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The development of witness plate method for the determination of wounding capability of illegal firearms

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Abstract

The legislation of firearms control is extremely strict in Taiwan. The domestic courts always require firearms experts to test the wounding capability of low-powered guns to prove they are controlled firearms. During the test, chronograph is routinely used to measure the projectile velocity which is then used to calculate the energy density (ED) of the fired projectile. An ED of 20.0 J/cm^2 is employed as the wounding capability criterion. Because the chronograph may fail to record the projectile velocity while smooth-bored guns are fired, this study developed a witness plate method to complement the chronographic method. In this method a 0.65 mm thick aluminum plate with a perforation criterion of 22.4 J/cm^2 was used as the target to monitor the terminal ballistic effects of the fired projectile. The terminal ballistic effects on the witness plate were used as criteria to evaluate the wounding capability of the tested gun when the chronograph failed to record the projectile velocity. The witness plate method was simultaneously used with the chronographic method to conduct wounding capability tests of varied types of guns in 3 criminal cases, the results of both methods were all in good accordance with each other. The successful application of this method proves that the witness plate method is valid and reliable in wounding capability test of illegal firearms.

Keywords: firearms examination, wounding capability of firearms, energy density, witness plate

Introduction

The legislation of firearms control is extremely strict in Taiwan. The civilian possession of both regular types of firearms and low-powered weapons is severely restricted by The Control Act of Firearms, Ammunitions, and Blades (The Act). According to the article 8 of The Act, illegal possession of air-powered guns and miscellaneous firearms that capable of discharging metals or ammunition with wounding capability will be sentenced to a penalty between 3 and 10 years in prison. Among various types of miscellaneous firearms, homemade and converted firearms are most frequently confiscated by local law enforcement agencies. Because these weapons could be easily manufactured with inexpensive materials, few tools, and limited skills, they are also commonly encountered in criminal cases in some other countries [1-6]. However, because of the crude construction of the homemade and converted guns, they can only fire projectiles at relatively low velocity. As a result, the domestic courts require firearms experts to test the wounding capability of these weapons to prove they are controlled weapons. Although the construction of air-powered guns ranges from toys to highly sophisticated air rifles, the kinetic energy of pellets discharged from air guns is usually smaller than that of bullets fired from propellant-powered guns; thus the determination of the wounding capability of police-seized air guns is also required.

The official definition of "wounding capability" of a firearm is that "at the most powerful and appropriate shooting distance, the discharged missile has the kinetic energy capable of perforating human skin." The minimum energy density(ED) necessary to perforate human skin recognized by domestic firearms experts

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is 20.0 joules per square centimeters (20.0 J/cm^2) [7]. Chronograph is routinely used to measure the muzzle velocity of projectiles discharged from suspected illegal firearms in domestic forensic ballistic laboratory. The weight and diameter of the recovered projectiles are measured. The ED of the discharged projectile is then calculated using the following equations:

$$E = mv^2/2 \quad (1)$$

$$a = \pi r^2 \quad (2)$$

$$ED = E/a \quad (3)$$

where **E** is the kinetic energy, **m** is the projectile weight, **v** is the muzzle velocity, **a** is the cross-sectional area of the projectile, **r** is the projectile radius.

However, there have been instances that the sensor of chronograph failed to record the passage of projectile because of unstable trajectory of projectile fired through smooth-bored homemade guns and air guns. Thus a complemental method that can be simultaneously conducted with the chronographic method should be developed and applied in order to make sure that definite result is obtained for every single wounding capability test. A thin sheet of aluminum has long been used as witness plate in American official standards to test the performance of both ballistic resistant protective materials [8] and armors [9]. The witness plate is located behind the ballistic test sample to detect perforating projectiles or spall. Any perforation of the witness plate is determined as the failure of the tested ballistic resistant protective material or armor. The thickness of the aluminum witness plate is 0.05 mm for transparent armors and vision devices and 0.50 mm for all other armors and ballistic resistant protective material. We assume that a projectile capable of perforating 0.05 mm thick witness plate has the potential to inflict an eye injury and that perforating 0.50 mm thick witness plate is able to perforate human skin. The potential for the witness plate method to apply to the wounding capability test of firearms has never been explored. Thus, the ballistic resistant performance of aluminum plates with varied thickness are studied here using the wounding capability criterion applied in Taiwan, i.e. 20.0 J/cm^2, to find an appropriate witness plate to be used in company with chronographic wounding capability test. The selected witness plate is then employed in real forensic cases to verify its validity.

Materials and methods

Research equipment

1.Chronograph, Ohler Model 55 (USA).
2.Chronograph, Chrony Gamma Master (USA).
3.Air rifle, SP-100, 6 mm caliber, powered by liquefied carbon dioxide (CO_2) in disposable cylinder.

Research materials

1.Steel pellets, 6 mm diameter, 0.88 g each.
2.Aluminum plates, 1100-H12, 350 mm × 270 mm with varied thickness of 0.50, 0.55, 0.60, and 0.65 mm, Dong I Industrial Factory Co. Ltd. (Taiwan).
3.Disposable cylinders filled with liquefied carbon dioxide (CO_2), 12 g each.

Development of witness plate method

The 6 mm caliber smooth-bored air rifle was used as test weapon to discharge steel pellets 6 mm in diameter and weighing an average of 0.88 g. The air rifle was mounted in a fixture with the barrel horizontal. The start sensor of the chronograph and the aluminum plate were placed 1 and 3 m, respectively from the muzzle of the test weapon as shown in Fig. 1. A cotton box was

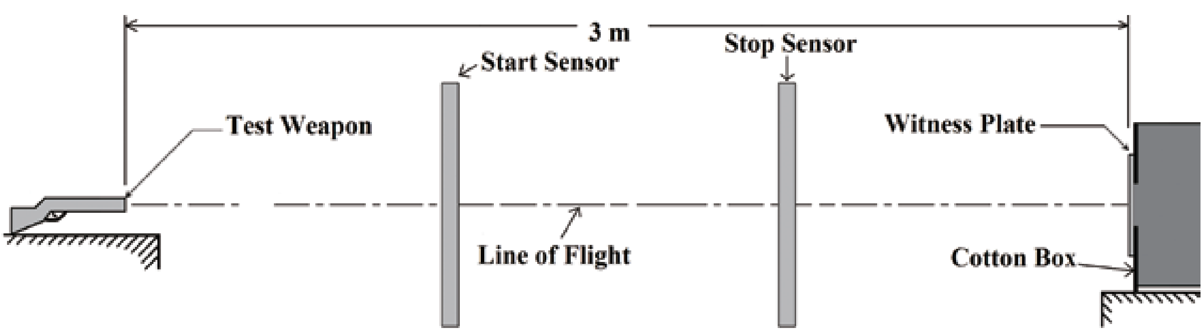

Fig. 1 The configuration of wounding capability test setup.

placed behind the aluminum plate to trap the perforating projectile for the purpose of recovering the projectile. The sensors and aluminum plate were arranged so that they defined planes perpendicular to the line of flight of the projectile. In every test firing the passage of projectile through the start senor turned on the chronograph. The chronograph was shut off by the stop sensor when the projectile passed through it. The velocity of projectile was calculated using the time of flight and the distance between two sensors. The ED of each discharged projectile was calculated as mentioned in the introduction section of this article.

After the test weapon was fixed, leveled, and positioned, one pellet was fired to impact the aluminum plate. The terminal ballistic effects on the aluminum plate were examined after the ballistic impact. The test result was classified as complete penetration only when the pellet passed through the aluminum plate and formed a round-shaped bullet hole on it (Fig.2). The formation of cracks or a bullet hole attached with a cap at its edge was classified as partial penetration instead (Figs. 3 and 4). The perforation criterion of an aluminum plate was defined as the minimum ED necessary to form a complete penetration. The perforation criterion of aluminum plate of certain thickness was determined by firing pellets at varied velocities and the examination of bullet holes. The rapid evaporation of liquid CO^2 to gas while firing the air rifle was an endothermic process which leaded to the drop of gas pressure. If the air rifle was fired at a rate faster than the gas cylinder could absorb heat from environment to counter the cooling effect, the pellet velocity would drop. So the varied pellet velocities could be obtained by continuously shooting the air rifle. Among the aluminum plates of different thickness, the one that had the perforation criterion in good accordance with the minimal kinetic energy required to perforate human skin was chosen as the witness plate for the wounding capability tests of confiscated illegal firearms.

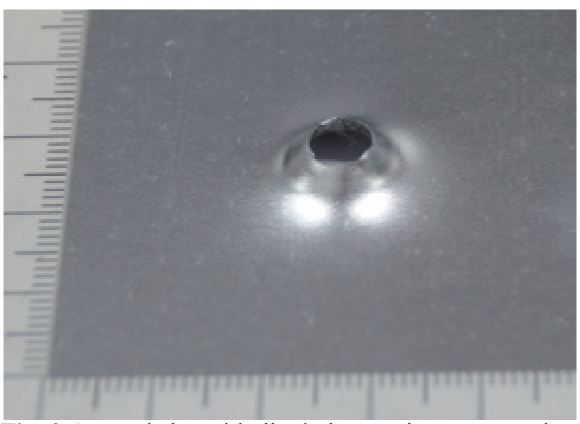

Fig. 2 A round-shaped bullet hole constitutes a complete penetration.

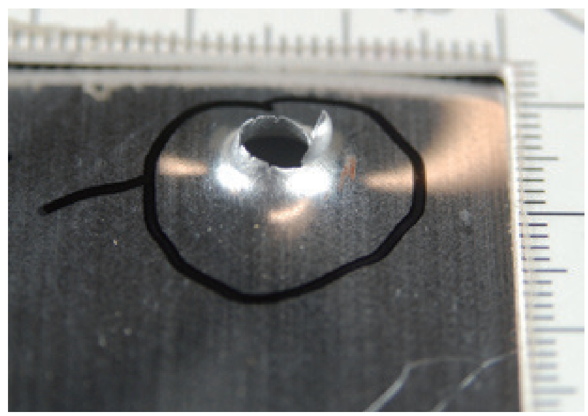

Fig. 3 A bullet hole attached with a cap at its edge is classified as a partial penetration.

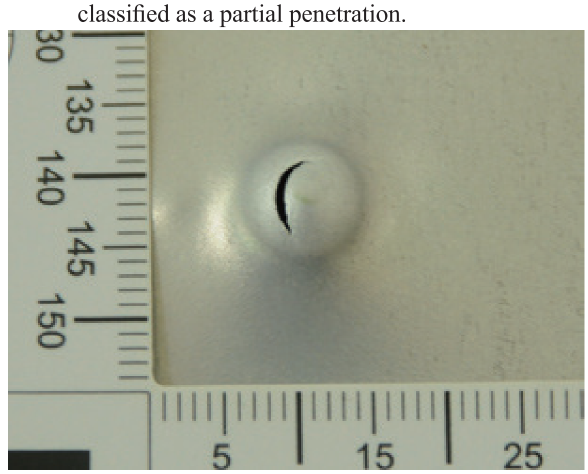

Fig. 4 A crack on the impact-induced deformation is classified as a partial penetration.

Application of witness plate method

Any crime-involved air guns and homemade firearms submitted to our labs for wounding capability test were simultaneously examined using both chronographic method and witness plate method. The results of both test methods from the same shot were compared with each other to see if the result of witness plate method was in good accordance with that of chronographic method.

Results and Discussion

Development of witness plate method

The velocities and energy densities (ED) of the fired pellets and the terminal ballistic effects on aluminum plates of all test firings are shown in Tables 1, 2, 3, and 4. The perforation criteria of aluminum plates with the thickness of 0.50, 0.55, 0.60, and 0.65 mm were 14.3, 15.8, 21.7, and 22.4 J/cm^2, respectively. The perforation criterion of the aluminum plate was in proportion to the thickness of the plate. The 0.50 mm thick aluminum plate is used as witness plate in American official standards for the test of ballistic resistant materials, so we assumed that the perforation criterion of it would be corresponding to the minimal ED required in perforating human skin that is recognized as 20.0 J/cm^2 in Taiwan. However, the results of this study revealed that the perforation criterion of 0.50 mm thick aluminum plate was 14.3 J/cm^2 which was much smaller than 20.0 J/cm^2. To solve this contradiction we reviewed a couple of literatures dealing with the issue of minimal velocity required to perforate human skin. The velocities, weights, and calibers of fired projectiles' in these studies were transferred to ED for the purpose of unequivocal comparison.

In 1907, Journee's experiments on human cadavers revealed that a lead sphere 11.25 mm in diameter and weighing 8.5 g required a minimal ED of 20.9 J/cm^2 to perforate the skin [10]. In 1974, Matoo at al. reported that a lead sphere 8.5 mm in diameter and weighing 4.5 g needed an ED of 20.2 to perforate human skin. In 1982, DiMaio et al. used human lower extremities to conduct a series of tests to determine the ED necessary for varied projectiles to perforate skin [12]. For 0.177 air gun pellets weighing an average of 0.54 g required a minimum ED of 18.0 J/cm^2 to initially perforate skin. At ED of 21.8 J/cm^2 and above, perforation always occurred. For caliber .22 air gun pellets weighing an average of 1.07 g required a minimum ED of 12.8 J/cm^2 to initially perforate skin, with perforation becoming consistent at 16.5 J/cm^2 and above. When a 7.32 g .38-caliber lead bullet was fired a minimal ED of 19.1 J/cm^2 is required to perforate skin.

These studies indicate that the minimal ED needed to perforate skin is not a constant. It can be as low as 12.8 J/cm^2 to initially perforate skin and as high as 21.79 J/cm^2 for consistent perforation while different types of projectiles are fired. When a person is protected by ballistic resistant equipments, the possibility of an impacting bullet to cause any significant injury should be reduced to nearly zero. Thus the 0.50 mm thick aluminum plate having a lower perforation criterion is chosen as the witness plate for the test of ballistic resistant materials. However, false positive results are not tolerable while conducting a forensic test of physical evidence that is used to against the suspect. Thus a stricter perforation criterion should be applied to the witness plate used in the wounding capability test of illegal firearms. The perforation criterion of the witness plate should be higher than the highest ED for consistent perforation of skin. Therefore we choose the 0.65 mm thick aluminum plate having the perforation criterion of 22.4 J/cm^2 as the witness plate for the wounding capability tests of all submitted illegal firearms.

Application of witness plate method

The 0.65 mm thick witness plate was simultaneously

Table 1. The ballistic test results of 0.50aluminum plate†, #

Pellet velocity (m/s)	Pellet ED (J/cm^2)	Terminal ballistic effects
94	13.7	PP
96	**14.3**	**CP**
99	15.2	CP
101	15.8	CP
102	16.1	CP
106	17.4	CP
138	29.6	CP

†PP represents a partial penetration of the aluminum plate target.

#CP stands for a complete penetration of the aluminum plate target.

Table 2. The ballistic test results of 0.55 mm aluminum plate†, #

Pellet velocity (m/s)	Pellet ED (J/cm^2)	Terminal ballistic effects
99	15.2	PP
101	**15.8**	**CP**
104	16.8	CP
105	17.1	CP
120	22.4	CP
123	23.5	CP
128	25.5	CP

†PP represents a partial penetration of the aluminum plate target.
#CP stands for a complete penetration of the aluminum plate target.

Table 3. The ballistic test results of 0.60 aluminum plate†, #

Pellet velocity (m/s)	Pellet ED (J/cm^2)	Terminal ballistic effects
100	15.5	PP
107	17.8	PP
115	20.6	PP
117	21.3	PP
118	**21.7**	**CP**
119	22.0	CP
127	25.1	CP

†PP represents a partial penetration of the aluminum plate target.
#CP stands for a complete penetration of the aluminum plate target.

Table 4. The ballistic test results of 0.65 aluminum plate†, #

Pellet velocity (m/s)	Pellet ED (J/cm^2)	Terminal ballistic effects
102	16.1	PP
108	18.3	PP
114	20.2	PP
118	21.7	PP
120	**22.4**	**CP**
126	24.7	CP
136	28.8	CP

†PP represents a partial penetration of the aluminum plate target.
#CP stands for a complete penetration of the aluminum plate target.

used with chronographic method while conducting wounding capability tests of firearms firing steel balls 6 mm in diameter in 3 criminal cases. The results of these tests are described as the followings.

Case 1

A 6 mm caliber smooth-bored air rifle (Fig. 5) using liquefied carbon dioxide as propelling power was submitted by local court for wounding capability test. Three test firing were conducted using steel pellets 6 mm in diameter and weighing an average of 0.88 g, the appearance of steel pellets is shown as Fig. 6. The recorded velocities of these shots were 157.9, 164.9, and 166.3 m/s, and their calculated energy densities were 38.8, 42.3, and 43.0 J/cm^2, respectively. All of the fired steel pellets completely penetrated 0.65 mm thick witness plates. The test results of the chronographic method and the witness plate method were in good accordance with each other. One of the three perforation bullet holes is shown as Fig. 7.

Fig. 5 The 6 mm caliber air rifle submitted for wounding capability test in case 1.

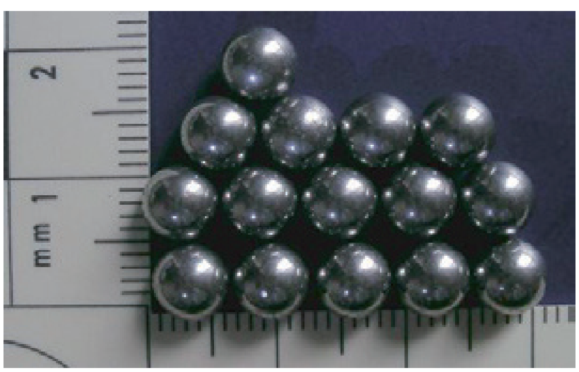

Fig. 6 The 6 mm caliber steel pellets used for test firings.

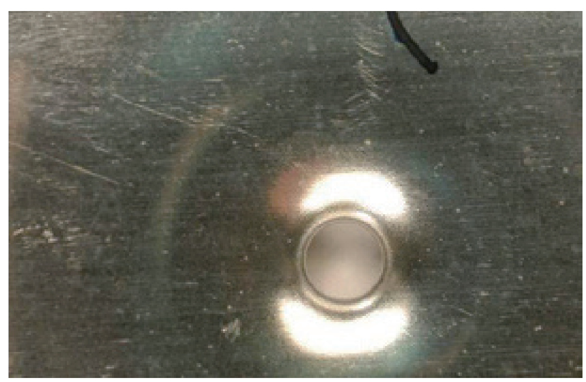

Fig. 7 A complete penetration bullet hole on the witness plate from the test of case 1 air rifle.

Case 2

A 6 mm caliber smooth-bored air rifle imitating an assault rifle was submitted by local court for wounding capability test (Fig. 8). The power source of this air rifle was a disposable cylinder filled with liquefied carbon dioxide. The air rifle was test fired for five times using 6 mm caliber steel pellets with an average weight of 0.88 g. The velocities recorded by the chronograph were 107.9, 89.8, 93.4, 93.6, and 93.7 m/s. The ED of these shots were 18.1, 12.6, 13.6, 13.7, and 13.7 J/cm^2, respectively. They were all lower than the wounding capability criterion of 20.0 J/cm^2. A partial penetration was observed on the witness plate of the first test firing as shown in Fig. 9. For the rest of the test firings the witness plates were only deformed by the impacting pellets without any penetration. The plastic deformation on the impacted area conformed to the shape of steel pellet as shown in Fig. 10. The results indicate that a partial penetration occurs when the ED of the pellet is smaller than but close to the wounding capability criterion. On the other hand, the pellet cannot produce any penetration at all when its ED is far below the wounding capability criterion.

Fig. 8 The appearance of the air rifle imitating an assault rifle in case 2.

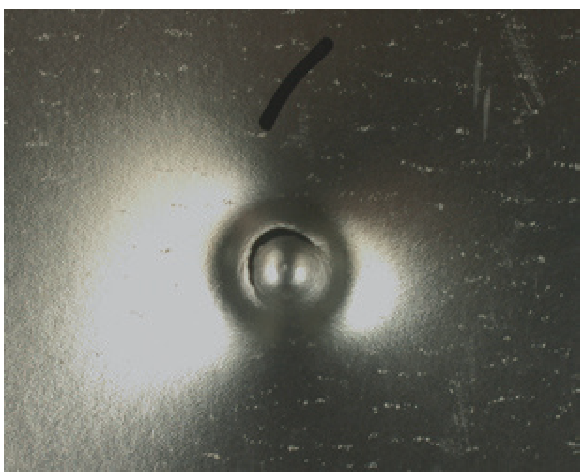

Fig. 9 A partial penetration occurs when the ED of the pellet is a little smaller than the wounding capability criterion.

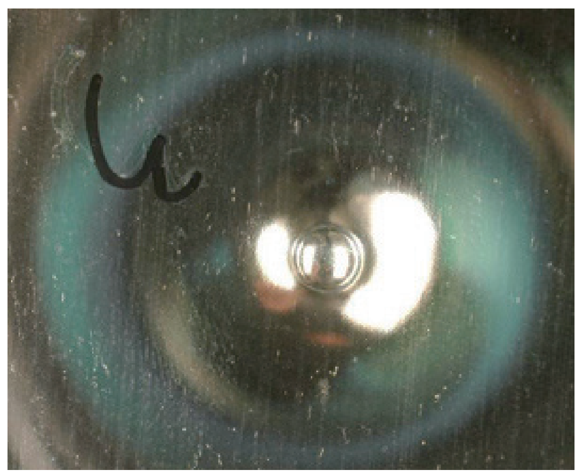

Fig. 10 A plastic deformation occurs when the ED of the pellet is far below the wounding capability criterion.

Case 3

A 6 mm caliber single-shot, smooth-bored homemade firearm was submitted by local court for wounding capability test (Fig. 11). The power source of this homemade firearm was rim-fire blank ammunition as shown in Fig. 12. The gun was chambered by inserting a round of .22 caliber blank ammunition from the breech end and loading a steel pellet with an average weight of 0.88 g from the muzzle. To fire the chambered gun the bolt should be firstly pulled back and held to the rear, the trigger was then pulled to let the bolt go forward and fire the ammunition in chamber. One test firing was conducted where two sheets of 0.65 mm thick aluminum plates were placed together as witness plate. The recorded pellet velocity was 527.3 m/s and the ED of the pellet was calculated to be 432.2 J/cm^2. The extremely high ED of the fired pellet resulted in the complete penetration of the two-layered witness plate. The completely penetrated pellet hole on the first layer of witness plate is shown as Fig. 13.

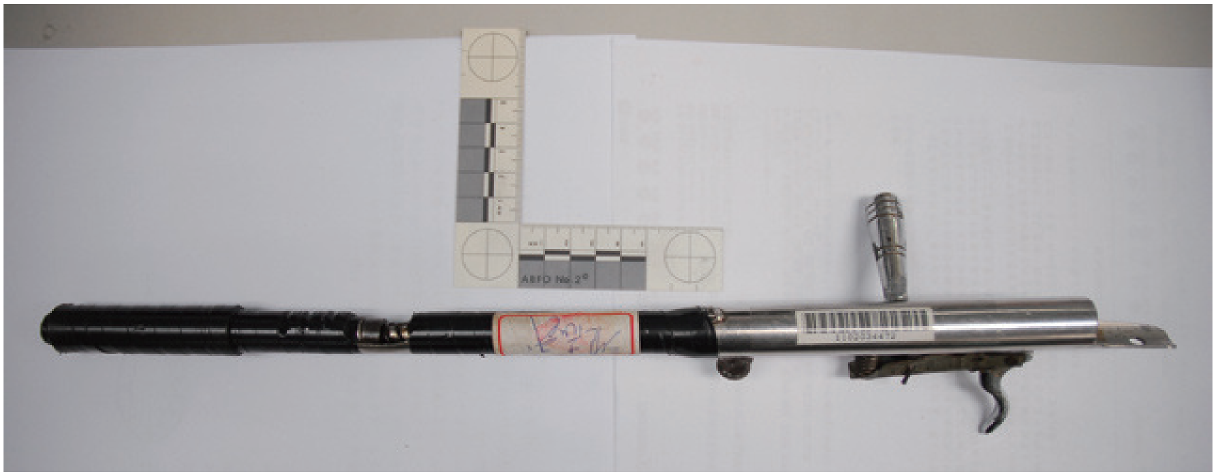

Fig. 11 The 6 mm caliber single-shot homemade firearm in case 4.

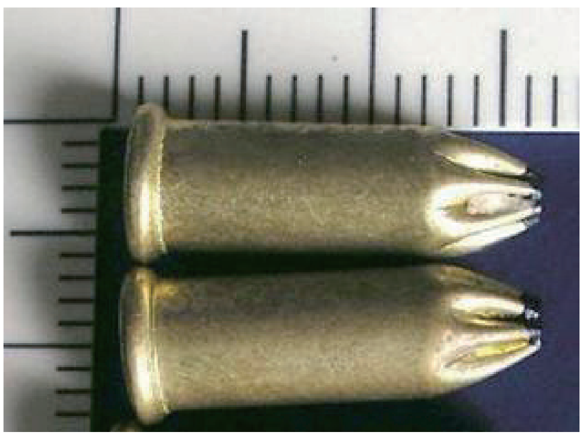

Fig. 12 The rim-fire blank ammunition used as power source for the 6 mm caliber single-shot homemade firearm in case 4.

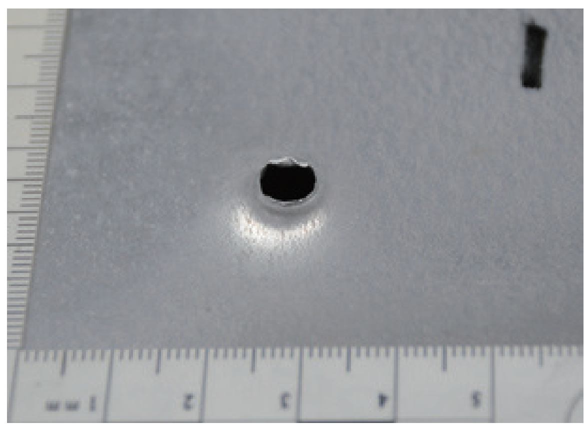

Fig. 13 The completely penetrated pellet hole on the first layer of witness plate in case 4.

The summarized test results of the cases reported in this study is shown in Table 5. These data indicated that the witness plate method is a reliable wounding capability test method. Its results were always in good accordance with the results of chronographic method. Although the ballistic limit of a target is traditionally defined in terms of projectile velocity [8, 10], the terminal ballistic effects are actually directly related to the projectile's kinetic energy which is in proportion to the mass of the projectile at fixed velocity. In addition to the kinetic energy, the cross-sectional area, the shape, and the hardness of the projectile will also affect its power of penetrating to the target. The use of energy density to evaluate the perforation criterion of a witness plate can reduce the affection of the variation of the projectile's mass and cross-sectional area. The importance for using the energy density to assess the penetration of skin has also been reported by Bir et al [13], they used E/a value to represent the energy density as we described in equation (3). They stated this issue in their published article as the followings.

In order to quantify the probability of penetrating the skin, the energy, as well as the area of impact, must be considered. Therefore, it is important to determine the energy per area of presentation ratio or E/a value. This value takes into account the mass, velocity, and the cross-sectional area of the projectile.

However because the hardness and the shape of the fired projectile can still significantly affect the terminal ballistic effects, the use of witness plate recommended by this study for wounding capability test should be limited to the guns firing steel balls only. To apply the witness plate method to test the guns firing other types of projectiles, such as Diabolo-style lead pellets, further studies should be conducted to find a witness plate with appropriate thickness in advance.

Table 5. Wounding capability test results of the cases reported in this study

Case No.	Weapon	Caliber (mm)	Pellet weight(g)	Pellet velocity (m/s)	Pellet ED (J/cm^2)	Terminal ballistic effects
Case 1	Air rifle powered by CO_2	6	0.88	157.9	38.8	CP[#]
				164.9	42.3	CP
				166.3	43.0	CP
Case 2	Air rifle powered by CO_2	6	0.88	107.9	18.1	PP[†]
				89.8	12.6	Deformation
				93.4	13.6	Deformation
				93.6	13.7	Deformation
				93.7	13.7	Deformation
Case 3	Homemade gun powered by blank cartridge	6	0.88	527.3	432.2	CP (2 sheets of witness plates)

[+] ：PP is a partial penetration of the aluminum plate target.

[#] ：CP is a complete penetration of the aluminum plate target.

Conclusions

Aluminum witness plate has long been used to monitor the results of ballistic resistant material test and armor test stated in the American official standards. However the potential of the witness plate to be applied in the wounding capability test of guns has never been explored. This work developed a procedure using 0.65 mm thick aluminum witness plate for wounding capability test of illegal firearms. The successful application of developed procedure to the forensic tests of varied types of illegal firearms proves that the witness plate method is valid and reliable. Because the only projectile type used in this study is steel ball, the use of 0.65 mm thick witness plate to test the guns firing other types of projectiles is not recommended. Further studies should be conducted to find witness plates with appropriate thickness for the test of firearms discharging other types of projectiles

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