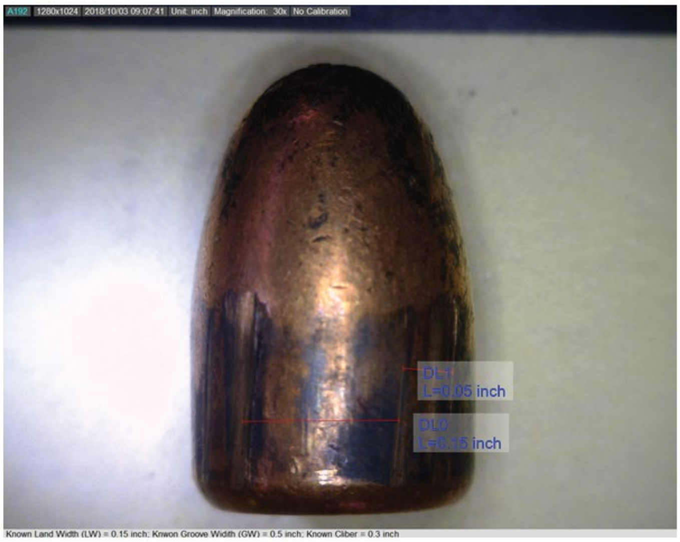

Figure 7. Control sample three (intact) by the same pistol (.30) with the digitally measures land width = 0.15 inch (dlo, bottom) and the digitally measured groove width = 0.05 inch (dl1, top).

Table 1. Comparison of the measuring results in the field among the three pairs of bullets

Samples Bullets (HDJBs)	Estimated Number of Rifling from Testing Samples	Estimated Number of Rifling from the Control Samples	Control Samples (Intact Bullet)	Error Margins between the Two Samples	Number of Rifling from Positive Control
9.1 × 3.14/LW3.12+GW1.39 (mm)	6.34	6.53	9 mm × 3.14/LW2.91+1.42 (mm)	-0.19	6 (9 mm pistol)
.35 × 3.14/LW0.10+GW0.11 (inch)	5.23	5.68	.38 × 3.14/LW0.10+GW0.11 (inch)	-0.45	5 (.38 revolver)
.29 × 3.14/LW0.15+GW0.05 (inch)	4.55	4.28	.30 × 3.14/LW0.15+GW0.07 (inch)	0.27	4 (A foreign made pistol)

Due to the non-definitive value of the Pi and the deformation of the bullet, the rifling number was calculated to the two places after the decimal point. However, if the result was taken as a whole number (the decimal number is ignored), the calculated whole number represents the total number of riflings of the highly deformed (jacketed) bullets under investigation. The same procedure was used for the control sample to calculate the estimated number of rifling from the intact bullets. The actual number of riflings was given as the ground truth reference (the three controls samples) by counting the actual number of riflings from the pistol, the revolver and the foreign made pistol. Finally, for a comparison purposes a margin error or the differences of the two estimated numbers of rifling (the sample bullets and the control sample bullets), was provided for a degree of freedom of confidence. The error margins between the estimated testing and the control samples (-.19, +.45, +.27) are less than the normal confidence level of 0.5. As a result, the accuracy and reliability of the total number of riflings from the three testing samples of the highly deformed (jacketed) bullets were calculated and determined by this quasi-experimental study using the proposed mathematical formula by the palm-sized digital scope.

Crime scene investigation of firearms-related evidence has seen several new methods to be introduced into the field [11,12]. Using a palm-sized digital device, this study provides a mathematical formula to calculate the total number of riflings from highly deformed bullets of a revolver (.38) and two pistols (9 mm and .30). The device can display real time images and digital measurements in a few minutes. Specifically, the HDBs from the pistol (9 mm, fully metal jacketed with the number of rifling = 6) correspond to that of the control sample bullet with right twist lands and grooves (6 R) and with a ratio of land and groove width (L=2G) (Figures 2 and 3).

The highly deformed bullet from the revolver (.38, lead) displays the same number of rifling (5) with that of the control sample with right twist lands and grooves (5 R) and with an equal land and groove width (L=G) (Figures 4 and 5). Finally, the highly deformed jacketed bullet from the foreign made pistol (.30, fully metal-jacked) indicates the same number of rifling (4) with that of the control sample bullet (4 R) with right twist lands and grooves and with a ratio of land and groove width (L=3G) (Figures 6 and 7).

Noticeably, the proposed mathematical formula was not affected by the types of bullet metal (fully metal jacketed *vs.* lead) or the measuring units (inch *vs.* mm). While this study focuses on the phenomena of highly deformed bullets from several previous studies [13-15], the new proposed mathematical formula was able to determine a correlation between highly deformed (jacketed) bullet on hard surfaces (car metal and concrete) and their total number of riflings, which is otherwise difficult to know.

Conclusion

To crime scene technicians and investigators, the highly deformed bullets (HDB) at shooting scenes post a challenge in determining the number of riflings, which is the common type of evidence and also one of key factors for the firearms examination. However, this evidential situation has not been discussed nor studied due to the technical limitations, namely, a palm-sized device and a mathematical calculation.

The new mathematical formula proposed by this quasi-experimental study may indicate three practical implications where a bullet is fired onto hard surfaces and becomes a highly deformed bullet (HDB). First, the strength of the proposed mathematical formula only requires one intact land width and one groove width for a simple mathematical calculation. Second, the examination needs a palm-sized device to measure the widths of one intact land and groove, for which a digital scope can do the measurements. Finally, the whole examination process only lasts about twenty minutes at the scene, which is the most important and practical value from this study.

It is hoped that future studies should be expanded to more samples from more types of firearms (rifles) and more types of surfaces, e.g. only jacked-pieces hit onto brick walls. Further, another situation should be considered where a bullet hits deep into the sand and results in many blurred riflings, but there is still one intact land and groove visible.

In conclusion, it is strongly believed that many applications of the proposes method (the mathematical formula and the palm-sized device) by this study may be carried out to test correlations between a small incidental/

ricochet angle and a deflection angle at plain floating glass [16], wood grain [17], and laminated particle board [18] for crime scene shooting examinations and reconstructions.

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