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Estimation of a Bullet's Diameter Using the Bullet Hole Identification Kit (BTK)

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ABSTRACT: Evaluation of the diameter of a bullet which caused an entrance hole by measuring the diameter of the color rings developed through use of the bullet hole identification kit (BTK) is presented. A direct estimation of the diameter of the bullet can be made, or a range of diameters can be determined. This range depends on the material of the target, and to an extent, on the kind of support behind the target. In the case of woven cotton textiles, this range was found to be small, and larger in other textile materials. Even in these latter cases, one can discriminate between the large and small diameters (for example, those of the 0.22 and 0.38 calibers). These results can be very useful when targets are dark colored or soiled to a degree where the black ring ("ring of dirt") around the entrance hole is unrecognizable.

KEYWORDS: criminalistics, ballistics, identification systems

Steinberg, et al. [*1*] introduced a bullet hole identification kit (BTK) for field use that was developed in the Toolmarks and Materials Laboratory of the Division of Criminal Identification, Israel National Police. The principle on which the implementation of the kit is based is a spot test identifying lead and copper [*2,3*]. On penetrating a target, a bullet deposits varying amounts of lead or copper or both on the perimeter of the bullet hole. The amounts vary according to the bullet's composition and the type of target. A detailed description of the kit and its use is found in Steinberg et al. [*1*].

The advantages of this kit are its reliability and the ease with which it is possible to obtain information. It is possible to answer the following questions:

1. Is a hole in a specific target indeed a bullet hole?
2. Does the bullet contain only lead or also copper?
3. From which direction did the bullet penetrate the target? (This determination is based on the side of the target which reacted positively to the spot tests.)
4. What is the angle of the shot? (This determination is based on the geometric shape of the color stain from the spot test.)

In this paper, we present additional information that can be gleaned from the spot tests and used in many cases to estimate, to a high degree of certainty, the diameter of the bullet

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that penetrated the target. It should be borne in mind that the diameter of the discharged bullet closely approximates that of the weapon used. Thus, a fair idea about the caliber, or group of calibers, can be reached.

Walker [*4*], as early as 1940, discussed the possibility of estimating the bullet's diameter according to the diameter of the "ring of dirt" surrounding the bullet hole. There are two principle difficulties with the above method of estimation:

1. The elasticity of the target material causes a difference between the "ring of dirt" diameter and the diameter of the bullet. This problem is especially prevalent in materials such as skin, rubber, and knitted textiles.
2. There are cases in which a "ring of dirt" is not deposited as a result of the relative cleanness of the bullet and the barrel before the shot. The "ring of dirt" can be difficult to recognize because of preexisting dirt on the target, the target color itself, or subsequent blood stains.

Use of the kit eliminates the above difficulties. A positive reaction of the spot test appears on the test paper which is placed over the bullet hole as a colored ring. Since the color reaction depends upon the presence of lead or copper or both deposited by the penetrating bullet, it is assumed that the diameter of the color ring is a simple function of the bullet diameter. The creation of the color ring is not influenced by the condition of the weapon, the target's color, or the dirt on the target (except in rare and unique cases).

Experimental Procedure

To examine the feasibility of estimating the diameter of a bullet by measuring the colored rings around the entrance hole, the following variables were examined:

(1) caliber ammunition,
(2) types of target supports,
(3) muzzle velocities, and
(4) target types.

Caliber Ammunition

Table 1 lists the firearms and ammunition used to produce the bullet holes that were examined.

Target Supports

To examine "forensically realistic" combinations of targets and supports, the following types of target supports were used (assuming all types of textile targets are realistic):

1. Suspended target within a frame, where the target has no backing whatsoever. Some examples of this target type, met within casework are: curtains blowing in the wind, loose fitting garments, or tent walls.
2. 120-mm layer of polyurethane foam mounted on a 50-mm wooden plank.
3. 50-mm wooden plank.
4. Sand pile.

These types of target support cover a wide range of hardness and density which one would expect to meet in real casework.

TABLE 1—*Types of weapons and ammunition examined.*

Weapon	Caliber	Bullet Diameter, mm[a]	Bullet Type
1. Beretta semiautomatic pistol	WI22LR	5.50	copper wash
2. M-16 assault rifle	223 Remington (5.56 mm)	5.50	lead core, copper jacket
3. Beretta semiautomatic pistol	32ACP	7.65	lead core, copper jacket
4. M-1 semiautomatic rifle	30M1 Carabine	7.66	lead core, copper jacket
5. Beretta semiautomatic pistol	380ACP	8.85	lead core, copper jacket
6. Uzi submachine-gun	9-mm Parabellum	8.85	lead core, copper jacket
7. Colt semiautomatic pistol	45ACP	11.25	lead core, copper jacket

[a]The relevant value is not the nominal diameter of the bullet (available data [5]), but its actual diameter after the shooting, which should approximate closely the inner diameter of the bore (either by expansion or contraction within the barrel). Data cited were taken from Svensson and Wendell [6].

Muzzle Velocities

Colored rings around entrance holes, produced by rifles and pistols of similar bore diameters, were investigated. The weapons and ammunition chosen differ substantially in their muzzle velocity (Tables 2 through 10).

Target Types

The majority of our experiments were carried out on cotton cloth. This material was chosen because of its common use in both civilian and military materials. We also examined targets of other textile types to find out to what extent this change will influence the results. Textiles used were knitted cotton, tricot, woven wool, woven synthetic fabric, and others.

For each statistical determination of the colored ring diameter, the weapons were fired six times at the same type of target. This number allows a significance level of 95% if a range of three standard deviations from the mean is taken.

Results and Discussion

Figures 1 through 5 are photographs of colored rings obtained from the spot tests for the presence of lead and copper.

Tables 11, 12, and 13 show the mean (x) and the standard deviation (SD) of the measured diameters of the black ring ("ring of dirt") and the colored rings following a positive reaction with lead and copper, respectively. The data presented are for woven cotton made targets.

Figures 6 through 8 show the colored ring diameters as a function of the weapon's bore diameter. There is a good match between the experimental points and the theoretical line for all three (black, lead, and copper) rings. The theoretical line is that which one would expect if all colored ring diameters equaled the diameters of the penetrating bullets. From the above mentioned figures, it is apparent that the different bullet diameters can be estimated by using both lead and copper colored ring diameters. Even if a range of three standard deviations from the mean value is taken for the measured ring diameter, it is possible to discriminate clearly between different bullet diameters which are not too close to each other, such as those of calibers 0.22 and 0.38, 0.32 and 0.45, and so forth.

TABLE 2—*Effect of muzzle velocity on black ring diameter (mm).*

0.22″		Support					
		Air		Foam		Wood	
Caliber	Muzzle Velocity, m/s	*x*	SD	*x*	SD	*x*	SD
223 Rem. (5.56 mm)	1000	5.38	0.19	5.49	0.09	5.15	0.13
WI22LR	360	5.63	0.15	5.63	0.20	6.03	0.12

TABLE 3—*Effect of muzzle velocity on lead ring diameter (mm).*

0.22″		Support					
		Air		Foam		Wood	
Caliber	Muzzle Velocity, m/s	*x*	SD	*x*	SD	*x*	SD
223 Rem. (5.56 mm)	1000	5.58	0.07	5.40	0.29	5.37	0.17
WI22LR	360	5.64	0.15	5.73	0.19	6.22	0.19

TABLE 4—*Effect of muzzle velocity on copper ring diameter (mm).*

0.22″		Support					
		Air		Foam		Wood	
Caliber	Muzzle Velocity, m/s	*x*	SD	*x*	SD	*x*	SD
223 Rem. (5.56 mm)	1000	5.21	0.09	5.41	0.20	5.45	0.15
WI22LR	360	5.42	0.09	5.65	0.29	5.97	0.15

TABLE 5—*Effect of muzzle velocity on black ring diameter (mm).*

0.32″		Support					
		Air		Foam		Wood	
Caliber	Muzzle Velocity, m/s	*x*	SD	*x*	SD	*x*	SD
30M1 Carabine	600	7.71	0.06	7.71	0.09	7.58	0.07
32ACP	290	7.31	0.10	7.60	0.23	7.81	0.27

TABLE 6—*Effect of muzzle velocity on lead ring diameter (mm).*

0.32″		Support					
		Air		Foam		Wood	
Caliber	Muzzle Velocity, m/s	*x*	SD	*x*	SD	*x*	SD
30M1 Carabine	600	7.73	0.10	7.70	0.09	7.56	0.08
32ACP	290	7.31	0.16	7.76	0.34	7.84	0.37

TABLE 7—*Effect of muzzle velocity on copper ring diameter (mm).*

0.32″		Support					
		Air		Foam		Wood	
Caliber	Muzzle Velocity, m/s	*x*	SD	*x*	SD	*x*	SD
30M1 Carabine	600	7.67	0.08	7.65	0.06	7.46	0.14
32ACP	290	7.16	0.15	7.50	0.14	7.94	0.27

TABLE 8—*Effect of muzzle velocity on black ring diameter (mm).*

0.38″		Support					
		Air		Foam		Wood	
Caliber	Muzzle Velocity, m/s	*x*	SD	*x*	SD	*x*	SD
9-mm Parabellum	400	9.12	0.21	9.02	0.14	8.97	0.25
380ACP	290	8.31	0.31	9.18	0.20	9.31	0.52

TABLE 9—*Effect of muzzle velocity on lead ring diameter (mm).*

0.38″		Support					
		Air		Foam		Wood	
Caliber	Muzzle Velocity, m/s	*x*	SD	*x*	SD	*x*	SD
9-mm Parabellum	400	8.36	0.04	8.90	0.33	8.90	0.25
380ACP	290	8.22	0.22	9.25	0.32	9.77	0.63

TABLE 10—*Effect of muzzle velocity on copper ring diameter (mm).*

0.38″		Support					
		Air		Foam		Wood	
Caliber	Muzzle Velocity, m/s	x	SD	x	SD	x	SD
9-mm Parabellum	400	8.64	0.16	9.16	0.23	8.99	0.29
380ACP	290	8.15	0.18	8.97	0.49	9.35	0.48

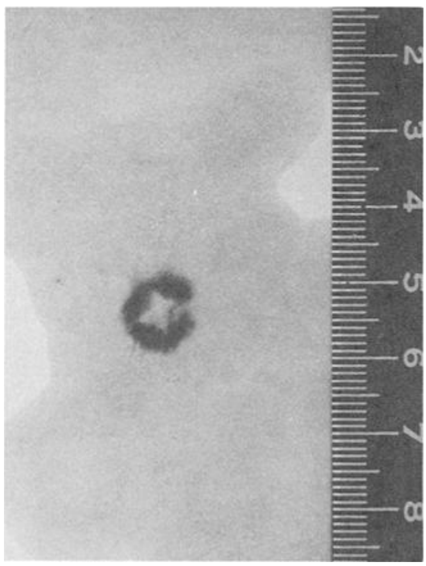


FIG. 1—*A color ring from copper reaction around 9-mm bullet hole.*

The significant finding is that all three parameters, that is, black, lead, and copper colored rings, are equivalent for use in estimating the bullet's diameter. Thus, if the black ring is unrecognizable as a result of the relative cleanness of both the bullet and weapon's bore, or in the case of dark target material or soiled material, the colored rings developed by the spot reaction can be adequate substitutes. Also, a positive lead reaction or a copper reaction, alternatively, will give the answer in cases where only one of them is developed. For instance, in the case of lead bullets, only the lead ring would be present, or in the case of copper jacketed bullets, often only a copper ring is formed.

The spread of the points around the theoretical line shows that the kind of support used has a negligible effect on the colored ring diameter. Lack of support ("air"—suspended target) tends to enlarge the deviation from that line in the direction of decreased colored ring diameter. A possible explanation is the elasticity of the fabric which results in contraction of the hole's margin after the penetration of the bullet. This last phenomenon is more

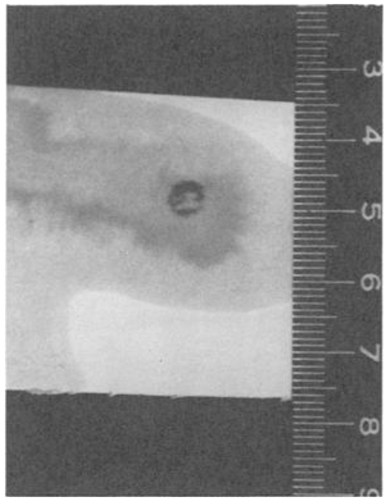


FIG. 2—*A color ring from lead reaction around 5.56-mm bullet hole.*

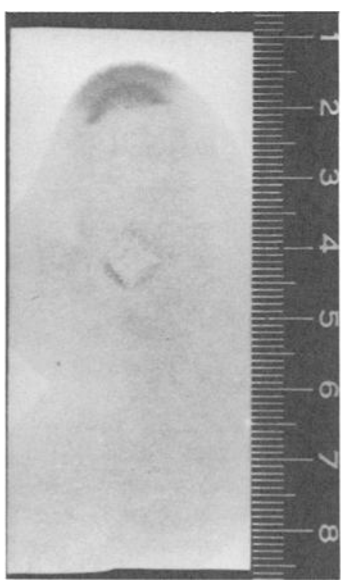


FIG. 3—*A color ring from lead reaction around 9-mm bullet hole.*

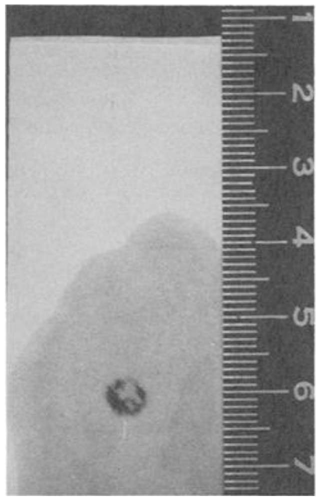


FIG. 4—*A color ring from copper reaction around 5.56-mm bullet hole.*

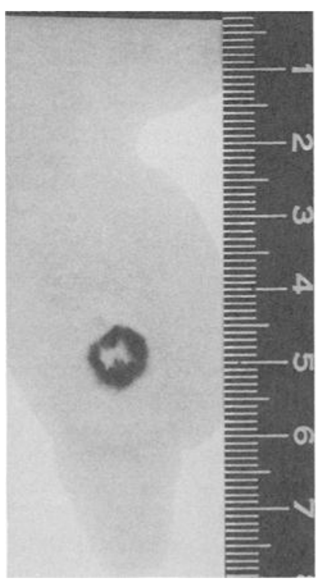


FIG. 5—*A color ring from copper reaction around 7.62-mm bullet hole.*

TABLE 11—*Black ring ("ring of dirt") diameter (values in mm).*

	Caliber							
	WI22LR		32ACP		380ACP		45ACP	
Support	x	SD	x	SD	x	SD	x	SD
Air	5.16	0.11	7.31	0.10	8.31	0.31	10.92	0.32
Foam	5.63	0.20	7.60	0.23	9.18	0.20	10.32	0.19
Wood	6.03	0.12	7.81	0.27	9.31	0.52	11.12	0.10
Sand	5.29	0.13	7.69	0.19	8.86	0.21	10.86	0.31

TABLE 12—*Diameter (in mm) of colored ring produced by positive lead reaction.*

	Caliber							
	WI22LR		32ACP		380ACP		45ACP	
Support	x	SD	x	SD	x	SD	x	SD
Air	5.64	0.15	7.31	0.16	8.22	0.22	10.11	0.07
Foam	5.73	0.19	7.76	0.34	9.25	0.32	10.90	0.39
Wood	6.22	0.19	7.84	0.37	9.77	0.63	11.28	0.17
Sand	4.90	0.14	7.55	0.16	8.99	0.32	10.88	0.40

TABLE 13—*Diameter (in mm) of colored ring produced by positive copper reaction.*

	Caliber							
	WI22LR		32ACP		380ACP		45ACP	
Support	x	SD	x	SD	x	SD	x	SD
Air	5.42	0.09	7.16	0.15	8.15	0.18	10.11	0.11
Foam	5.65	0.29	7.50	0.14	8.97	0.49	10.79	0.27
Wood	5.97	0.15	7.94	0.27	9.35	0.48	10.93	0.45
Sand	4.94	0.14	7.51	0.24	9.00	0.26	10.96	0.23

pronounced as the bullet diameter increases. Presence of a support tends to limit the expansion of the fabric.

To examine the effect of the weapon's muzzle velocity on the bullet diameter, comparison between various calibers of similar bore diameters was made, again for various support types. Results (for cotton made targets) are given in Tables 2 through 10. Data concerning muzzle velocity were taken from Speer [5].

It is quite clear from the above data that although different muzzle velocities have, as expected, some effect on the colored ring diameter, that effect does not prevent one from estimating the bullet's diameter. The above mentioned remark about the three standard deviations' range is valid even when considering a substantial difference in muzzle velocities, such as that of WI22LR and 223 Remington (5.56-mm) calibers.

As was mentioned before, our main research was carried out using woven cotton targets. The influence of the target material on the size of the colored ring should be substantial. Two

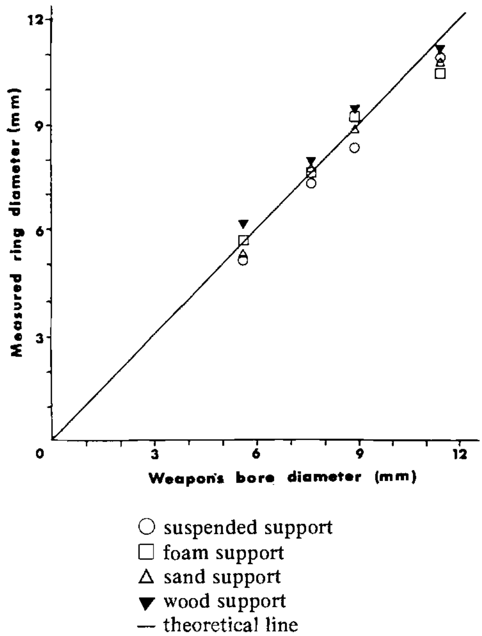


FIG. 6—*The diameter of the black ring plotted against weapon's bore diameter for different target support types.*

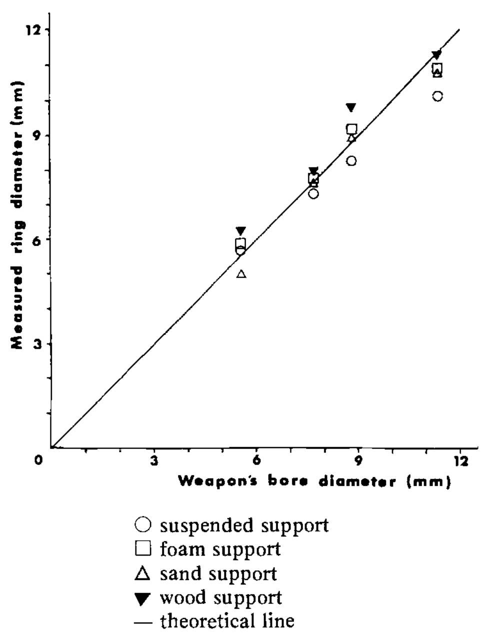


FIG. 7—*The diameter of the lead ring plotted against weapon's bore diameter for different target support types.*

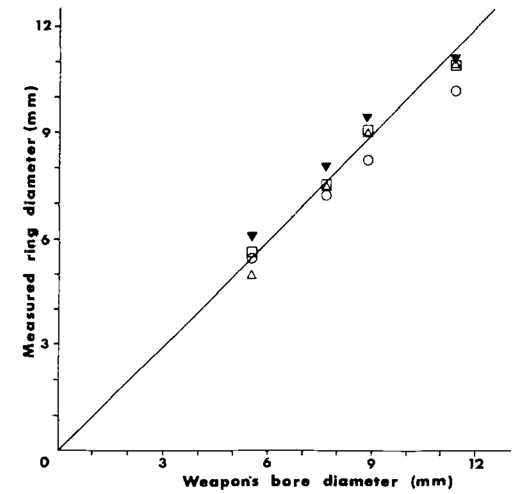


FIG. 8—*Diameter of the copper ring plotted against weapon's bore diameter for different target support types.*

kinds of deviations from the theoretical line are expected, and were indeed found in the course of our experiments, one being smaller colored ring diameters, apparently caused by the contraction of the material around the bullet after its penetration. This contraction would occur in material which is more flexible than the woven cotton textile. The second kind of deviation are larger colored ring diameters which were encountered cases where unravelling of the textile around the entrance hole takes place. This last effect is more likely to be found in knitted textiles.

Tables 14 through 16 present a few examples of the diameters of the colored rings in several types of target materials, with wood as a support. Figures 9 through 11 demonstrate the relation of those diameters to the bullet's (weapon's bore) diameter.

Because of the wide variety of textile materials, there is not much sense in a comprehensive research of the possible effect of the target material on estimating the bullet diameter from the colored ring diameter. However, one should not conclude that this application of the

TABLE 14—*Black ring diameter (mm) in different target textiles.*

	Caliber							
	WI22LR		32ACP		380ACP		45ACP	
Target	x	SD	x	SD	x	SD	x	SD
Knitted cotton	6.03	0.12	7.81	0.27	9.31	0.52	11.12	0.10
Tricot	6.13	0.13	7.91	0.26	8.90	0.29	11.37	0.31
Knitted synthetic	5.52	0.34	7.01	0.58	8.86	0.57	10.36	0.52
Velvet synthetic	6.26	0.68	9.03	0.34	10.00	0.37	12.20	0.30

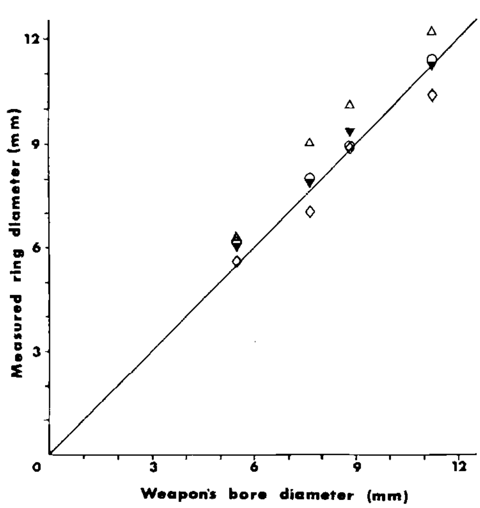
TABLE 15—*Lead ring diameter (mm) in different target textiles.*

	Caliber							
	WI22LR		32ACP		380ACP		45ACP	
Target	x	SD	x	SD	x	SD	x	SD
Knitted cotton	6.22	0.19	7.84	0.37	9.77	0.63	11.28	0.17
Tricot	6.09	0.15	7.90	0.29	8.50	0.49	10.71	0.59
Knitted synthetic	7.23	0.94	7.13	0.90	9.14	0.47	11.08	0.26
Velvet synthetic	6.48	0.21	9.19	0.32	9.98	0.66	12.22	0.36

TABLE 16—*Copper ring diameter (mm) in different target textiles.*

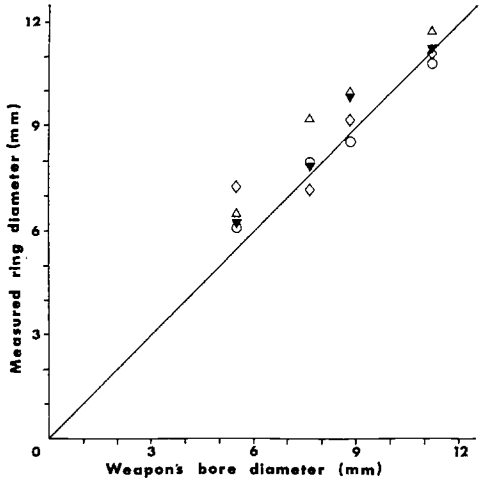
	Caliber							
	WI22LR		32ACP		380ACP		45ACP	
Target	x	SD	x	SD	x	SD	x	SD
Knitted cotton	5.97	0.15	7.94	0.27	9.35	0.48	10.93	0.45
Tricot	*[a]		*		*		*	
Knitted synthetic	7.02	1.00	7.20	0.98	9.02	0.45	10.34	0.48
Velvet synthetic	6.20	0.11	9.18	0.29	10.12	0.17	12.06	0.44

[a]No reaction with the reagent for copper.



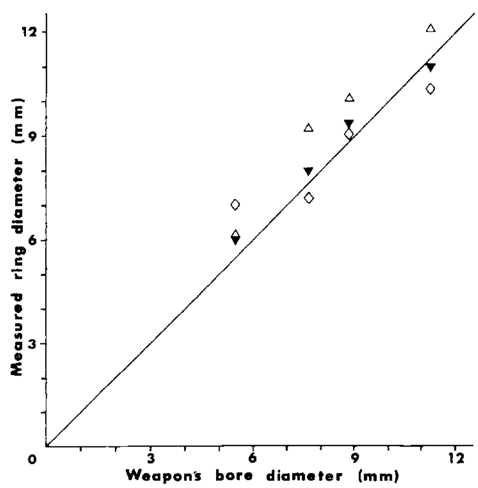
▼ woven cotton textile
○ knitted cotton textile
◇ knitted synthetic textile
△ synthetic velvet
— theoretical line

FIG. 9—*Diameter of the black ring plotted against weapon's bore diameter for different target materials.*



▼ woven cotton textile
○ knitted cotton textile
◇ knitted synthetic textile
△ synthetic velvet
— theoretical line

FIG. 10—*Diameter of lead ring plotted against weapon's bore diameter for different target materials.*



▼ woven cotton textile
○ knitted cotton textile
◇ knitted synthetic textile
△ synthetic velvet
— theoretical line

FIG. 11—*Diameter of copper ring plotted against weapon's bore diameter for different target materials.*

BTK has no relevance to textiles other than woven cotton. In any case, where doubts arise concerning the possible effect of the target material, a test-firing should be carried out with the same target material to enable the evaluation of the bullet diameter. Even without the test-firing, a range of diameters can be determined.

Finally, it should be emphasized that the values of the colored ring diameters are significant only in those cases in which it can be assumed that the shot angle was perpendicular to the target. This assumption is based on the near circular shape of the colored ring [*1*]. In the case of an acute angle shot, the colored stain on the test paper has an elliptical, rather than a circular, shape. The length of the short axis of the ellipse can be assumed to be close to that of the diameter of the penetrating bullet.

Conclusion

A novel application of the bullet hole identification kit (BTK) in estimating the bullet's diameter is reported. The colored rings developed around the entrance hole were found to be equivalent to that of the black ring ("ring of dirt") around the entrance hole. The diameters of these rings are a good estimation of the bullet's diameter in woven cotton made targets. In other types of material, a range of diameters is determined, thus enabling exclusion of certain bullet diameters and hence certain calibers as well.

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