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The Muzzle Energies of Aboriginal Homemade Long Guns Discharging Blank Cartridges

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Abstract

Aborigines are legally allowed to manufacture and possess homemade muzzle-loading shotguns for their traditional and cultural activities in Taiwan. However, homemade long guns firing rimfire blank cartridges to propel metallic projectiles have been used by aborigines in recent years. This results in the quarrel and debate of the legality of these breech-loading homemade long guns possessed by aborigines. It is worthwhile to study the muzzle energies, which are correlated with wounding capabilities, of this type of homemade long guns.

Fourteen homemade long guns confiscated by local police forces were test fired in this work to study the effect of the differences of calibers, barrel lengths, types of blank cartridges, and projectile materials to the muzzle energies of these guns. The results reveal that projectiles discharged by the extra-long black-coded blank cartridges possess the highest muzzle energies that are even higher than those of bullets discharged from 9mm Luger pistols. Among the normal-sized blank cartridges, which are all less powerful than the black-coded extra-long ones, the black-coded ones produce the highest muzzle energies, followed by the red-coded ones, and the yellow-coded cartridges are least powerful. When the same type of blank cartridges were fired, the smaller the calibers of the guns and projectiles, the higher the muzzle energy densities produced.

When the barrel length was under 50cm, the combustion gases propelled the projectile for a relatively short period of time, the projectile exited the barrel before reaching its maximum velocity, and thus the lowest muzzle energy was produced. When the barrel length was over 90cm, the expansion and cooling down of combustion gases resulted in the reduction of chamber pressure, propelling force was overcome by friction between the projectile and the barrel, thus the muzzle energy diminished as the barrel length increased. For the guns with intermediate barrel lengths, the muzzle energies of projectiles were positively correlated with the barrel lengths.

Among lead, steel, and aluminum projectiles, aluminum ones have the lowest density and the highest air drag, this resulted in quick loss of kinetic energies after they left the muzzle. Higher muzzle energies were obtained when steel and lead projectiles were discharged. However, the penetration power of steel projectiles is so strong that they are not safe enough for aborigines' traditional activities. Lead projectiles have the highest density and the lowest air drag. Lead projectiles are easily deformed while impacting targets, the penetration power of them is thus reduced. Lead projectiles are suitable for aborigines to fire their homemade long guns in traditional activities.

Keywords: firearms examination, homemade long guns, muzzle energy, rimfire blank cartridges, wounding capability

Introduction

Illegal firearms often jeopardize the social order and public safety. Crimes involved with gunshots usually result in high rates of mortality and injury. As early as 1518 Maximilian I, the Roman Emperor, enacted the first gun control law to ban the public carrying of wheel lock guns, a type of muzzle loaders [1]. The wounding capability and firing power of modern guns are even stronger than those of obsolete muzzle loaders. The

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threat of illegal firearms to the safety of modern societies is so severe that gun control policies and laws are adopted by a number of developed countries. Basing on the same impetus, Taiwan enforced the Control Act of Firearms, Ammunitions, and Blades (the Firearms Act) in 1983 to ban the manufacture, sale, transfer, possession, modification, and use of firearms [2].

The first clause of the Firearms Act declares that the purpose of this Act is to maintain the social order and to ensure the safety of the lives and properties of people. However, in order to secure the cultural rights of aborigines to continue their traditional social activities and cultures, an amendment was enacted in 1997 to permit the aborigines to make, possess, and use homemade long guns through legal procedures prescribed in the Authorization and Management Act of Firearms (the Authorization Act). Homemade long guns are defined as muzzle loading firearms loaded with black powders and multiple sub-caliber projectiles in the Authorization Act. However, comparing to a breech loader, the loading and discharging of a muzzle loader is not only time-consuming but also dangerous. So the aborigines have manufactured and used illegal long guns using breech-loaded rimfire blank cartridges to discharge single projectile in recent years. The prosecution of the owners of these illegal guns always attracts criticism from human right defenders and usually results in verdicts of not guilty. A lot of law enforcement and justice resources have wasted in dealing with this type of crimes for nothing.

Since one of the reasons to permit the aborigines to use homemade muzzle loaders is that the firing power and wounding capability of muzzle loaders are smaller than those of breech loading shotguns. Thus it is worthwhile to study the muzzle energies of homemade long guns that use breech-loaded blank cartridges to propel single projectile. The results can be consulted by the authorities to decide if the ban of breech loading homemade guns to the aborigines can be lifted or not.

Materials and Methods

Research equipments and materials

1. Ballistic chronographs: Chrony Gamma Master and Ohler Model 55, USA.
2. Fourteen confiscated homemade long guns submitted by local police forces for forensic examination were test fired. The barrels of these guns have varied nominal calibers of 6 mm, 8 mm, 10 mm, and 11 mm. The barrel chambers of these guns were made to fire either 0.25in or 0.27in rimfire blank cartridges. The designated sample number, nominal caliber, barrel length, and chambered cartridge of each gun are shown in Table 1. The appearance of two typical homemade long guns test-fired in this work is shown as Fig. 1.

Table 1. Designated sample numbers, nominal calibers, barrel lengths, and chambered cartridges of guns used.

Sample No.	Nominal caliber	Chambered cartridge	Barrel length	Sample No.	Nominal caliber	Chambered cartridge	Barrel length
01	10mm	0.27in	104cm	08	8mm	0.27in	57cm
02	10mm	0.27in	94cm	09	10mm	0.27in	62cm
03	10mm	0.27in	93.5cm	10	10mm	0.27in	66cm
04	8mm	0.27in	52cm	11	10mm	0.25in	77cm
05	8mm	0.27in	58cm	12	10mm	0.27in	51cm
06	8mm	0.27in	64cm	13	11mm	0.27in	75cm
07	8mm	0.27in	43cm	14	6mm	0.27in	60cm

Fig. 1 Two typical homemade long guns test-fired in this work: No. 03 and 04.

3. Rimfire blank cartridges: (1) 0.25in blank cartridges with yellow color code on the case mouth. (2) 0.27in blank cartridges with yellow, red, or black color codes (Fig. 2). (3) 0.27in blank cartridges with black color code and extra-long cases. All rimfire blank cartridges bear the head stamps of 'HILTI' (Fig. 3). The crimps and varied color codes of blank cartridges are shown as Fig. 4. The comparison of lengths and diameters of 0.27in. extra-long, 0.27in., and 0.25 in. blank cartridges are shown as Fig. 5.

Fig. 2 0.27in. Blank cartridges with black, red, and yellow color coded case mouths.

Fig. 3 The head stamp of rimfire blank cartridges used in this work.

Fig. 4 The crimps and varied color codes on case mouths of blank cartridges.

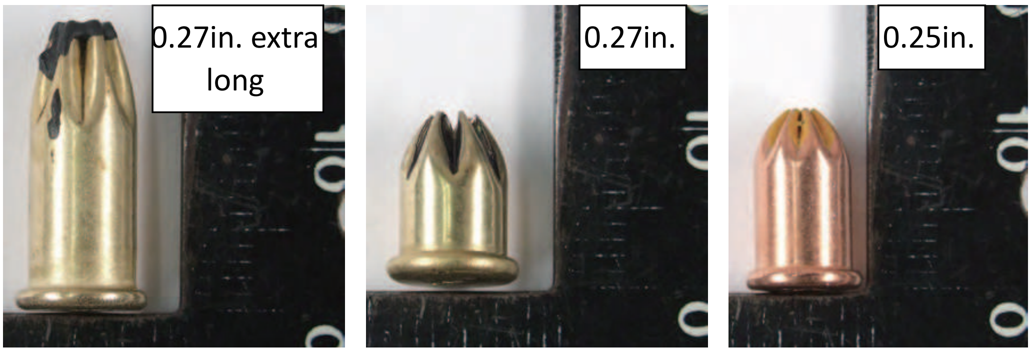

Fig. 5 The comparison of lengths and diameters of 0.27in. extralong , 0.27in., and 0.25 in. rimfire blank cartridges.

4. Projectiles used in this work include steel balls with diameters of 6, 8, 10, or11 mm. The mass of these steel balls are 0.89, 2.1, 4.1, or 5.5g, respectively. Aluminum balls (8mm in diameter and 0.71g in mass) and lead balls (10mm in diameter and 5.94g in mass) were also used. The appearance of 8 mm steel ball and 10 mm lead balls are shown as Fig. 6.

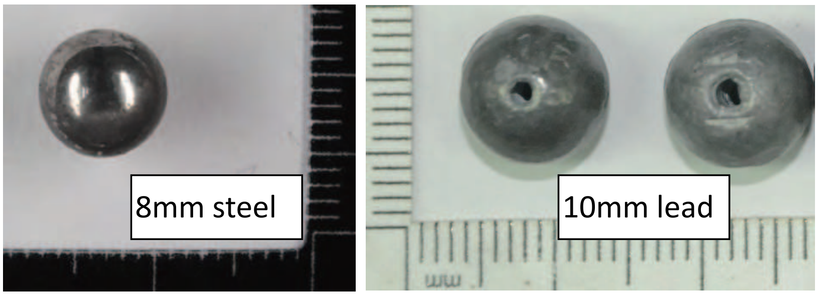

Fig. 6 The appearance of 8 mm steel ball 10 mm lead projectiles..

Muzzle energy determination

Each of the homemade long guns listed in Table 1 was chambered with rimfire blank cartridges from the breech to discharge the muzzle-loaded metal projectiles. The velocity of each discharged projectile was recorded using ballistic chronograph and the muzzle energy (ME) and muzzle energy density (ED) of the fired projectile were calculated as described in Ref. [3].

The effect of cartridge type to muzzle energies

The No.04 gun was chambered with 0.27in. blank cartridges with yellow, red, or black color codes. An 8mm steel ball was then loaded from the muzzle to fire the chambered gun. Test firings were repeated for five times using each type of blank cartridge. The muzzle velocity of each test firing was measured, and the ME and ED were calculated. The mean values and standard deviations of ME and ED were calculated. A Student's t test was used to establish the significance of differences in ME and ED between two compared type of blank cartridges; a confidence level of 95% (p value = 0.05) was chosen for the test.

The effect of barrel length to muzzle energies

The No.01, 02, and 03 guns that have the same nominal caliber of 10mm and different barrel lengths were chambered with 0.27in. black-coded blank cartridges. 10mm lead projectiles were loaded from the muzzles to conduct test firings. The muzzle velocity (MV), ME, and ED of each fired projectile were obtained as procedures described above. The effect of barrel length to ME and ED was studied. Since only a limited number of cartridges were usually submitted for examination when working on criminal cases, statistic analysis was not conducted here and the rest of test firings in this work.

The effect of cartridge length to muzzle energies

The No.6, 09, and 10 guns having a nominal caliber of either 8mm or 10mm were test fired. Two types of 0.27in. black-coded blank cartridges, one has normal case length and the other has extra-long case length (Fig. 5), were employed to chamber each gun. Steel projectiles with an appropriate diameter to each gun were then loaded from the muzzle to fire the chambered gun. The effect of cartridge case length to MV, ME, and ED of projectiles was studied.

The effect of projectile type to muzzle energies

The No.07 gun was chambered with 0.27in. black-coded blank cartridges. An 8mm aluminum ball was then loaded from the muzzle to fire the chambered gun. The muzzle velocity of the projectile was recorded, and the ME and ED were calculated.

Other factors that affect muzzle energies

The guns designated as No.05, 08, 11, 12, 13, and 14 were physical evidence from different criminal cases submitted by local police departments. Each gun was loaded with one blank cartridge and one steel projectile available from each case and then test fired. The MV, ME, and ED were obtained as procedures mentioned above.

Results and Discussion

The effect of cartridge type to muzzle energies

In Taiwan the "wounding capability criterion" of a firearm is defined as "when the firearm is fired at the most powerful and appropriate shooting distance, the discharged missile has the kinetic energy capable of perforating human skin." The minimum energy density required to perforate human skin recognized by domestic firearms experts is 20 J/cm^2 [4]. The means and standard deviations of ME and ED of 8mm steel projectiles discharged from the No.04 gun using three different types of rimfire blank cartridges are shown in Table 2. The results reveal that the ED of steel projectiles discharged from the No.04 gun are all much higher than 20 J/cm^2 regardless of the type of blank cartridges fired. This indicates that the wounding capability of this type of homemade long guns is extremely high.

In order to compare the wounding capability of homemade long guns with that of 9mm Luger pistols, which are the most frequently encountered illegal guns in Taiwan, a Beretta 92FS 9mm pistol was test fired for three rounds of full-metal-jacketed (FMJ) cartridges. The means of ME and ED obtained were 507.35 J and 797.5 J/cm^2, respectively. This shows that the ED of steel projectiles discharged from the No.04 homemade long gun is about half of that of bullets discharged from a Beretta 92FS 9mm pistol. Because the penetrating power of steel projectiles is much stronger than that of FMJ bullets, the homemade long guns discharging steel projectiles are actually not safe for aborigines' traditional and cultural activities.

Table 2. ME and ED of steel projectiles discharged from the No.04 gun using 0.27in. blank cartridges with varied color codes

Type of blank cartridge	ME (J)		ED (J/cm^2)	
	Mean	SD†	Mean	SD†
Yellow color codes	178.68	3.15	360.95	6.45
Red color codes	210.36	5.99	424.98	12.03
Black color codes	222.61	9.28	448.47	16.27

†SD represents standard deviation.

Firing black-coded cartridges produced the highest muzzle energies of projectiles, followed by firing red-coded cartridges, and firing yellow-coded cartridges gave the lowest muzzle energies of projectiles. A Student's t test was used to establish the significance of differences in ME and ED of steel projectiles fired from No.4 gun using different types of blank cartridges listed in Table 2. The p values of t test are shown in Table 3. A confidence level of 95% (p value = 0.05) was chosen for the test. All of the p values of ME and ED of compared types of blank cartridges are smaller than 0.05. These results indicate that the differences of ME and ED of projectiles fired using different types of blank cartridges are significant. Twelve rounds of each type of blank cartridges were disassembled to recover propellant powders contained in each cartridge. The weight of propellants of each cartridge was measured and the means and standard deviations of the propellant contents of blank cartridges with yellow, red, and black color codes were calculated to be 0.173g ± 0.003g, 0.202g ± 0.003g, and 0.239g ± 0.004g, respectively. This result reveals that varied amount of propellants contained in cartridges causes the significant differences of ME and ED of projectiles discharged using varied types of blank cartridges.

Table 3. The p values of t test of means of ME and ED between different types of blank cartridges listed in Table 2

	Yellow vs. red	Red vs black	Black vs. yellow
t test of means of ME	0.0002	0.025	8.0E-05
t test of means of ED	0.0002	0.021	3.2E-05

The effect of barrel length to muzzle energies

No.01, 02, and 03 guns have the same nominal caliber but different barrel lengths. The MV, ME, and ED of lead projectiles discharged from each gun chambered with 0.27in black-coded blank cartridges are shown in Table 4. The MV, ME, and ED obtained from firing these guns decreased as the barrel length increased. The results contradict to the general understanding of that the longer the barrel the higher the muzzle velocity [5]. In well-designed weapons, longer barrel gives more time for the high pressure propellant gases to accelerate the projectile inside of the barrel. Thus longer barrels usually provides higher MV, ME, and ED. However, as the projectile moves down the barrel the propellant's gas pressure diminishes because of expansion and cooling down. If the propellant charge is relatively small and the barrel is long enough, there would finally be a point at which the force applied to the projectile by propellant gases would equal to the friction between the projectile and the barrel. The velocity of the projectile would decrease as it travelled down the barrel beyond this point. It is postulated that the barrel lengths of No. 01, 02, and 03 guns are so long that the MV, ME, and ED of fired projectiles decreased as the barrel length increased.

The muzzle energies of 10mm lead projectiles fired from the No. 03 gun were similar to those of 8mm steel projectiles fired from the No. 04 gun when both guns used the same type of blank cartridges. However, the energy densities of the former are much smaller than those of the latter as shown in Tables 2 and 4. This also results in smaller penetration power and wounding capability for the former. Besides, lead projectiles are much easier to deform when impacting targets than steel projectiles. This would further reduce the penetration power of lead projectiles. Considering the safety of participants, lead projectiles with bigger diameters are ideal projectiles to be fired from homemade long guns for aborigines' traditional and cultural activities.

Table 4. MV, ME, and ED of projectiles fired through guns with varied barrel lengths

Gun No.	Barrel length (cm)	MV (m/s)	ME (J)	ED (J/cm^2)
01	104	230.7	158.1	190.9
02	94	249.8	185.3	223.7
		248.0	182.7	220.5
03	93.5	276.2	226.6	273.5
		284.0	239.5	289.1

The effect of cartridge length to muzzle energies

The ME and ED of steel projectiles discharged from No.06, 09, and 10 guns using 0.27in. black-coded blank cartridges with different case lengths (Fig. 5) are shown in Table 5. The results indicate that projectile fired using 0.27in. black-coded extra-long cartridges always has higher ME and ED than that fired from the same gun using cartridges with normal length. Furthermore, no matter which gun was fired, the energy densities of steel projectiles discharged using 0.27in. black-coded extra-long cartridges are higher than the ED of 9mm Luger bullet fired from a Beretta 92FS 9mm pistol. These results imply that the 0.27in. black-coded extra-long blank cartridges are capable of discharging projectiles that have higher wounding capability than 9mm bullets fired from pistols. After disassembling the cartridges and measuring the weights of recovered propellants, the average amount of powder charge of each 0.27in extra-long black-coded blank cartridge was determined to be 0.355g, which is much more than the propellants contained in any other types of blank cartridges employed in this work.

Table 5. TheME and ED of projectiles fired from three guns using 0.27in. black-coded blank cartridges with different case lengths

Gun No.	Caliber (mm)	Barrel length (cm)	Cartridge length	ME (J)	ED (J/cm^2)
06	8	64	Normal	163.4	325.1
			Extra-long	438.3	872.0.
09	10	62	Normal	413.1	526.0
			Extra-long	702.2	894.1
10	10	66	Normal	459.5	585.1
			Extra-long	665.2	847.0

The effect of projectile type to muzzle energies

The ME and ED obtained after discharging an 8mm aluminum ball from the No.07 gun using 0.27in. black-coded blank cartridges are 16.59 J and 33.0 J/cm^2, respectively. The ED determined is only slightly higher than the wounding capability criterion, 20 J/cm^2, and is much lower than the ED of any other projectiles fired from the other guns used in this work. There are two reasons for the low ME and ED of the aluminum ball fired from the No.7 gun. The relatively short barrel, which is only 43cm, would be the first one. The other reason is the low ballistic coefficient, C, of the aluminum ball. The ballistic coefficient is defined as

$$\mathbf{C=m/d^2} \qquad (1)$$

where m and d are the mass and diameter of the projectile[6].

Since the density of the aluminum ball is much smaller than that of the steel ball, its ballistic coefficient is also much smaller. This results in higher air resistance which acts in the opposition to the aluminum ball's velocity [7]. Thus the velocity and kinetic energy of the aluminum ball quickly diminished before it reached the screens of ballistic chronograph. So aluminum projectiles are not suitable for aborigines' to fire homemade long guns in their traditional and cultural activities.

Other factors that affect muzzle energies

The No.05, 08, 11, 12, 13, and 14 guns were fired using blank cartridges and steel projectiles submitted for forensic examination in each criminal case. The ME and ED obtained of each gun and cartridge combination are shown in Table 6.

The No.11 gun chambered and fired the 0.25in. yellow-coded blank cartridge. This type of cartridge contained the smallest amount of propellant among all types of blank cartridges fired in this work, thus the projectile propelled by it possessed the lowest ME and ED.

The No.05 and 12 guns, although have different calibers, both chambered and fired the 0.27in. black-coded extra-long blank cartridges, which contained the biggest amounts of propellants among all types of blank cartridges fired in this work. Thus the ME and ED determined are much more than any other weapon combinations listed in Table 6. The ME of projectile fired from No.05 is smaller than that of No.12, however, since the caliber of No.05 is smaller than that of No.12, the ED of the former is higher than that of the latter. This indicates that when the same type of blank cartridges is fired, the projectile fired from the gun with smaller caliber will possess stronger penetration power and wounding capability.

The No.08, 13, and 14 guns all used the 0.27in. black-coded cartridges to discharge steel projectiles with varied diameters. The ME of fired projectiles increased as the barrel length increased. This indicates that the barrel lengths of No.08, 13, and 14 guns (57, 75, and 60cm, respectively) are all shorter than the length that the propellant gas force equals to the friction between the projectile and the barrel. However, the energy densities of projectiles are inversely correlated with the calibers of guns. The results further prove that the projectiles discharged from guns with smaller calibers have higher penetration power and wounding capability when the same type of blank cartridges is fired.

Table 6. The ME and ED of projectiles fired from six guns using varied types of cartridges

Gun No.	Caliber (mm)	Barrel length (cm)	Cartridge length	ME (J)	ED (J/cm^2)
05	8	58	0.27in. black extra-long	352.0	700.3
08	8	57	0.27in. black	125.2	249.0
11	10	77	0.25in. yellow	118.6	151.0
12	10	51	0.27in. black extra-long	484.6	617.0
13	11	75	0.27in. black	175.8	185.0
14	6	60	0.27in. black	143.6	507.9

The propellants contained in all types of blank cartridges disassembled in this work are smokeless ball powders as shown in Fig. 7. Smokeless powders are more powerful than the black powder employed in muzzle-loading homemade shotguns[8]. The combustion of smokeless powders inside a gun chamber produces much higher chamber pressure and temperature and further results in higher muzzle energy. Thus the wounding capability of the single projectile of breech-loaded homemade guns is stronger than that of the multiple projectiles of muzzle-loaded traditional homemade guns.

Two cases of shooting death firing rimfire blank cartridges and steel projectiles through breech-loaded homemade guns have been reported in Taiwan. In the first case the victim was shot from a distance of 58m [9]. The steel ball entered the body from the left side of the thorax, perforated left lung, heart, and right lung, and eventually stopped in the intercostal muscles on the right thorax. The gunshot wounds lead to an immediate death of the victim. In the second case the victim was shot from a distance of 26.5m [10]. The steel ball entered the neck at a point on the anterior midline 1.5cm above the clavicle. The victim died from hemorrhage. If the victims in these two cases have been shot by muzzle-loaded shotguns they could had suffered much less severe gunshot wounds because of rapid falling-off velocities of the shots. Furthermore, it has been reported that the use of blank cartridge to discharge projectiles might result in the explosion of the gun caused by the ultrafast burning powder [11]. Thus the use of homemade long guns to fire blank cartridges and steel projectiles is not only a threat to the public security but also dangerous to the aboriginal shooters.

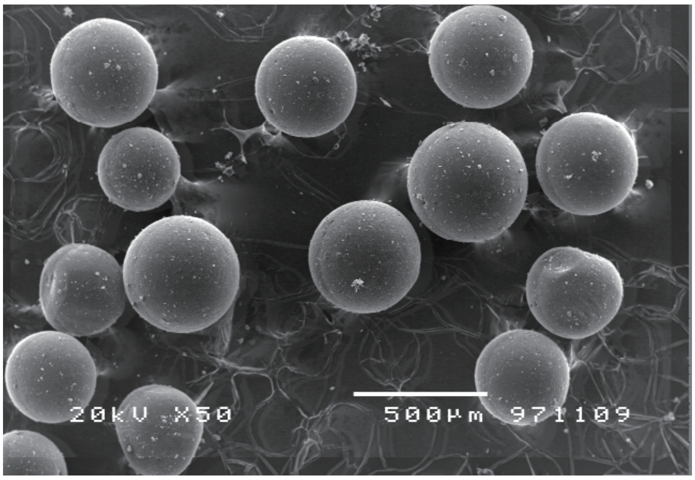

Fig. 7 Scanning electron micrograph of smokeless ball powders recovered from an unfired rimfire blank cartridge

Conclusions

When different types of blank cartridges were discharged from the same homemade long gun, the differences of muzzle energies produced by different types of cartridges are statistically significant. Among the 0.27in. rimfire blank cartridges, projectiles discharged by black-coded extra-long cartridges have the highest muzzle energies, which are even more powerful than the bullets fired from 9mm Luger pistols. Among the normal-sized blank cartridges, which are all less powerful than the black-coded extra-long ones, the black-coded ones produce the highest muzzle energies, followed by the red-coded ones, and the yellow-coded cartridges are the least powerful ones.

For the guns studied in this work, when the barrel length is shorter than 50cm, the time for the propellant gases to accelerate the projectile inside the barrel is too short, so as to the muzzle energy of the projectile is extremely low. When the barrel length is longer than 90cm, the force of the propellant gases is smaller than the friction due to the diminished gas pressure resulted from expansion and cooling-down, the muzzle energies of projectiles are inversely correlated with the barrel lengths. For the guns with intermediate barrel lengths, the muzzle energies of projectiles are positively correlated with the barrel lengths.

The relatively low density of the aluminum projectiles leads to small ballistic coefficient. Thus the velocity and kinetic energy of the aluminum ball quickly diminished before it reached the targets. Considering the aerodynamic forces acting the projectile, steel and lead are better projectile materials than aluminum. However, steel projectiles are not deformable when impacting soft targets, they would perforate the targets and jeopardize bystanders. Thus lead would be the best projectile material for aborigines to fire homemade long guns in their traditional and cultural activities.

According to the results of this work it can be concluded that the determinants of the penetration power and wounding capability of homemade long guns that firing rimfire blank cartridges and metal projectiles are cartridge type, barrel length, and projectile caliber and material. If the ban of manufacturing and possession of breech-loading homemade long guns by the aborigines are planned to be lifted, we recommend that the blank cartridges intended for the homemade long guns should be restricted the normal sized rimfire cartridges with a caliber smaller than 0.27in, the barrel length should exceed a certain low limit, and the projectile should be restricted to lead projectiles.

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