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The Influence of Reduced Powder Charge on the Forensic Examination of Fired Cartridge Cases

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Abstract

It is currently impossible for domestic forensic laboratories to determine the wounding potential of a questioned firearm unless the weapon is seized. To break through this limitation, we conducted a series of firing tests utilizing one short recoil operated pistol and one gas-delayed blowback pistol and cartridges with varied amounts of powder charge. The muzzle velocity (v) and energy density (ED) of the fired bullets were determined based on a ballistic chronograph. The breechface marks, firing pin aperture marks, firing pin aperture shear marks, and chamber marks on fired cartridge cases were examined. The results indicated that the ED and the distribution length (L) of striated chamber marks were proportional to the amount of powder charge. And the ED was also proportional to the barrel length of fired pistol. Correlation analysis revealed that L was linearly correlated with logarithm transformed value of ED (ln ED). The coefficient of determination (R^2) between L and ln ED was greater than 0.99. Two-variable linear equation was used to calculate the evaluated energy density (ED_E). Verification firing tests were conducted using one blowback pistol and seven rounds of reducing-powder-charged cartridges. To calculate ED_E, we employed L and the linear equation. The percentage differences between ED and ED_E were all less than 3.5%. These results demonstrate that the method developed in this study is effective and practical for evaluating the wounding potential of a questioned firearm through the examination of cartridge cases fired from it.

Keywords: ***firearms examination, reduced powder charge, breechface marks, firing pin aperture marks, firing pin aperture shear marks, chamber marks, muzzle energy density***

Introduction

When a semi-automatic pistol is loaded and discharged the component parts in the weapon that interact with the cartridge case cause both impressed and striated toolmarks that possess class and individual characteristics. The fired cartridge cases are automatically ejected from the pistol after firing. They are thus often found at the scene of shooting incidents and used as important physical evidence. Firearm examiners have been asked by local judges to help assess whether or not a fired cartridge case can be employed to estimate the muzzle kinetic energy or determine the wounding potential of the fired firearm. Function testing and kinetic energy determination are used by domestic forensic practitioners to determine the wounding potential of propellant guns and airguns, respectively. It is impossible to perform the function testing and kinetic energy determination unless the questioned firearm is seized. Thus, the development of new methods is required to satisfy the needs of local judges.

Among the toolmarks left on the fired cartridge

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case, the features of breechface marks, firing pin aperture marks and chamber marks are most likely affected by the chamber pressure of fired weapon. Haag used hand-loaded cartridges with incrementally increased powder charge for firing tests. The correlation between the muzzle velocity and the chamber pressure and the influence of chamber pressure on the depth of breechface markings were investigated. Haag's results verified that the muzzle velocity is proportional to the peak chamber pressure. However, the depths of breechface marks on hard primers and primers crimped into their primer pockets were not affected by increased chamber pressures [1]. Scholars have reported that the morphology and depth of the firing pin marks were significantly modified by the spatial orientation (vertical upwards, horizontal or vertical downwards) of the firearms when revolvers were fired [2]. Hazon et al. fired homemade and converted firearms to conduct toolmarks examination of fired cartridge cases. Conventional and unconventional chamber marks on the sidewall of fired cartridge cases were observed. The morphology and development of these marks were clearly described [3]. A ring of chamber marks around the sidewall of the cartridge cases fired from both converted and unaltered Walther PPQ pistols were observed about 4 mm from the case mouth by Carlsson et al. The agreement between striated chamber marks from two cartridge cases discharged in the same pistol was also reported [4]. Unusual chamber marks resembled fluting marks were found by Murphy on a cartridge case fired from a Hi-Point pistol. These marks were regarded as accidental and fluted chambers were not observed in other Hi-Point manufactured guns [5]. Streine reported a triple homicide case where the fired pistol was recovered from a chemical toilet. With the exception of the chamber, the pistol was badly corroded. The internal surface of the chamber was protected by a live cartridge. Thus, the chamber marks were used to make identification between fired cartridge cases recovered at the crime scene and the test fired cartridge cases from the questioned pistol [6].

Despite the aforementioned literatures have investigated the effect of the chamber pressure on the features of toolmarks, such as breechface marks and chamber marks on fired cartridge cases, more research is still required to verify the influence of the chamber pressure on the distribution length of striated chamber marks and the depth of the breechface marks. We conducted a series of firing tests using cartridges loaded with incrementally reduced powder charge. The features of breechface marks, firing pin aperture marks, and chamber marks on the fired cartridge cases were carefully examined. The aim of the current study was to assess the feasibility of utilizing the change of the features of these toolmarks to evaluate the muzzle energy density, and thus the wounding potential, of the fired firearms.

Materials and methods

Research equipment and materials

The experiments in this study were performed using two 9 mm Luger caliber semi-automatic pistols, one short recoil operated Glock 17 pistol (USA) and one gas-delayed blowback operated Vektor CP1 pistol (South Africa). Additionally, the experiments employed regular 9 mm Luger cartridges with nominal powder charge weight being 0.39 g and two types of hand-loaded cartridges with reduced powder charge measuring 0.29 g and 0.20 g, respectively. All cartridges used are loaded with full metal jacketed bullets (measuring 7.50 g) and have head stamps of "9 mm 14". A Mettler Toledo balance (AX204, Switzerland) was used to measure the mass of bullet and powder charge. The bullet mass stated in this study is the mean of measured data of five bullets. The amount of powder charge in regular cartridges was the nominal value rather than measured data. The amount of powder charge loaded in every reducing-powder-charged cartridge was precisely measured before the hand-loading process.

A sample ID composed of the pistol model and the amount of powder charge was utilized for each firearm and cartridge combination. The symbols used for the pistol model were "G17" for Glock 17 and "VCP1" for Vektor CP1. Symbols for the amount of powder charge were "F39" for regular cartridges and "R29" and "R20" for reducing-powder-charged cartridges with 0.29 g and 0.20 g of powder charge, respectively. The sample ID, brand and model of pistol, and amount of powder charge for each firearm and cartridge combination are presented in Table 1.

Table 1 The sample ID, brand and model of pistol, and amount of powder charge for each firearm and cartridge combination

Sample ID	Pistol brand and model	Amount of powder charge
G17-F39	Glock 17	0.39 g
G17-R29	Glock 17	0.29 g
G17-R20	Glock 17	0.20 g
VCP1-F39	Vektor CP1	0.39 g
VCP1-R29	Vektor CP1	0.29 g
VCP1-R20	Vektor CP1	0.20 g

Experimental method design

The experimental setup for the firing tests is shown in Figure 1. The muzzle velocity (v) was measured using a ballistic chronograph equipped with two infrared light screens suitable for all light conditions (BMC 19, Kurzzeit, Germany). The start and stop sensors of the BMC 19 were designed to be 34.5 cm apart. The start sensor was placed at a distance of 85 cm from the muzzle of the pistol. The pistol was gripped by a shooter and leveled so that the line of flight of the bullet was perpendicular to the planes defined by the light screens of ballistic chronograph. All test firings were conducted in an indoor ballistic laboratory at an ambient temperature of 23 °C. Furthermore, the kinetic energy and energy density (ED) of the fired bullet were calculated by employing the equations from a previous study [7]. Five and eleven repeated firings were conducted for each set of firing test using the Glock 17 and Vektor CP1 pistols, respectively. The mean of measured muzzle velocities ($\overline{v}$) and the mean of muzzle energy densities ($\overline{\text{ED}}$) and their standard deviations (SDs) of each set of firing test were calculated. The fired cartridge cases were recovered for further examination.

A stereo microscope (Leica M125, Germany) was used to find and identify the breechface marks, firing pin aperture marks, firing pin aperture shear marks, and chamber marks left on the fired cartridge cases. The firing pin aperture shear marks found on cartridge cases fired from Glock 17 pistol were compared with each other using a comparison microscope (Leica FSC, Germany). A digital caliper (Mitutoyo, Japan) was utilized to measure the distribution length (L) of striated chamber marks found on the cartridge cases fired from Vektor CP1 pistol. The L was measured from the case mouth to the rearmost boundary of the observed striated chamber marks.

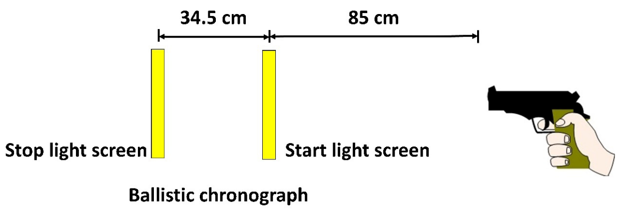

Fig. 1 The experimental setup for firing tests.

Statistical tests

To examine the influence of the amount of powder charge on the muzzle energy density (ED) and the distribution length (L) of striated chamber marks, independent sample *t-test*s were used to establish the significance of the differences of the mean of ED ($\overline{\text{ED}}$) and the differences of the mean of L ($\overline{\text{L}}$) between paired firing test samples using different pistols and cartridges with varied amounts of powder charge. A confidence level of 99% (p-value = 0.01) was used for the t-tests.

Taking the logarithm transformed value of ED (ln ED) as independent variable and the the distribution length (L) of striated chamber marks as dependent variable, a correlation and simple linear regression analysis was used to measure the strength of the correlation and to model the relationship between the L and ED obtained from the firing tests using the Vektor CP1 pistol. The obtained linear equation and L were employed to calculate the evaluated muzzle energy density (ED_E).

To verify the effectiveness and practicality of using the linear equation developed in this study and L to evaluate the ED, the Vektor CP1 pistol was subjected to further firing tests. Seven rounds of reducing-powder-charged cartridges were fired. The L, *v*, ED, and ED_E values for each firing test were determined. The percentage difference between ED and ED_E obtained for each firing test was calculated by dividing the difference between ED and ED_E by the mean of ED and ED_E and multiplying the quotient by 100%.

Results and discussion

Among the fifteen cartridge cases recovered from the firing tests using Glock 17 pistol and cartridges with varied amounts of powder charge, the five G17-F39 cartridge cases were found to have distinct breechface marks, rectangular firing pin aperture marks, and firing pin aperture shear marks. Less apparent breechface marks were observed on four out of the five G17-R29 cartridge cases, however, firing pin aperture marks and firing pin aperture shear marks were not found on all five G17-R29 cartridge cases. No visible breechface marks, firing pin aperture marks, or firing pin aperture shear marks were observed on all five G17-R20 cartridge cases. Typical images of toolmarks observed on the primers of G17-F39, G17-R29, and G17-R20 cartridge cases are shown in Figure 2. Among the five G17-F39 samples, the breechface marks on the primer of every cartridge case were in good agreement with each other. The matched breechface marks on the compared pair of G17-F39-01 and G17-F39-03 cartridge cases that possess the highest ED (716.74 J/cm^2) and the lowest ED (687.85 J/cm^2), respectively, are shown in Figure 3. Although wide variations in EDs were observed among the five G17-R20 samples as shown in Table 2, no significant differences of toolmarks among these cartridge cases were found. The toolmarks on the primers of the compared pair of G17-R20-05 and G17-R20-04 cartridge cases that possess the highest ED (127.54 J/cm^2) and the lowest ED (56.84 J/cm^2), respectively are shown in Figure 4.

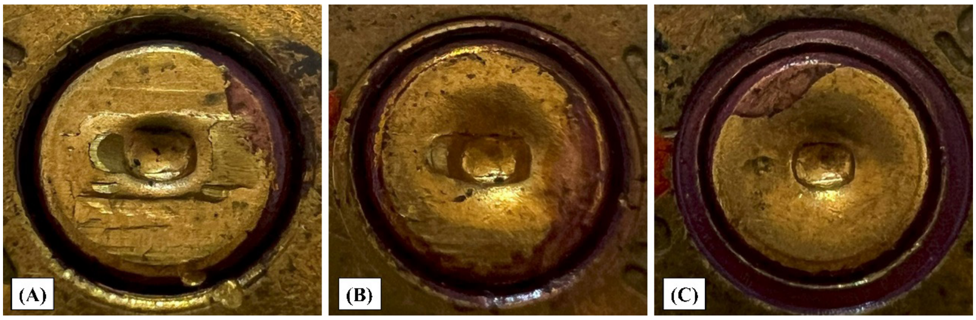

Fig. 2 Distinct breechface marks, rectangular firing pin aperture marks, and firing pin aperture shear marks found on the primer of G17-F39-01 (ED = 716.74 J/cm^2) cartridge case (A), less apparent breechface marks found on the primer of G17-R29-02 (ED = 507.08 J/cm^2) cartridge case (B), no visible breechface marks, firing pin aperture marks, and firing pin aperture shear marks found on the primer of G17-R20-04 (ED = 56.84 J/cm^2) cartridge case (C).

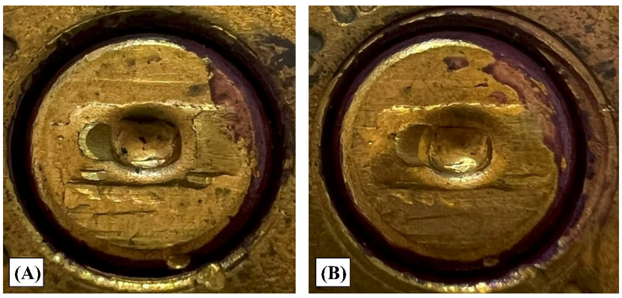

Fig. 3 The matched breechface marks on the compared pair of G17-F39-01 (ED = 716.74 J/cm^2) cartridge case (A) and G17-F39-03 (ED = 687.85 J/cm^2) cartridge case (B).

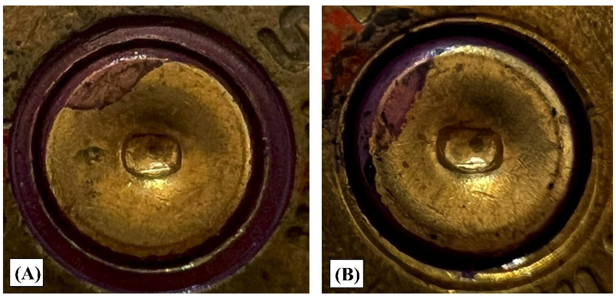

Fig. 4 The toolmarks on the primers of the compared pair of G17-R20-04 (ED = 56.84 J/cm^2) cartridge case (A) and G17-R20-05 (ED = 127.54 J/cm^2) cartridge case (B).

Rectangular firing pin aperture marks are important class features for cartridge cases fired from many models of Glock pistols. Warren et al. utilized the rectangular firing pin aperture marks to differentiate the cartridge cases fired using Glock 19 pistol from the cartridge cases possessing rounded firing pin aperture marks discharged using Springfield XD-S 45 pistol [8]. Similarly, in this study, the shapes of the firing pin aperture marks were used to distinguish the cartridge cases fired from Glock 17 from those fired using Vektor CP1. The Clock 17 is a short recoil operated pistol with tilting barrel design; the primer of the fired cartridge case inside the chamber of tilting barrel would move against the breech face and be scratched by the edge of the firing pin aperture after the gun is fired. Consequently, firing pin aperture shear marks are created on the fired cartridge cases during the unlocking process. The firing pin aperture shear marks have valuable class characteristics that are often employed to identify the operation method of questioned firearm. The results of microscopic comparisons demonstrate that sufficient agreement of striations was observed in firing pin aperture shear marks on all compared pairs of G17-F39 cartridge cases and thus they were matched with each other. The matched striations in firing pin aperture shear marks on the compared pair of G17-F39-01 and G17-F39-02 cartridge cases are shown in Figure 5.

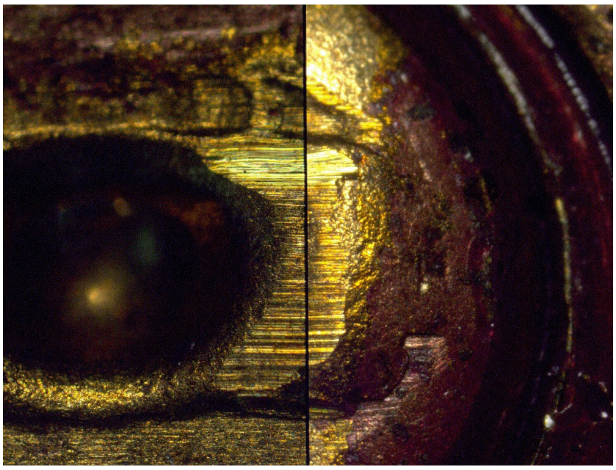

Fig 5. The matched striations in firing pin aperture shear marks on the compared G17-F39-01 (left) and G17-F39-02 (right) cartridge cases.

Among the thirty three cartridge cases collected from the firing tests employing Vektor CP1 pistol and cartridges with different amounts of powder charge, apparent breechface marks and rounded firing pin aperture marks were observed on the eleven VCP1-F39 cartridge cases. Less apparent breechface marks and firing pin aperture marks were found on nine and seven out of the eleven VCP1-R29 cartridge cases, respectively. Less clear breechface marks and firing pin aperture marks were observed on seven and four out of eleven VCP1-R20 cartridge cases, respectively. The Vektor CP1 is a gas-delayed blowback operated pistol, the barrel does not tilt down after the pistol is fired, and thus no firing pin aperture shear marks are created on the fired cartridge cases. Representative images of toolmarks observed on the primers of VCP1-F39, VCP1-R29, and VCP1-R20 cartridge cases are shown in Figure 6. The significant differences of the morphology of firing pin aperture marks between the cartridge cases fired from Glock 17 and Vektor CP1 pistols were resulted from differently shaped firing pin apertures of these pistols as shown in Figure 7.

From these results, it can be concluded that the amount of powder charge has a significant effect on the presence and clarity of breechface marks, firing pin aperture marks, and firing pin aperture shear marks on the fired cartridge cases. Therefore, we recommend that in the comparison of fired cartridge cases for case work, care should be taken when correlating aforementioned marks on cartridge cases suspected to be originated from reducing-powder-charged cartridges.

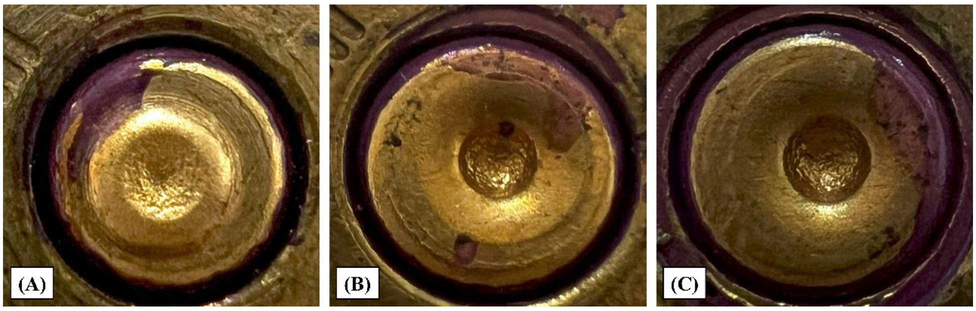

Fig. 6 Distinct breechface marks and rounded firing pin aperture marks found on the primer of VCP1-F39-05 cartridge case (A), less apparent breechface marks and rounded firing pin aperture marks found on the primer of VCP1-R29-01 cartridge case (B), less clear breechface marks and rounded firing pin aperture marks found on the primer of VCP1-R20-06 cartridge case (C).

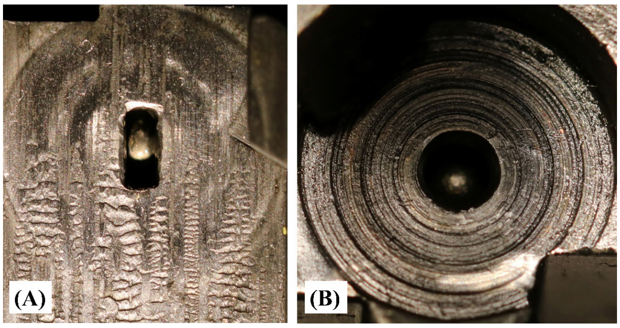

Fig. 7 The rectangular and rounded firing pin apertures of the Glock 17 (A) and Vektor CP1 (B) pistols, respectively.

The $\bar{v}$ and $\overline{ED}$ data and their standard deviations (SDs) of each set of firing test samples using different pistols and cartridges with varied amounts of powder charge are presented in Table 2. For the firing tests of Glock 17 pistol, the values of G17-R20, G17-R29, and G17-F39 samples were 125.3 m/s, 240.3 m/s, and 345.3 m/s, respectively. And the $\overline{ED}$ values of these samples were 94.06 J/cm^2, 340.60 J/cm^2, and 702.87 J/cm^2, respectively. For the firing tests of Vektor CP1 pistol, the values of VCP1-R20, VCP1-R29, and VCP1-F39 samples were 119.5 m/s, 204.3 m/s, and 300.0 m/s, respectively. And the $\overline{ED}$ values of these samples were 87.22 J/cm^2, 246.93 J/cm^2, and 530.96 J/cm^2, respectively. The results indicated that the muzzle velocity and muzzle energy density of a fired pistol were proportional to the amount of powder charge of the fired cartridge. As observed from Table 2, regardless of the amount of powder charge loaded in the cartridges, the $\overline{ED}$ values of the bullets fired from the two pistols were all significantly higher than the legal power limit for the controlled firearms in Taiwan (20.0 J/cm^2).

Table 2 The $\bar{v}$ and $\overline{ED}$ and their SDs for each set of testing sample using different pistols and cartridges

Sample ID	$\bar{v}$ ± SD (m/s)	$\overline{ED}$ ± SD (J/cm^2)	n
G17-R20	125.3 ± 17.7	94.06 ± 25.47	5
G17-R29	240.3 ± 5.8	340.60 ± 16.47	5
G17-F39	345.3 ± 3.0	702.87 ± 12.38	5
VCP1-R20	119.5 ± 24.0	87.22 ± 36.97	11
VCP1-R29	204.3 ± 12.3	246.93 ± 29.22	11
VCP1-F39	300.0 ± 9.7	530.96 ± 34.62	11

As shown in Table 2, the $\overline{ED}$ values of the bullets fired from Glock 17 pistol were higher than those of the bullets fired from Vektor CP1 pistol using cartridges with the same amount of powder charge. There are two possible fundamental reasons for this. The first reason is that for a gas-delayed blowback pistol, such as Vektor CP1 pistol, propellant gases are vented from the barrel into a cylinder with a piston to delay the opening of the slide before the bullet leaving the muzzle. This would result in a decrease of chamber pressure and thus a lower kinetic energy of the fired bullet. The second reason is that in an internal ballistic situation, a shorter rifled barrel would result in a lower kinetic energy of the fired bullet as shown in Equation (1).

$$(m_p v^2)/2 = [(m_g R T_i \ell^{(\gamma-1)})/(1-\gamma)][(\ell+L)^{(1-\gamma)}-\ell^{(1-\gamma)}] \quad (1)$$

where m_p and v are the mass and velocity of bullet, respectively; mg and T_i are the mass and initial temperature of propellant gases, respectively; R is the specific gas constant, γ is the specific heat ratio of propellant gases, and ℓ and L are the lengths of chamber and rifled barrel, respectively [9].

In this study, the total barrel lengths of Glock 17 and Vektor CP1 pistols are 114 mm and 102 mm, respectively. The ℓ value is 19 mm for both pistols. Thus the L values for Glock 17 and Vektor CP1 pistols are 95 mm and 83 mm, respectively. In comparison with the Glock 17 pistol, Vektor CP1 pistol has a shorter rifled barrel and lower peak camber pressure while firing the cartridges with the same amount of powder charge. Thus the $\overline{\text{ED}}$ of the bullets fired from Vektor CP1 pistol were lower than those of bullets discharged from Glock 17 pistol using the same type of cartridges.

Independent sample *t*-tests were used to establish the significance of the differences for $\bar{v}$ and $\overline{\text{ED}}$ data between paired sets of firing test samples using the different pistols and cartridges with the same amount of powder charge. A confidence level of 99% (p-value = 0.01) was used for the *t*-test. All *p*-values of the *t*-tests for the $\bar{v}$s and $\overline{\text{ED}}$s of the compared sample pairs were less than 0.01 except those of the sample pair of G17-R20/VCP1-R20, as shown in Table 3. This indicates that the values of $\bar{v}$ and $\overline{\text{ED}}$ of a given bullet are considerably affected by the length and structure of the gun barrel when the same type of cartridges are used for firing.

Table 3 The *p*-values of the *t*-tests of the mean velocities ($\bar{v}$s) and mean energy densities ($\overline{\text{ED}}$s) for the compared pairs of samples

Paired samples	*T*-test of $\bar{v}$s	*T*-test of $\overline{\text{ED}}$s
G17-R20/VCP1-R20	0.636	0.716
G17-R29/VCP1-R29	2.6×10^{-5}	1.1×10^{-5}
G17-F39/VCP1-F39	9.2×10^{-8}	4.4×10^{-8}

It can be further observed from Table 2 that the values of $\bar{v}$ and $\overline{\text{ED}}$ for samples fired from the same pistol were proportional to the amount of powder charge.

For the interior ballistics of propellant firearms, the force (F) that acts on the bullet is determined by the chamber pressure (P) and the sectional area (A) of the bullet as

$$F = PA \quad (2)$$

The force is also determined by the mass (m_p) and acceleration (a) of the bullet propelled in the barrel as stated in the following equation:

$$F = m_p a \quad (3)$$

Equations (2) and (3) is

$$a = PA/m_p \quad (4)$$

We assume that the acceleration is constant and the muzzle velocity (v) of the bullet can be calculated as follows:

$$v = v_0 + at \quad (5)$$

where v_0 is the bullet velocity at time t = 0.

Since $v_0 = 0$ when a firearms is fired, we can rewrite Equation (5) as

$$v = at \quad (6)$$

Combines Equations (4) and (6) gives

$$v/t = PA/m_p \quad (7)$$

Equation (7) shows that the muzzle velocity is proportional to the chamber pressure. Because the P increases as the amount of powder charge in the fired cartridge is increased, the muzzle velocity and energy density are proportional to the amount of powder charge when a pistol is fired. The *p*-values of the *t*-tests to examine the significance of the differences of the $\overline{\mathrm{ED}}$ data between paired sets of firing test samples are shown in Table 4. All *p*-values of the *t*-tests for the compared sample pairs were less than 0.01. The results reveal that the muzzle energy density and the wounding potential of a fired weapon are significantly affected by the amount of powder charge of the cartridge discharged.

Table 4 The *p*-values of the *t*-tests of mean energy densities ($\overline{\mathrm{ED}}s$) for the compared pairs of samples

Paired samples	*T*-test of $\overline{\mathrm{ED}}$s
G17-R20/G17-R29	4.1×10^{-7}
G17-R20/G17-F39	3.1×10^{-16}
G17-R29/G17-F39	3.5×10^{-10}
VCP1-R20/VCP1-R29	4.3×10^{-10}
VCP1-R20/VCP1-F39	7.8×10^{-18}
VCP1-R29/VCP1-F39	5.1×10^{-15}

The observation of the sidewall of each fired cartridge case showed that no visible striated chamber marks were found on the cartridge cases fired from Glock 17 pistol. And the impressed chamber marks on these cartridge cases were not apparent. In contrast, distinct striated chamber marks were found on all cartridge cases fired from Vektor CP1 pistol. And the distribution length of the striated chamber marks were found to be proportional to the amount of powder charge of the cartridge fired as shown in Figure 8. The means ($\overline{\mathrm{L}}$) and standard deviations of the distribution lengths of the VCP1-F39, VCP1-R29, and VCP1-R20 samples were 11.95 ± 0.43 mm, 9.29 ± 0.47 mm, and 5.32 ± 1.43 mm, respectively. The *p*-values of the *t*-tests to examine the significance of the differences of $\overline{\mathrm{L}}$ between compared pairs of VCP1-R20/VCP1-R29, VCP1-R20/VCP1-F39 and VCP1-R29/VCP1-F39 were all less than 0.01, and they were 1.4×10^{-6}, 4.7×10^{-9}, and 1.0×10^{-11}, respectively. The results demonstrate that the distribution length of striated chamber marks on a cartridge case fired from Vektor CP1 pistol is significantly affected by the amount of powder charge in the fired cartridge.

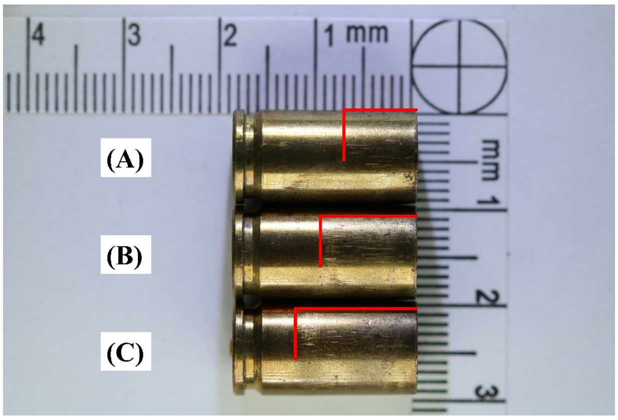

Fig. 8 The distribution lengths of striated chamber marks on the fired cartridge cases of VCP1-R20-05 (A), VCP1-R29-05 (B), and VCP1-F39-01 (C).

For the interior ballistics of blowback operated pistols, the cartridge case is not designed to sustain the propellant gas pressure and should be supported by the chamber walls. The hoop stress loaded to the cartridge case by the propellant gases would lead to the expansion of the cartridge case. And the cartridge case would expand enough to firmly contact the chamber walls and receive impressed chamber marks from the chamber sides. The following extraction of the fired cartridge case resulted from the blowback operation would create striated chamber marks on the fired cartridge case. The hoop stress (σ_Θ) is determined by the propellant gas pressure (P) and the diameter (D_m) and thickness (δ) of the sidewall of the cartridge case as following equation [10]:

$$\sigma_\Theta = PD_m/2\delta \quad (8)$$

The hoop stress is proportional to the propellant gas pressure and inversely proportional to the case wall thickness as shown in equation (8). When a firearm is fired, a greater amount of powder charge leads to a higher propellant gas pressure and thus a longer distribution of striated chamber marks. Besides, the case wall is thinner at the forward end of a cartridge case. Thus, the cartridge case mouth sustains the highest hoop stress and the greatest expansion. As a result, the striated chamber marks are distributed around the front part rather than the rear part of the fired cartridge case.

The *v*, ED, logarithm transformed ED (ln ED), and L data of each sample fired from Vektor CP1 pistol are presented in Table 5. The correlation analysis results showed that the R^2 values between L and ln ED were 0.9954. This finding revealed that when Vektor CP1 pistol was discharged, the distribution length (L) of striated chamber marks on the fired cartridge case was linearly related to logarithm transformed energy density (ln ED) of the fired bullet. The linear equation obtained via simple linear regression analysis was L = 3.559 ln ED – 10.334, as shown in Figure 9.

Table 5 The muzzle velocity (*v*), muzzle energy density (ED), logarithm transformed ED value (ln ED), and the distribution length (L) of striated chamber marks on the fired cartridge case of each sample fired from Vektor CP1 pistol

Sample ID	*v* (m/s)	ED (J/cm^2)	ln ED	L (mm)
VCP1-F39-01	317.3	593.47	6.39	12.86
VCP1-F39-02	295.8	515.77	6.25	11.72
VCP1-F39-03	285.6	480.81	6.18	11.40
VCP1-F39-04	298.6	525.58	6.26	12.21
VCP1-F39-05	297.6	522.06	6.26	11.61
VCP1-F39-06	299.7	529.46	6.27	12.21
VCP1-F39-07	287.0	485.53	6.19	11.45
VCP1-F39-08	296.1	516.81	6.25	11.79
VCP1-F39-09	302.2	538.33	6.29	11.80
VCP1-F39-10	313.8	580.45	6.36	12.23
VCP1-F39-11	306.1	552.31	6.31	12.15
VCP1-R29-01	200.0	235.79	5.46	9.24
VCP1-R29-02	197.4	229.69	5.44	8.84
VCP1-R29-03	208.0	255.03	5.54	9.36
VCP1-R29-04	213.9	269.70	5.60	9.48
VCP1-R29-05	215.1	272.73	5.61	9.58
VCP1-R29-06	202.2	241.00	5.48	9.28
VCP1-R29-07	177.2	185.09	5.22	8.54
VCP1-R29-08	197.6	230.16	5.44	8.85
VCP1-R29-09	224.9	298.15	5.70	10.34
VCP1-R29-10	202.9	242.67	5.49	9.32
VCP1-R29-11	208.5	256.25	5.55	9.36
VCP1-R20-01	98.2	56.84	4.04	4.06
VCP1-R20-02	128.2	96.88	4.57	5.84
VCP1-R20-03	110.3	71.71	4.27	4.78
VCP1-R20-04	168.5	167.36	5.12	8.12
VCP1-R20-05	133.2	104.58	4.65	6.06
VCP1-R20-06	154.0	139.80	4.94	7.56
VCP1-R20-07	102.7	62.17	4.13	4.33
VCP1-R20-08	102.9	62.41	4.13	4.34
VCP1-R20-09	107.5	68.12	4.22	4.61
VCP1-R20-10	94.3	52.42	3.96	3.83
VCP1-R20-11	114.4	77.15	4.35	5.02

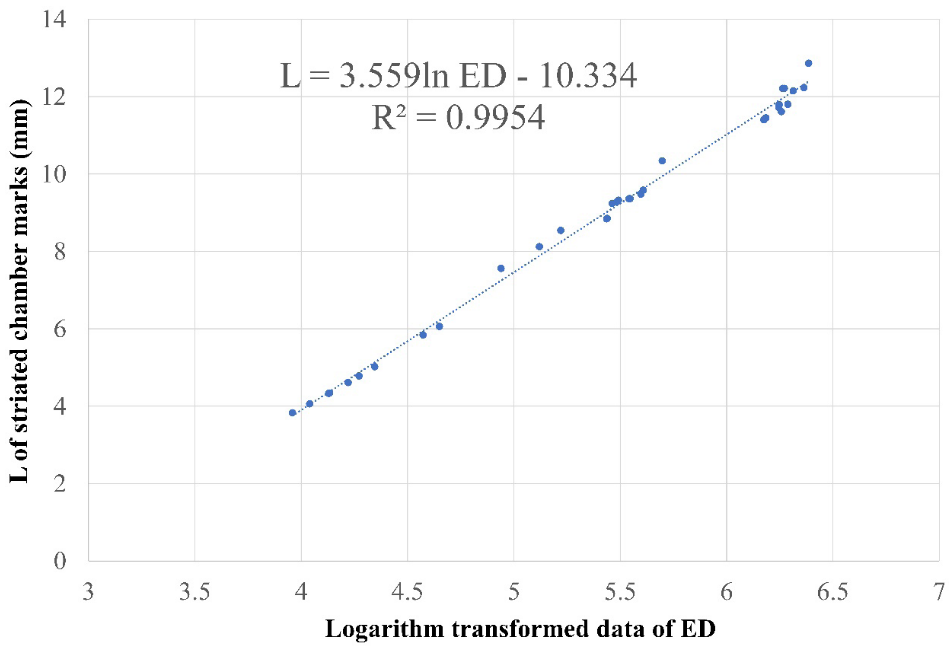

Fig. 9 Linear relationships between distribution length (L) of striated chamber marks and logarithm transformed data of energy density (ln ED).

In the verification firing tests of seven rounds of reducing-powder-charged cartridges, the L value in each firing test was used to calculate the corresponding evaluated ln ED value using the aforementioned linear equation. Subsequently, ED_E value was calculated. The data for L, *v*, ED, ED_E, and the percentage differences (PD_{ED}) between ED_E and ED are listed in Table 6. As inferred from Table 6, the ED_E data from the verification firing tests of the seven rounds of reducing-powder-charged cartridges agree well with the corresponding ED data, and the PD_{ED} values are all less than 3.5%. The results indicate that the distribution length of striated chamber marks on cartridge cases fired from a blowback operated firearm can be accurately utilized to evaluate the muzzle energy density, and thus the wounding potential, of the fired weapon employing the methods developed in the present study.

Table 6 The data for L, *v*, ED, ED_E, and PD_{ED} between ED_E and ED of each verification sample fried from Vektor CP1 pistol

Sample ID	L (mm)	*v* (m/s)	ED (J/cm^2)	ED_E (J/cm^2)	PD_{ED} (%)
VCP1-F39-T1	11.67	291.2	499.85	484.27	3.2
VCP1-F39-T2	11.76	294.4	510.90	496.67	2.8
VCP1-F39-T3	12.19	312.3	574.91	560.45	2.5
VCP1-F39-T4	11.64	289.8	495.05	480.20	3.0
VCP1-R29-T5	9.36	208.5	256.25	253.05	1.3
VCP1-R29-T6	9.41	211.0	262.43	256.63	2.2
VCP1-R29-T7	9.43	212.8	266.93	258.07	3.4

Conclusion

This study verified that the presence and depth of breechface marks and firing pin aperture marks on the primers of fired cartridge cases are strongly correlated with the amount of powder charge loaded in the discharged cartridges. The rectangular firing pin aperture marks and firing pin aperture shear marks are important class characteristics for the identification of Glock pistols. However, these marks may be absent on the fired cartridge cases when reducing-powder-charged cartridges are fired. This would lead to wrong conclusions being made by the crime scene officers or forensic practitioners. We suggest that in cartridge case examination for shooting incident investigation, care should be taken to avoid incorrect conclusions of firearm identification resulted from the use of reducing-powder-charged cartridges by the shooters.

The muzzle energy density (ED) of a fired pistol was verified to be proportional to its barrel length and the amount of powder charge. Additionally, the distribution length (L) of striated chamber marks on cartridge cases fired from Vektor CP1 pistol was verified to be linearly related to ED through a series of firing tests. A linear equation modelling the relationship between L and ln ED was derived and was determined to be practical for the calculation of the ED_E, enabling evaluation of the wounding potential of Vektor CP1 pistol through the examination of fired cartridge cases. The results of the verification tests using reducing-powder-charged cartridges demonstrated that the developed method was useful for evaluating the wounding potential of Vektor CP1 pistol when it is not available for kinetic energy determination. We expect that the results of this study will help forensic laboratories develop similar methods using cartridge cases fired from other models of blowback pistols to determine the legal status of unseized questioned firearms.

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