Firing pin impressions: a valuable feature for determining the orientation of the weapon at the time of shooting

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Abstract

Sometimes the firearm forensic examiner is required to provide information useful to discriminate between suicide, homicide or accident, or between contradictory reconstructions of the events (like attempted murder versus accidental discharge). In such situations, knowledge of the position and orientation of the firearm at the time of firing can be of fundamental help for the reconstruction of events. To achieve these goals the analysis of the firing impressions is very important and this study elucidates the correlation between the characteristics of the firing pin impression and the spatial orientation (vertical upwards, horizontal or vertical downwards) of a revolver. The depth and morphology of the firing pin impression have been studied using both optical methods and surface topography analysis, showing that indeed from these data the orientation of the firearm at the time of shooting can be deduced.

Keywords

Ballistics; firearm identification; 3D profilometry; microscopy

Introduction

Forensic firearm identification is an application of forensic ballistics which is primarily concerned with identifying, by comparison with known reference samples suitably test-fired, whether fired ammunition components recovered from a crime scene have been fired from a specific suspect weapon. Other aims of this discipline are determining the number of firearms used in a shooting incident, or linking crime scenes together on the basis of fired ammunition components [1,2]. As such, this activity can be considered part of toolmarks examination [3]. Indeed, when ammunition is shot with a firearm, the interaction between the mechanical parts of the weapon and the bullet or the cartridge case create characteristic toolmarks called ballistic signatures, which can be divided into impressed and striated marks [1,2,4].

Impressed toolmarks are originated when the surface of a tool is compressed into an object: on the surface of that object, a negative image of the tool surface is originated. Striations are generated by a shearing stress exerted by the relative motion of the weapon mechanical parts and the ammunition. Usually the impressed and striated marks are produced by different mechanisms of the firearm, but sometimes a single device can produce both types of marks.

Among the many different kinds of markings left on ammunition, those left by the firing pin are particularly informative. The firing pin dents the primer cup, rapidly compressing against the anvil the primer mixture, causing its ignition. The indentation of the primer cup by the striker is the most important example of impressed toolmark in ballistics. The imperfections and the shape of the tip of the firing pin are transferred on the primer cup metal. Many types of firing pins exist, different by geometry and mechanism of action, thus yielding a particularly rich variability in the shape and morphology of the impressions left [1].

Firing pin impressions are particularly valuable to the firearm examiner for a number of reasons [5]. First of all, they are usually markings quite clear and rich in details. Primer cups are in fact manufactured with a rather soft material [6] because they must be deformable enough to expand easily, in order to provide an efficient gas tight seal, and also to allow the penetration of the striker, with a consequent ignition of the primer by compression against the anvil.

Opposite to the bullets, which are often deformed or contaminated by contact with bodies or objects encountered in their trajectory, cartridge cases are much less prone to deterioration and their markings are clearer. For some types of guns, for example revolvers, ejector and extractor signs are missing, so the only markings useful for identification are those on the primer cup and on the cartridge case bottom. The same is true for recharged ammunition, where the primer cup is the only element surely related to the weapon with which the last shot was fired, whereas extractor and ejector marks can be multiple, depending on how many times the shell had been used before.

Many factors influence the quantity and quality of the marks produced on ammunition during the firing process [2,7,8].

Weapon related factors are chamber pressure, the fouling and regularity of the breech face and the morphological and structural features of the mechanical elements. Ammunition related features are the materials used for bullet and cartridge case, and the type and amount of propellant.

In particular, several factors have a role on determining the size and depth of firing pin impressions [9]. Obviously, penetration depth depends on the shape of the firing pin. Then, a too tight fitting of the cartridge in the chamber, due to their relative sizes or to rough or dirty surfaces, may hold the cartridge case in a fixed position, hindering the rearward and the expansion movements normally associated to normal functioning. Fitting of the primer cup is also an important variable, because it may influence the relative position and motion of firing pin and primer cup. Firearm position has also been advocated to be influential, because a muzzle up firing position is expected to force the cartridge against the breech face, whereas a muzzle down orientation should move it farther from the breech face, yielding deeper and shallower firing pin indentations, respectively [9].

Shooting factors have a role as well. This has already been studied by other authors, given the possible importance during the investigations, for example to discriminate between homicide, suicide or accident. Ojena and Murdock [10] reported the examination of a Winchester level action rifle to determine if it was fired from a half-cock or from a normal position. They observed that the impression was less deep than normal, when the weapon was in half-cock position. Haag [11] demonstrated that the depth of the firing pin impression was deeper than normal in the case of “drop-fire” events and of a weapon which suffered a blow, e.g. because it was dropped after firing, confirming previous reports [9]. However, this just tells the examiner that something out of the ordinary occurred. Only an observation of the morphology of the markings allows to distinguish between these two events [11].

In this work, the morphology and topography of firing pin indentations were studied in order to single out the effect of the weapon orientation on the markings of the primer cup. Bolton-King and coworkers were among the first to recognize the potential of 3D profiling systems applied to firearms and toolmark identification [12].

One of the objectives of the present work was assessing how a quantitative approach to the description of such features could help identifying a correlation with the orientation of the weapon, yielding precious information about the dynamics of a shooting.

Another objective of this study was to investigate the reason why a different orientation of the weapon should reflect on the extent of the markings produced thereof. With such aim, the pressure exerted by the propellant and the velocity of the bullet when the weapon is directed in different shooting positions was measured and correlated with the depth of the firing pin impression.

Materials and methods

Ammunition and weapons

The ammunition used in this study was produced by Fiocchi: Type TCCP, 357 Mag caliber, lot no. 5904005-005, with a 158 grs bullet.

Given the relevance on the extent and morphology of indentation of features like the thickness, the composition and the hardness of the head of the shell [1], the consistency of such variables among the ammunition was accurately maintained by manufacturing ad hoc a lot with very strict specifics (Table S1 in the supporting information). Ammunitions were verified to check that primers were fitting well and their extrusion was regular.

Three revolvers were used for firing tests, all of them were .357 Magnum caliber, with hemispherical shape of the firing pin and 6 inches barrel.

Weapons 1 and 2 were Smith & Wesson 686-3 models, with hammer pin. Weapon 1 had an extrusion of the firing pin of 940 μm and a long history of shots in its life (70,000). Weapon 2 had an extrusion of 1290 μm and a lower number of shots (20,000). Weapon 3 was a Taurus model 669, with flying firing pin (extrusion of 1540 μm) and a medium history of shots (45,000). Therefore, the firing pin design (hemispherical) was the same for the different weapons, while the extrusion of the firing pin from the breech face and the mechanism of action of the striker ranged. The extrusion of the firing pin from the breech face was measured with a manual tool (Firing Pin Gauge, Brownells, USA).

Firing tests

Shots were all fired in single action, from the same cylinder chamber of the various revolvers, orienting the weapon in three different directions: horizontal, vertical directed upwards and vertical directed downwards. Ten shots were fired for each orientation with each weapon for a total of 90 shots. Bullets were fired in a swinging barrel, containing clean and untreated cotton batting, in a setting specifically designed to allow a safe implementation of the tests, especially in the upwards orientation, where it is not possible to predict the bullet trajectory. Cartridge cases were collected after each firing session, and they were identified according to the weapon number (1, 2 or 3) and the orientation (U = upwards, D = downwards, H = horizontal).

Bullet speeds were measured with a Magnetospeed chronograph, mounted on the barrels of the weapons. The pressure was measured with piezoelectric transducers (Kistler 6203 High Pressure Quartz Pressure Sensor s/n 5252762) coupled with an instrumented barrel mounted on ballistic breech (s/n ACL0943).

Optical and topographical analysis

Both fired and non-fired ammunition was examined optically and topographically.

Non-fired cartridges were preliminary observed with a Leica A60 stereomicroscope to identify possible sub class characteristics. The micro-characterization on the surface of the primer cap, imparted by the firing pin, and the surface of breech face were optically examined, focusing attention on the firing pin hole mark**.** In this way, the repetitive impressions were identified by position and shape and then identified as individual characteristics of a weapon.

Topographic analysis of the primer cup was performed on all cartridge cases before the shooting tests, to identify any anomalies in morphology and specifically significant protrusions from the shell body of the primer cup and/or evidence of anomalies in its fitting. It is in fact known that a loose-fitting primer cup can move to the rear and bring about a modification in firing pin indentation depth [9].

Measurement of the depth of the firing pin indentation

The topographic analyses were carried out a with a motorized comparator microscope Leica FS C equipped with the Leica Map software which is based on the Mountains Technology® algorithms for the characterization of the surface geometry and the extrapolation of the profiles of the firing pin impressions (Figure 1). Topographic analyses allowed also to quantify the depth of the impression and the degree of flattening of the primer cup, and to quantitatively describe its morphology, according to the ISO 5436-1:2000 standard.

Since the irregular shape of the impression may produce shadows or obstacles to the optical sensors of the topographic module, each sample was examined according to the following protocol:

1. after a preliminary observation of the firing pin impression and of its edge, a reference point was identified on the edge of the primer cup;
2. from such reference point, a diameter of the primer cup was traced and the correspondent topographical profile was extracted;
3. the sample was rotated clockwise by 90° and another profile, perpendicular to the one previously acquired, was extracted;
4. the sample was rotated 90° clockwise and the same profile as that of point 2 was acquired;
5. the sample was rotated 90° clockwise and the same profile as that of point 3 was acquired.

This procedure, which was repeated twice for each sample, allowed to get rid of the illumination effect on the topographical measurements.

At the end of these operations, an average value was obtained for each fired cartridge case.

Statistical analyses were carried out with the Statgraphics Centurion XVI software (Statpoint Technologies, USA).

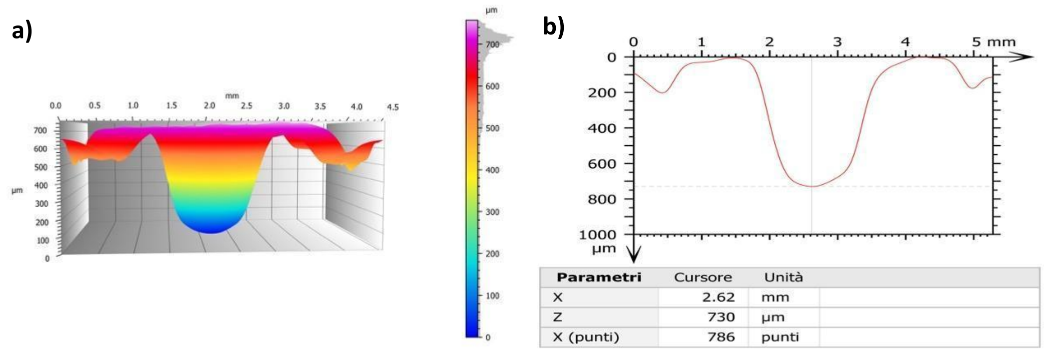

Figure 1. a) Example of a) a topographic profile measured for a cartridge primer surface, fired with weapon 2. b) 2D contour profile extracted from a).

Results and discussion

Individual characteristics, which are key to identify a specific weapon, are micro-traces present within the macroscopic impressions (class characteristics) of bullets and cartridge cases [2]. They are marks produced mainly by the random and unique microasperities present in the weapon mechanisms, which are themselves produced during manufacturing or shaped by use, corrosion or damage [13].

Due to the lack of the extractor and ejector in revolvers, the analysis of the firing pin impression and of the breech face impressions are the only sources of information left on the cartridge cases of ammunition fired by this type of weapons.

The three revolvers used for this study all have both the firing pin and the breech plane rich in morphological features, in particular the firing pin hole, i.e. the opening in the breech face through which the firing pin protrudes [13].

For example, Figure 2 shows the breech block of weapon 2, where some characteristic features of the firing pin can be clearly seen, notably the patterned edge (pink arrow) and some morphological defects (red arrows).

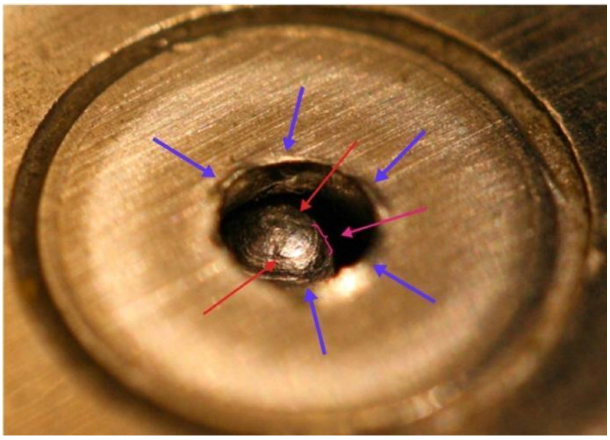

Figure 2. Micrograph of the breech face of weapon 2. Blue arrows show the firing pin hole, the pink arrow shows the patterned edge of the firing pin and red arrows indicate morphological defects of the firing pin.

A detailed morphological analysis of the firing pin impressions left on the cartridge cases by weapon 2, oriented in different directions is shown in figures 3 and 4. As may be seen, the individual characteristics identified by the red arrows are visible; they are more marked for the upward shots than for downward or horizontal shots. However, the concentric rings pattern, due to the feature highligthed in pink in Figure 2, becomes undetectable in the cartridges shot with the weapon oriented downwards, while remaining clear in the rounds shot horizontally or upwards.

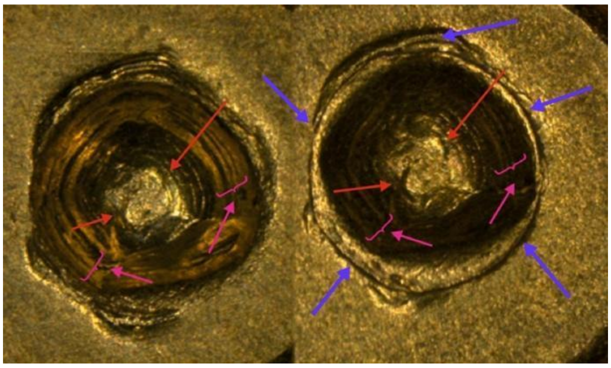

Figure 3. Comparison of firing pin impressions by weapon 2 oriented horizontally (left) and upwards (right). The blue arrows show the firing pin hole marks, red arrows and pink arrows indicate the marks left by the corresponding features shown in Figure 2.

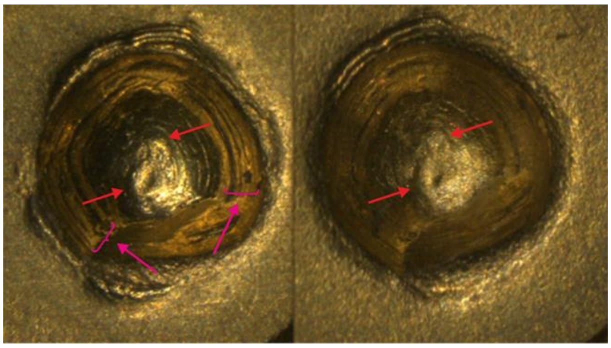

Figure 4. Comparison of firing pin impressions by weapon 2 oriented horizontally (left) and downwards (right). Red arrows and pink arrows indicate the marks left by the corresponding features shown in Figure 2

Another morphological feature that varies critically with the orientation of the gun are firing pin hole marks, i.e. toolmarks originated by the rearward flow of primer cup metal into the firing pin hole [14]. In Figs 5 and 6, it can be appreciated how the sharp edges of the firing pin hole marks are clearly visible only in the cartridge cases shot upwards.

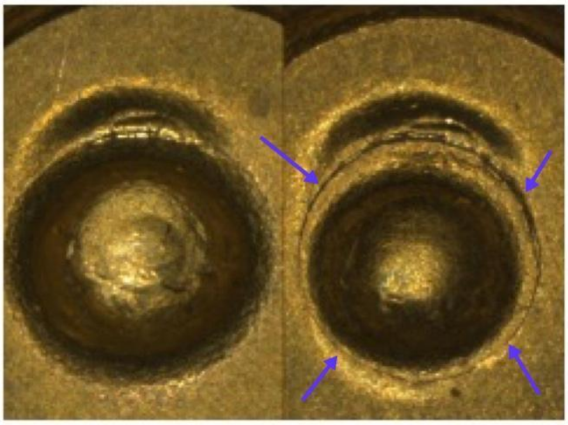

Figure 5. Comparison of firing pin impressions by weapon 1 oriented horizontally (left) and upwards (right). The blue arrows show the firing pin hole impressions.

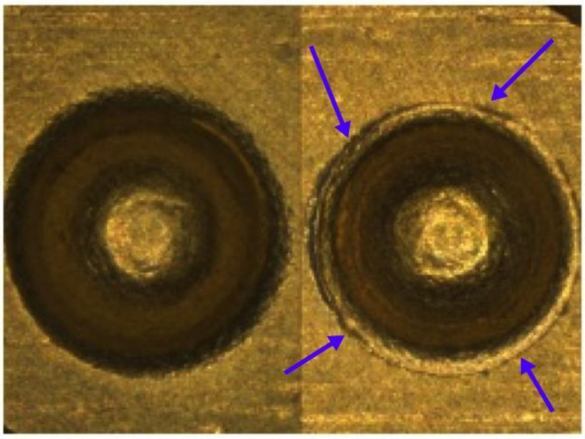

Figure 6. Comparison of firing pin impressions by weapon 3 oriented horizontally (left) and upwards (right). The blue arrows show the firing pin hole impressions.

Such sharpness in firing pin hole marks in the upwards shots is recurrent in the 3 weapons used in this study (Figs 5 and 6, and S1, S2 and S3 in the supporting information).

The optical comparison highlighted the different morphology of the primer capsule around the percussion impression.

Among the authors in the field of firearm examination, Burrard is the one who discussed in the greatest detail the effect of pressure on the tool markings on the primer cup. The pressure generated in a cartridge case causes an expansion not only of the sides of the case, but also of the base back, which is driven against the breech face of the weapon. This brings about a flattening of the base of the primer cup [8]. Such observation, which in the literature is reported in qualitative terms, can be quantified by an optical and topographical approach. Figure 7 shows how the flattening of the cup is lighter at the edges of the percussion impression, and the recess of the attacker more rounded, for the cartridge cases obtained by shooting downwards, compared to the ones shot horizontally.

The cartridge cases of ammunition shot upwards show a more pronounced flattening and a sharper indentation. These optical differences are difficult to appreciate visually, and therefore they are hard to transmit to a Judge or to a Jury. For this reason, the differences have been quantified topographically (Figure 8).

As may be seen, the profile of the edge of the primer cup for the ammunition shot upwards is much flatter than those recorded in the cases of horizontal or downwards shots. Moreover, the descent into the firing pin impression is very steep and abrupt for the upward shots, and shallow and gradual in the other two sets of tests.

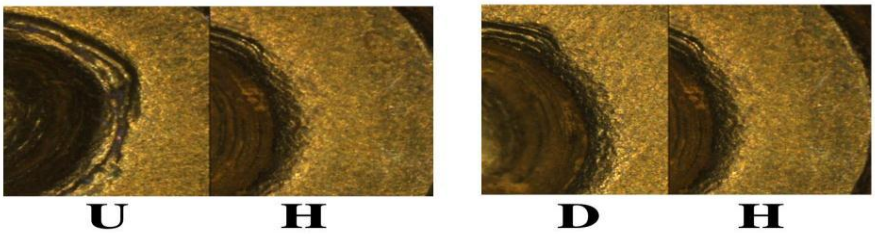

Figure 7. (left) optical comparison between the degree of flattening of ammunition fired upward and horizontally; (right) optical comparison between the degree of flattening of ammunition fired downward and horizontally.

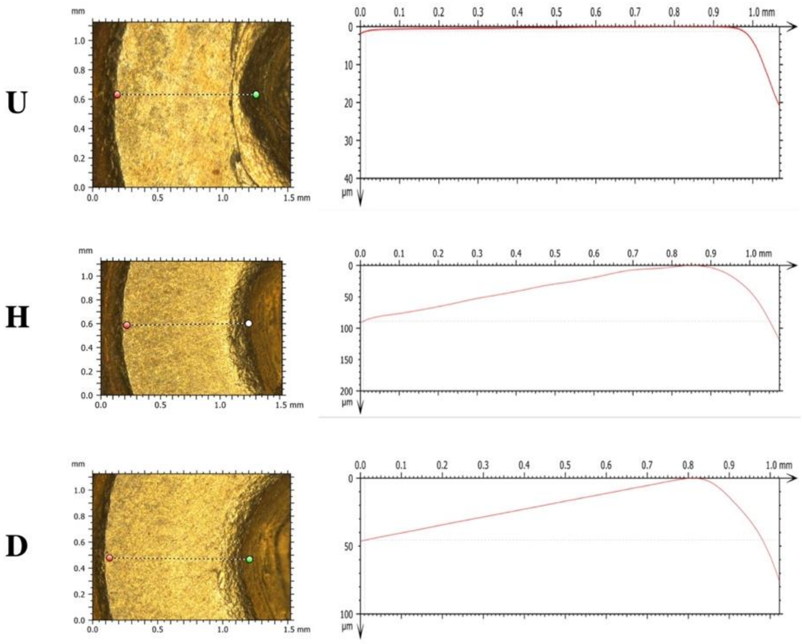

Figure 8. Optical images (left) and topographical profile (right) of the primer capsules around the firing pin impressions, shot in different positions (from top to bottom: upwards, horizontally, downwards).

Depth of firing pin impression

Figure 9 shows an example where the irregularities of the apical part of the firing pin impression, produced by various factors, are particularly pronounced. This requires a careful evaluation to avoid to jeopardize the correct measurement of the depth. In fact, as shown in the graphs of figure 10, the depth value can undergo variations even greater than 100 microns in nearby locations. This is the reason why a complex measurement protocol was used, as explained in the Materials and Methods section, which combines 8 measurements for each firing pin impression to find its depth.

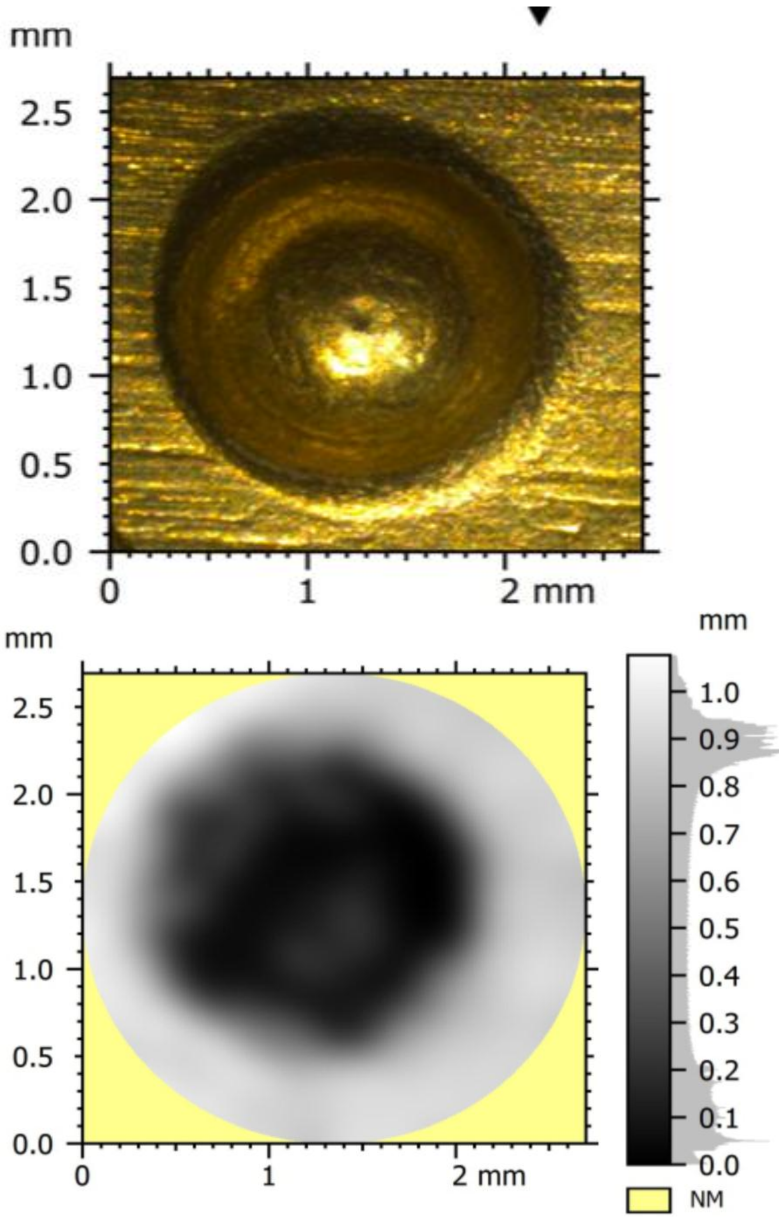

Figure 9. a) firing pin impression on a cartridge fired with weapon 3 kept horizontally, with irregularities in the apical part. b) topographical surface of the area a).

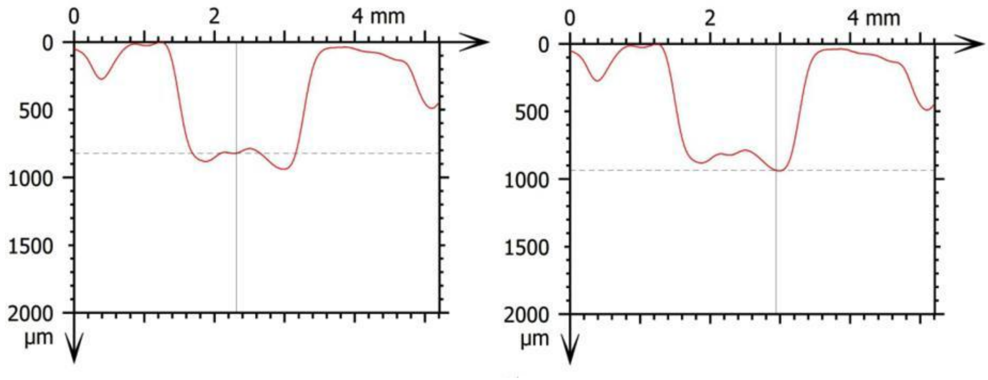

Figure 10. Topographic profiles of the depth of the firing pin impression of figure 9. The two images show how, taking the depth measurement in different but nearby locations, significantly different values are obtained.

It's important to notice that the firing pin impression depths are always smaller than firing pin extrusion lengths. This is caused, in the horizontal position, primarily by the space between the bottom of the cartridge case and the breech face.

The measurements of the craters for the three different weapons, each fired in the three different positions (D, H and L) are summarised in Table 1.

For each weapon, the depth values detected for different orientations were significantly different, as evidenced by several statistic tests, such as the Student t test, the Kruskal Wallis test and the Mood test, all yielding p-values smaller than 10^{-5}. This means that is possible to establish, starting from a cartridge case found on a crime scene and carrying out suitable tests with the same ammunition, if a certain shot was fired pointing the weapon upwards, downwards or horizontally. This is of invaluable utility for the reconstruction of certain types of crime dynamics.

Table 1. Depth of the crater (in µm) left on the primer cup by the firing pin. Values are the average, with the corresponding standard deviation, from 10 replicates.

	Orientation		
Weapon	Upwards	Horizontal	Downwards
1	762 ± 45	676 ± 27	545 ± 27
2	999 ± 33	778 ± 51	627 ± 34
3	1268 ± 33	1132 ± 60	941 ± 22

In the supporting information are reported, for the three weapons and the three shooting positions, the complete series of firing pin impression depths and their statistical distributions, from which it can be deduced the possibility of discriminating, for each weapon, the different firing positions.

Correlation between depth of crater and speed of the bullet

The correlation between the depth of the firing pin impression and the velocity of the bullets was investigated to elucidate that the difference in depth was not caused only by the action of gravity on ammunition weight, and by geometric issues related to how the striker hit the primer cap, but also by more complex causes related to internal ballistics.

Table 2 reports the velocities of the bullets fired by the different weapons in the different positions.

Table 2. Muzzle velocity of the bullet (in m/s) measured by Magnetospeed

	Orientation		
Weapon	Upwards	Horizontal	Downwards
1	376 ± 3	339 ± 9	325 ± 5
2	378 ± 7	355 ± 13	329 ± 2
3	351 ± 5	335 ± 5	300 ± 6

Figure 11 shows that for every weapon there is a correlation between the depth of the craters (in μm in the figures) and the speed of the bullets (in m/s). As the speed of the bullet increases, the firing pin indentation becomes deeper. For weapons 2 and 3 the correlation coefficient values (R = 0.990 and 0.993, respectively) reflect a linear relationship between these variables. The linearity for the data points in weapon 1 is less evident (R = 0.93).

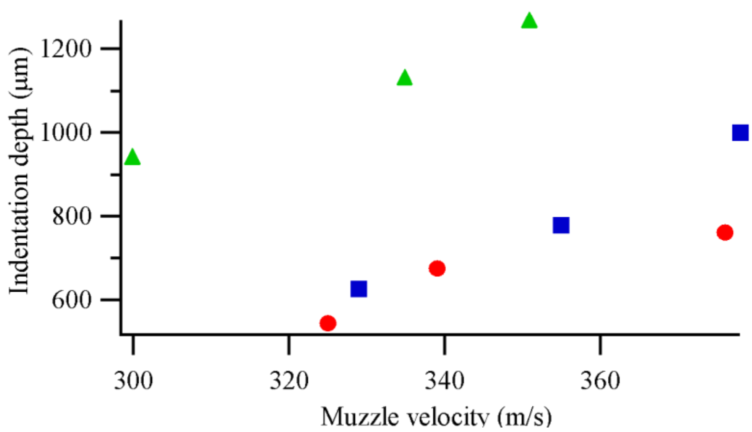

Figure 11. Indentation depth as a function of muzzle velocity. Circles: weapon 1, squares: weapon 2, triangles: weapon 3.

Correlation between position of shooting and internal pressure

The changes in crater depth and bullet speed as a function of the orientation of the weapon can be explained in terms of internal pressure [5,8]. To simulate shooting in different positions, ammunition was specifically manufactured with the exact features of those used in the rest of the study, but pressing gunpowder toward the bullet (to simulate shooting downward) or toward the cartridge case (to simulate shooting upward). As a reference, normal CIP ammunitions were used. Table 3 confirms the correlation between pressure and "orientation" of the weapon.

Table 3. Pressure and velocity at the muzzle measured by a pressure gauge barrel

Orientation	Pressure (bar)	Muzzle velocity (m/s)
Upwards	2122 ± 175	380 ± 8
Horizontal	1905 ± 230	374 ± 8
Downwards	1319 ± 98	350 ± 8

Due to the general direct correlation between pressure and bullet velocity (Figure S7 in the supporting information shows such correlation in the present case), this result has a significant practical importance. Bullet speed can be considered as a proxy for pressure, which is quite complex to experimentally measure. The results presented in this report, in fact, are strictly valid for the weapons and ammunition used. In casework, a similar study should be performed, using the suspect weapon and ammunition as similar as possible to that used for the shooting being investigated. Firing pin indentation and muzzle velocity can be straightforwardly quantified in such simulations, verifying their mutual correlation and their relationship with the orientation of the weapon.

Conclusions

This work has shown that, using optical analysis to examine the morphology of individual characteristics, studying the degree of flattening of the primer capsules around the percussion impressions, and measuring firing pin impression depths with the use of topography is a suitable protocol to understand if a shot by a revolver was fired holding the weapon upwards, downwards or horizontally.

This can be of critical importance for a Judge or a Jury for reconstructing the events with a suitable amount of details. The main instance when this information can be useful is when the relative positions of the shooter and the victim must be elucidated, which is often the case when legitimate self defense is challenged. Other examples include distinguishing between real and staged suicides and deciphering particularly complex crime scenes.

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Supporting information

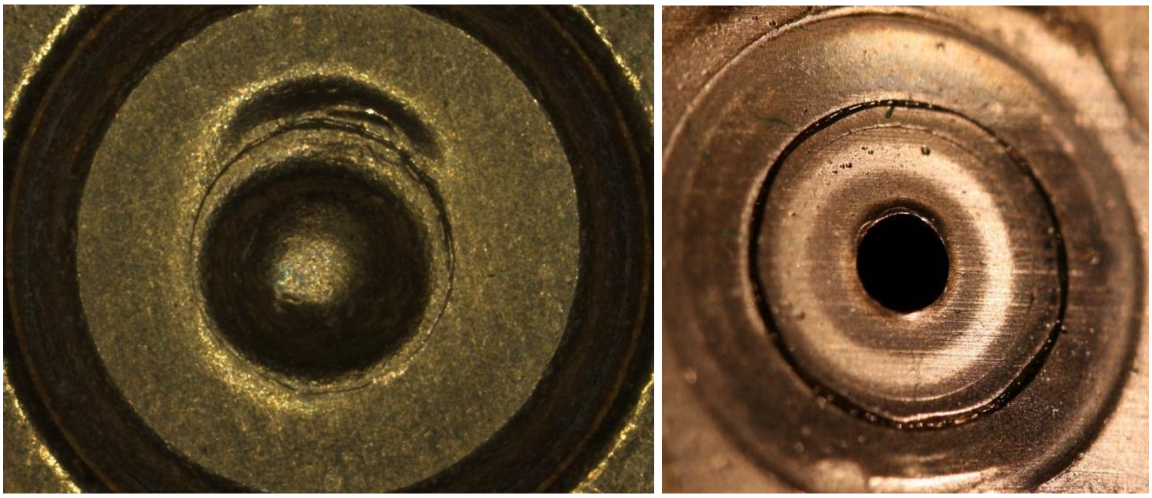

Figure S1. Primer shearing marks on the firing pin indentation (left column) and breech face (right) for weapons 1.

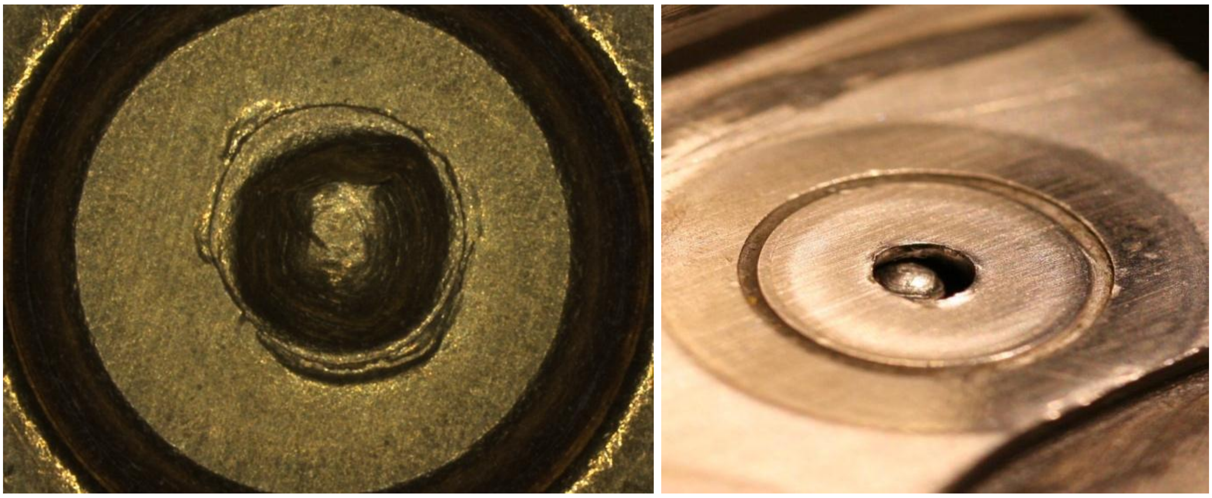

Figure S2. Primer shearing marks on the firing pin indentation (left column) and breech face (right) for weapons 2.

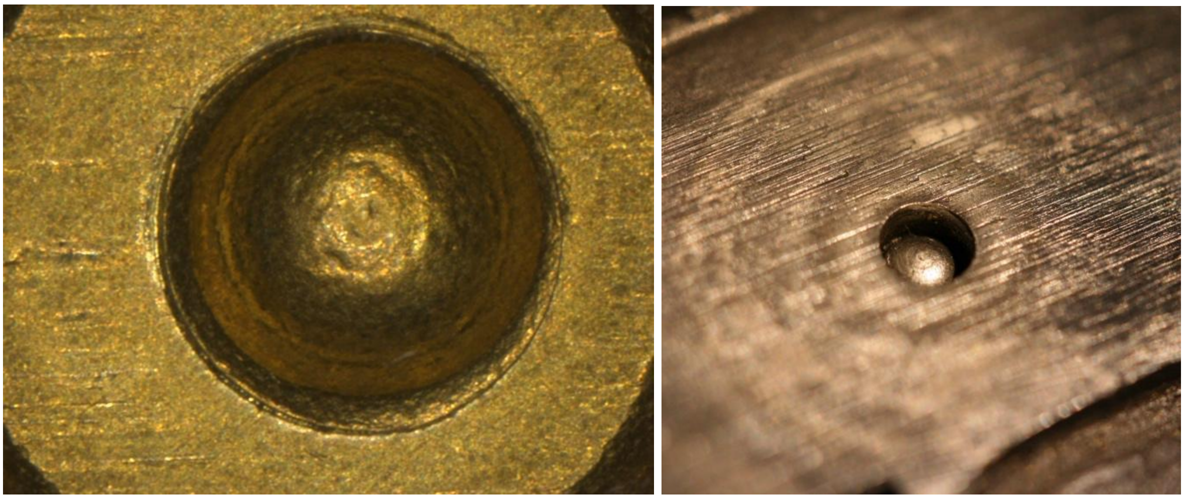

Figure S3. Primer shearing marks on the firing pin indentation (left column) and breech face (right) for weapons 3.

Table T1. Complete series of firing pin impressions depth, weapon 1 (in µm)

H	U	D
692	798	556
706	725	603
664	743	563
705	841	524
625	696	519
677	749	534
680	761	550
692	803	551
639	715	547
680	789	506

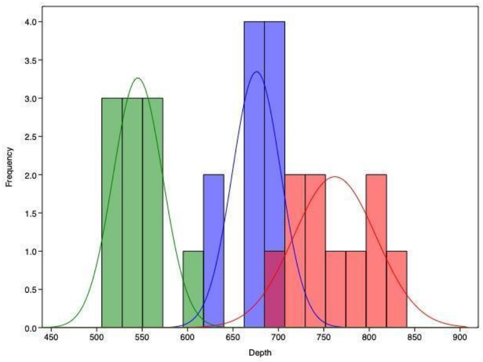

Figure S4. Statistical distribution of weapon 1 firing pin impression depths (green: downward - blue: horizontal - red: upward)

Table T2. Complete series of firing pin impressions depth, weapon 2 (in µm)

H	**U**	**D**
716	1045	652
768	983	625
809	960	599
780	1009	657
702	983	582
786	945	571
857	983	656
807	1027	665
831	1026	613
730	1031	649

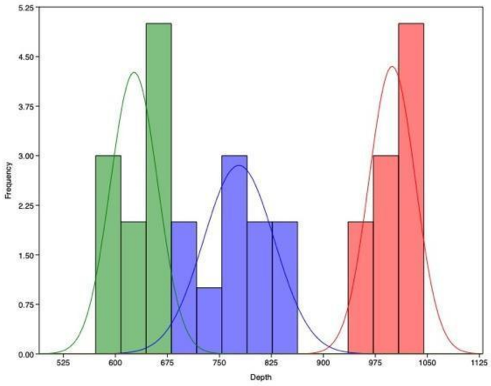

Figure S5. Statistical distribution of weapon 2 firing pin impression depths (green: downward - blue: horizontal - red: upward)

Table T3. Complete series of firing pin impressions depth, weapon 3 (in µm)

H	**U**	**D**
1287	1280	978
1087	1260	929
1071	1297	932
1112	1232	945
1102	1228	955
1132	1238	936
1132	1250	961
1115	1270	953
1163	1331	908
1118	1292	908

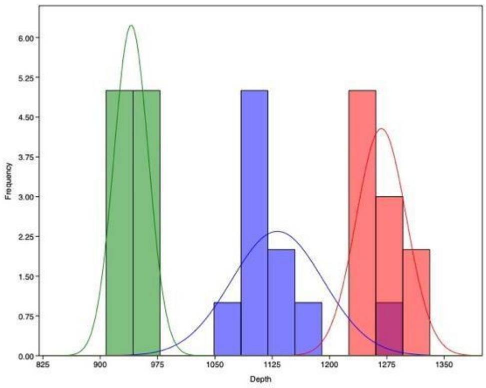

Figure S6. Statistical distribution of weapon 3 firing pin impression depths (green: downward - blue: horizontal - red: upward)

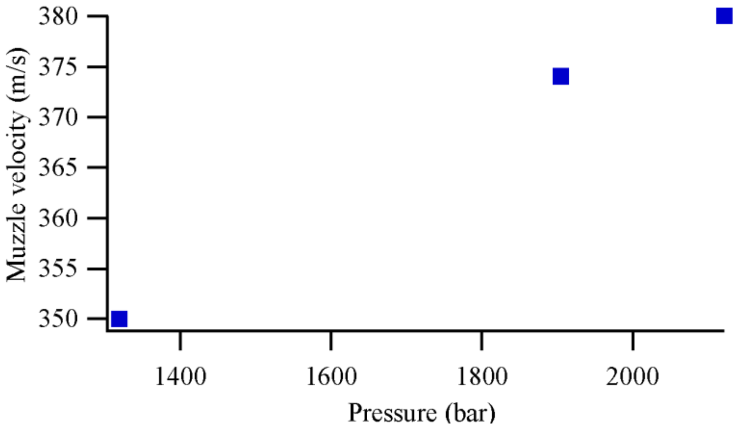

Figure S7. Muzzle velocity as a function of pressure, measured by a pressure gauge barrel.