

## Modern Trends in Forensic Ballistics

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### ADLİ BALİSTİK ÇALIŞMALARINDA YENİ EĞİLLİMLER

#### Özet

Modern adli balistik ile ilgili problemler ve metodolojiler geniş bir biçimde gözden geçirildi. Bu yapılırken, mekanik silahlarla ilgili özelliklerin ve patlayıcı madde ayırımının yapılması yöntemleri yerine, kuvvetler, patlamalı mermilerin çıkış hızları ile etkili oldukları en uzun menzil, standard/el yapısı kurşunlarla yapılan atışların eser elementleri, kurşun yarasındaki kalıntılar, bunların araştırılmasında kullanılan enstrümental yöntemler ve GSR' nin alınmasında sulandırılmış harbi fırçalarının avantajları üzerinde özellikle duruldu.

#### Summary

A comprehensive review of modern forensic ballistics problems and methodologies to answer these, has been presented with special emphasis on energetics, threshold velocities, extreme effective range of shotgun missiles, trace elemental pattern of standard/home made lead shot, gunshot residues, some instrumental methods used in their detection, and practical advantages of aqueous swabs to remove GSR's, etc., in addition to pertinent aspects of operational firearms and ammunition identification.

**Keywords :** *Forensic ballistics - Firearms identification - Wound ballistics - Energetics - Extreme effective range - Gunshot residues - Trace elemental pattern - Emission spectrography - Neutron activation analysis - Laser microspectral analysis*

### INTRODUCTION

The term "*forensic ballistics*" has come to stay. Although diverse examinations undertaken in the Ballistics Divisions of Forensic Science Laboratories i.e. identification of firearms, ammunition, fired shot / bullets / empties, residues of fired ammunition / gun shot residues, wound ballistics and energetics, etc., generally fall under "*firearm identification*", the latter is taken synonymous with forensic ballistics. Much of the firearm identification work earlier would be carried out by experts having army / police background with little of formal scientific grounding. Today, forensic ballistics work is dealt with in a full fledged scientific manner by analytical scientist,

chemist and physicist, covering far beyond the conventional firearms examination and comparison microscopy. The methodology applicable at present to forensic ballistics work includes amongst other things microchemical, spectrographic, atomic absorption, neutron activation analysis, scanning electron microscopy, microprobe X-ray / X-ray fluorescence for residues analysis, electronic chronometry for measuring initial and residual bullet velocities and energetics studies, etc.

It is obviously not possible to deal with all aspects of modern forensic ballistics work in a short presentation. It is therefore proposed to take a few selected aspects on the basis of our experience in this field over last decade and more. The adoption of relevant modern methodology both in the areas of chemical residues analysis, comparative trace analysis and energetics will be given special attention. The pertinent aspects of firearm identification work and reporting norms in certain situations will also be dealt with.

## EXAMINATION OF GUNS

Excepting the rare occasions, when all other exhibits but not the gun, are submitted to the laboratory, the usual physical examination of the crime gun enable one to arrive at the conclusion:

- (i) Whether the gun is in working order (test firing having been done successfully),
  - (ii) Whether the gun is in mechanical working order (mechanically sound in all respects, but test firing not possible, say, for non-availability (of the right type of ammunition),
  - (iii) Whether the gun is not in working order for the reason such as wilful removal or malicious damage to vital components of the gun mechanism, e.g. firing pin severed, field off or bent to render its hit ineffective,
  - (iv) Whether prone or not prone to accidental discharge (especially, when the trigger pull is unusually low, etc.), these vital aspects of the examination being conventional,
  - (v) Whether the gun has been fired or not, before submission to the laboratory.
- Though the time of firing cannot be ascertained by chemical analysis of gun shot residues in the barrel, this has been often found a useful circumstantial evidence. Ordinarily after normal use of a gun the genuine user would for the proper upkeep of his valuable device, clean and oil the chambers/barrel in which case no residues are detected in the laboratory. In crime situations, however, the barrel washings are good positive for residues of fired smokeless ammunition or gun powder (black powder) as the case may be (the latter, especially in home-made-ammunition or re-filled cartridges used in breech loaders). The type of powder used can readily be discerned. In the case of smokeless powder, the non-alkaline pH and the absence of sulphur/sulphates, etc. and potassium cation distinguishes it from the residues detected in black powder ammunition firing, presence of nitrite being common to both.

(vi) *Effectiveness of the gun.* Whether the gun delivers the shot / bullet with effective velocity in order to cause wounding / casualty consistent with the history of the crime case in question and the injury / post-mortem observations recorded by the medical officer. The effectiveness of the standard shoulder arms / handguns is well documented. Even so, in the ideal case the crime gun muzzle velocity should be measured in order to ensure that the standard gun was performing normally but in the case of countrymade handguns use of which accounts for more than half of our total case load, it is desirable to measure the velocity in each and every case as the performance of these guns varies every widely. Such 12 bore breech loaders may have  $V_0$  (muzzle velocity) as low as ineffective 200 ft/sec right upto sufficiently damaging 700 ft/sec or so. Smooth bored countrymade handguns delivering .22/.32/.38/.455 revolver / pistol ammunition as also .30 and other caliber rifle ammunition have generally relatively low to very low velocities (of the order of 350 ft/sec in the case revolver / pistol ammunition as against the normal range of 600-1000 ft/sec for the aminunitions in question; in the case of rifle ammunition  $V_0$  is relatively very low, ca. 300 ft/sec against the usual 2500 ft/sec or so. In a recent fatal shooting case, however, we came across a smooth bore country-made handgun capable of firing 0.315 rifle ammunition with muzzle velocity  $1100 \pm 75$  ft/sec; another similar gun held recently in an illegal possession case gave muzzle velocity  $680 \pm 40$  ft/sec.

## ENERGETICS

Briefly this involves the gun, the shot/bullet in question, the target material and the distance from which it is fired at. The basic concept is that the striking velocity should be in excess of the threshold velocity  $V_{th}$  for the particular shot or bullet size for rupture of skin and penetration into soft tissue which is well established by both theory and experimentation (1-4). Specific threshold energy for penetration into human skin and soft tissue is given as:

$$E_{th} / \underline{a} = 16.7 \text{ J/cm}^2 = 79.4 \text{ ft lbs/sq inch} \quad \dots(1)$$

On the basis of constancy of this value, the theoretically predicted as well as experimentally determined values of  $V_{th}$  vary from, say, .38 revolver and shot gun shot size LG - 190 and 213 feet per sec respectively to 0.22/0.177 air gun pellets - 246 and 331 ft/sec (fps) respectively, etc.

*Calculation of Threshold Velocity:*

We have,

$$\underline{m}V_{th}^2 : 2a = 16.7 \times 10^7$$

$$V_{th} = 182.8 \sqrt{a : \underline{m}} \quad \text{meters/sec} \quad \dots(2)$$

where  $a : \underline{m}$  is in  $\text{cm}^2/\text{g}$  units, or

$$\underline{m}V_{th}^2 : 2a \text{ g} = 79.4 \quad (\text{g} = \text{accel. due to gravity})$$

$$V_{th} = 71.3 \sqrt{a : \underline{m}} \quad \text{ft/sec} \quad \dots(3)$$

Where  $a : \underline{m}$  is in  $\text{inch}^2/\text{lb}$  units.  $a : \underline{m}$  is also known as inverse sectional density,  $a$  and  $\underline{m}$  being the area of cross section and the mass of the bullet/shot respectively. The previously held criterion like 58 (or higher) ft lbs of energy required to cause a casualty, though relevant as a military criterion, has to be drastically reviewed in forensic situations, where missiles with much less energy could cause/have caused grievous injuries. Likewise, effectiveness of a shotgun held to be around 4 yds is alright for bird shooting but has to be cautiously guarded against forensic misuse (5), when bigger buckshot etc. is involved; an LG/12 Gauge ball would be effective up to around 300/600 yards respectively (*vide infra*).

Further, the wounding capacity is established by not only the intrinsic (total) kinetic energy,  $E_o$ , possessed by the striking missile, but by the amount of kinetic energy dissipated in wound production,  $E_w$ , in the target (6,7).

$$E_w \simeq 2 \text{ k} E_o \quad \dots(4)$$

$E_w/E_o \simeq 40\%$  for full metal jacketed bullets and  $> 90\%$  for soft/hollow point bullets. The wound ballistics takes cognizance also of the damage caused by the pulsating tempo-

rary cavity, especially in the case of energetic missiles. Such work has been carried out using human cadaveric tissue/animal (pig) tissue and more recently, widely on simulated material such as 20% gelatin gel (6).

The striking velocity of bullet/shot at a given distance X, can be worked out with the help of space functions recorded in Ballistics Tables.  $V_0$  is determined in the laboratory by electronic chromometer over a distance of 3 ft or so, using make / break electrical contact screens (8) or better, photoelectrical screens:

We have, 
$$X = C ( S V_x - S V_0 ) \quad \dots(5)$$

or simply, as : 
$$X = C : A \ln V_0 / V_x \quad \dots(6)$$

where  $C (=m/i d^2)$ , the ballistics coefficient of the shot or bullet, can be evaluated from its mass, sectional diameter and  $i$  the shape factor.  $A = 1/17696$ . Thus having calculated the striking velocity, the energetics of the missile in question, can be objectively assessed. In the context of the extreme effective range (how far the gun/shot can hurt?) as against the extreme/maximum range (how far the shot can reach?) recorded in the literature, the following may be cited as an illustration (9,10) :

Table I. The extreme/effective ranges for typical shotgun missiles.

Eqn (3)	Shot fired from standard shotgun ( $V_0 = 1050$ fps)	Extreme Range (Lit.) (Journèè)	Extreme Effective Range	
			Eqn (5) Av. Values using Ingalls / British Tables	Eqn (6)
<u>fps</u>		<u>yds</u>	<u>yds</u>	<u>yds</u>
169	12 G Ball	1420	673	664
213	LG	790	338	327
373	No. 2	295	81	77
426	No. 6	225	54	51
465	No. 8	190	41	39

Extreme effective range should however, not be confused with the overall effectiveness of the firing from the shotgun, overlooking the spread of the pattern and the few number of shot striking the body at large distance. This range merely indicates the penetration potential of the individual shot at this long distance.

### EXAMINATION OF CARTRIDGES / CARTRIDGE CASES

This involves identifying the type of crime cartridge or the usual microscopic examination of the crime cartridge case connecting it with the crime gun. The latter is a well established forensic ballistics microscopic examination. The former is generally readily possible on the basis of dimensions, as also the head stamp markings. On occasions, however, the paucity of literature from certain areas like that for *USSR/East European* ammunition, renders the task somewhat difficult. In a terrorist shooting, for instance, we came across 9 mm pistol ammunition close to that of 9 mm *Makarov* but for the non-availability of its head stamp markings, the identification could not be completed.

Occasionally it has been found profitable to test for fired ammunition residues in the cartridge was established by detection of characteristic residues in the crime cartridge case and the same on the clothing of the victim (close range firing).

There are instances where a pistol bullet fired from a revolver e.g. a 9 mm pistol cartridge from 0.38 revolver, a *vice-versa*, e.g. .320 revolver cartridge from a 7.65 mm pistol. Normal firing of 0.320 Rev-cartridge from 7.65 mm pistol when repeat fire and ejection of the empty may rupture or at times jam the pistol, has been reported (11). In the former, the absence of the ejector mark and in the latter, the presence of extractor and ejector marks throws light on the situation. In the case of some countrymade hand guns, where firing pin punctures the primer cup rendering the identifications of cartridge cases on the basis of firing pin mark impossible, the presence of peculiar bulging below the rim of the fired cartridge case, would prove very useful in the identification of the crime gun.

The reporting norms vary from characteristic features in the firing pin, breech face and other impressions (full identification) to broad matching in respect of general features in the firing pin or other markings, to non-matching as the case may be. Some times, the non-availability of the right type of ammunition submitted to the laboratory for test firing (e.g. a brass primer in the crime cartridge case as against aluminium primer in the cartridge(s) submitted by investigating officer), as also special problems like presence of rotating firing pin in the country-made handguns, etc. add to the difficulties in the identification work, though not making it impossible.

## BULLET COMPARISON

Examination of the fired bullet in order to relate it to the crime gun on the basis of striations registered from lands/grooves of the rifled barrel, is a very important aspect of forensic ballistics work which when done with care, after satisfying the preliminaries like, number, width and the direction and magnitude of twist of the land/groove impressions, should ordinarily not present much of a problem to arrive at the conclusion of the type of weapon (make and model) involved as also the characteristic striations tallying or not tallying to identify the crime gun. Though it is the ballistic expert's discretion to submit photomicrographs of bullet (or cartridge case) comparison with his report, it has been widely recognised and accepted that it is not obligatory to do so for purely technical reasons in the interests of justice.

Occasionally in the case of metal jacketed bullets fired from rather worn out barrels, the characteristic striations may not be present to the degree required for positive identification, in which case the opinion possible under the circumstances would be that the details on the crime bullet are *consistent* with its having been fired from the weapon in question. In "no gun" cases the examination of fired bullets may be necessary to indicate whether one or more guns have been fired in the incident or to throw light on the type (make and model) of the gun which has been used. In a terrorist shooting, for example, the rather uncommon land/groove widths on the crime bullets pointed to a 9 mm Mannlicher or Walther pistol.

The bullet comparison work, may occasionally be rendered difficult by skid marks or slips as in the case of slightly larger barrel (worn out barrel or use of not properly matched ammunition), or in the case of a gun malfunctioning after its use in the crime case in question. In the latter case it has been found that a sulphur/paraffin cast taken at the muzzle end of the gun in question is very helpful in relating the fired bullet to the gun, indicating that the striations left on the bullet, imprinted on it during the dynamics of its progress through the barrel, are mainly from its passage through the last few cms of the barrel.

Though ordinarily, smooth bore country-made handguns would not give an opportunity for bullet comparison, there have been instances where due to constructional features (e.g. a sight fixture protruding inside at the muzzle end) bullet comparison has been unambiguously positive (12). Air gun pellets fired from air rifles also are amenable to gun identification.

Matching of bullet composition readily possible by semi-quantitative emission spectrographic analysis, is useful on many occasions. While in the case of standard ammunition this may have a merely corroborative significance in relating the crime bullet/shot to the stock of the ammunition seized from the accused, such examination has proved more purposeful having high evidential value in relating the crime shot (recovered from the deceased or from the crime scene) used in muzzle loading guns or

refilled cartridges with the lead shot available with the accused (13). The matching (Table II) has been convincing over a number of trace elements and the high evidential value is obvious from widely different trace elemental pattern (TEP) from one case to another.

Table II. Typical correspondence or otherwise between crime and comparison lead shots.

Case No	Source identity / non-identity	Trace element							
		Copper	Tin	Bismuth	Iron	Silver	Antimony	Aluminium	Others
I	v ≡ s ≡ a	vf	vf	mf	f	Nil	ms	Nil	Nil
II	v ≡ a	mf	m	Nil	vf	Nil	f	Nil	Nil
III	v ≡ s	m	mf	Nil	vf	mf	mf	vf	Nil
IV	v ≠ a	m/m	vf/m	Nil/ Nil	Nil/ Nil	Nil/ Nil	f/ Nil	mf/ Nil	Nil/ Nil

Note: 1) v = shot recovered from victim at post-mortem examination, a = seized from accused, s = recovered at the scene of crime.

2) vf (very faint), f, mf, m, ms (medium strong) are the observed emission spectrographic analytical line intensities.

## MICROCHEMICAL / INSTRUMENTAL ANALYSIS OF GUNSHOT RESIDUES

Before dealing with the subject of GSR's (inorganics like Pb, Sb, Ba, Cu etc. as it is envisaged today) mention may be made of the use of nitrite patterns visualized by conventional diazo and coupling chemical test for opinion on close distance firing, keeping also in view the other obvious close distance firing phenomena observed around the shothole on the target material such as clothes etc. This has been done successfully, even when the fabric around the shothole was substantially blood stained, as against the reported difficulty in such a situation (14).

Lot of work has been done on metallic GSR's in the hand washing of persons suspected to have fired a gun. The data is highly variable (15,16). *Nesbitt* (15) found in the case of 0.38 revolver firing *outdoors*, GSR's : Pb  $0.64 \pm 0.33$  and Sb  $0.04 \pm 0.04$  as against average hand blank values of 0.4 and  $< 0.01 \mu\text{g}$  respectively. *Krishnan* (16) reports non-firing hand values : Pb (1.3 - 4.0, Av. 2.4  $\mu\text{g}$ ), Sb (0.001 - 0.02, Av. 0.008  $\mu\text{g}$ ) as against GSR's: Pb (7.5 - 20.0, Av. 13.4  $\mu\text{g}$ ) and Sb (0.014 - 0.45, Av. 0.097  $\mu\text{g}$ ), presumably for *indoor* firing of 0.38 Revolver ammunition. In this context, hand washings were examined by us for presence of nitrite, after single shot firing of .32/.38/.455 revolvers and 12 bore country-made handgun when levels of the order,  $1.85 \pm 0.40$ ,  $2.14 \pm 0.98$ ,  $1.66 \pm 0.62$  and  $1.83 \pm .43 \mu\text{g NO}_2^-$  respectively were observed<sup>17</sup> as against the hand blank levels in Bombay population (high pollution levels) of the order of  $1.19 \pm 0.3 \mu\text{g NO}_2^-$ .

A study of GSR's around shotholes is useful in throwing light on the close distance of firing and at times on the nature of ammo used. In terrorist shootings of the victims in their cars, the GSR's taken on aqueous swabs with appropriate controls (car/reagent control) on neutron activation analysis (referred to *Bhabha Atomic Research Centre, Bombay*) showed significant GSR levels consistent with close range firing on the cars (Table III), plus identification of the alleged ammunition (18).

Table III. Gunshot residues on vehicles - NAA.

Sr. no.	Ammo	Swabs taken from	GSR's in $\mu\text{g}$		
			Barium	Copper	Antimony
1	9 mm pistol	Shothole car	19.6 (1.9 blank)	3.3 (1.04 blank)	0.97 (0.02 blank)
2	7.62 mm pistol	Car window frame	Negative *	2.4 (1.5 blank)	0.135 (0.03 blank)

\* Barium negative in the alleged ammunition too.

The use of scanning electron microscope with x-ray analytical facility, so also Atomic Absorption for GSR's has been reported to be useful. We have tried in this context laser probe microspectral analysis of GSR around the shotholes directly on the target material (19) (no sample preparation, wet ashing, reagent blank, etc.). A ten pulse

non-Q switched Nd<sup>3+</sup> glass laser probe in the case of 0.22 rifle/.38/.455 revolver shots, could detect Pb/Ba/Sb/Cu at various close distances as indicated in Table IV below:

Table IV. Laser probe around shotholes on cotton cloth.

GSR Detected *	0.22 rifle	0.38 Rev.	0.455 Rev.
	KF Amm.**		
Up to 8"		Pb/Ba	Sb
Up to 15"	Pb/Ba/Cu	Cu	Cu
Up to 3 ft	-	-	Pb
Not detected	Sb	Sb	Ba

\* 1 cm away from shothole. GSR roughly decreasing in intensity with increasing firing distance [ the GSR's detected by *x-ray fluorescence* have been reported as not reproducible (20) ].

\*\* *Kirkee Ammunition Factory.*

## CONCLUSION

It will be obvious from the above that the forensic ballistics as required to be practiced today, demands expertise not only in the areas of the conventional identification of firearms but far beyond, including the modern sophisticated analytical methodology. Forensic ballistics has graduated to a sophisticated multidisciplinary applied science in its own right.

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