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Research Paper

Anatomical distribution and autopsy features of gunshot injuries to support the manner of death

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ABSTRACT

The autopsy features of gunshot wounds can be useful in understanding the manner of death. This research aims to provide concrete data to help to discriminate between homicide and suicide based on specific autopsy findings.

A search of the database of the Cook County Medical Examiner's Office from August 2014 through April 2019 identified 3491 deaths due to gunshot wounds. Deaths due to complication from delayed fatal gunshot wounds, subjects who received hospital care prior to death, and decomposed bodies were identified and excluded. The following data were recorded: manner of death, demographic data, firearm and bullet type, number and location of gunshot wounds, range of fire, toxicology, and additional injuries. The study primary focused on the analysis of the bullet trajectory. A course leftward-upward-backward was the most frequent observed trajectory in suicides; a course rightward-upward-frontward was the most frequent observed trajectory in homicides.

When the internal trajectory of a bullet is interpreted in the light of all available evidence it can impeach or corroborate witness statements and highlight consistencies as well inconsistencies in investigative reports and scene examinations.

1. Introduction

Firearm-related deaths are a common cause of fatalities worldwide. Careful evaluation of the pathologic/autopsy findings, in conjunction with the investigative report, relevant medical history, and other ancillary studies is mandatory for an accurate determination of manner of death.

Examining features such as the location of the entrance wound, range of fire, and wound course did not assist in discriminating/differentiating between suicidal and homicidal gunshot wounds.

A careful evaluation of all the available evidence is needed when investigating gunshot-related deaths. In particular, scene investigation and investigative findings are usually essential to accurately determine the manner of death. In the same way, the autopsy features of gunshot wounds can be useful in interpreting the circumstances of death and supporting an association between a specific injury and the manner of death. In rare instances, however, the manner of death can be uncertain due to insufficient investigative data. In these cases, the role of the autopsy is crucial.

The typical features of gunshot wounds have been extensively reported in the forensic literature in numerous case series, especially between 1980 and 2000.[1–6] While the classic morphological findings of gunshot wounds are primarily useful in distinguishing between entrance and exit wounds,[7] features such as the location of the wound, the range of fire and the trajectory of the bullet can help differentiate a self-inflicted injury from a non-self-inflicted one.[8]

This study will illustrate distinct differences between suicidal and homicidal wounds that should be considered while investigating gunshot-wounds related deaths.

2. Material and methods

The files of the Cook County Medical Examiner's Office (Chicago - IL) were searched for deaths due to gunshot wounds between August 2014

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and April 2019. Only those cases in which gunshot wounds were the primary immediate cause of death were included in the study. Decedents between the ages of 0 and 99 years were included in this study. Deaths due to complications from delayed fatal gunshot wounds were excluded. No other limits were imposed.

The investigative, autopsy, and toxicological reports were reviewed in each case. The data obtained were then divided into two groups: deaths due to single gunshot wound (SGSW), and deaths due to multiple gunshot wounds (MGSW), meaning >1 gunshot wound. Both groups were subsequently subcategorized as to the manner of death (suicide, homicide, accident, or undetermined). Every manner of death determination was confirmed based on objective findings such as: suicide notes, previous attempts, suicidal ideation, etc., for suicides; witness statements, range of fire, investigations, scene findings, etc., for homicides.

The following data were collected in a Microsoft Excel® spreadsheet: manner of death, gender, race and age, firearms, and bullet type (if available), number and sites of entrance and exit wounds, range of fire, trajectory of the bullet path, positive blood levels for drugs and alcohol, and additional relevant injuries (meaning injuries not directly related to the bullet activity).

The trajectory of the bullet path was reconstructed according to the anatomic planes of the body (Fig. 1):

- A) *Sagittal plane*: leftward (L), rightward (R), or without left or right deviation (/);
- B) *Transverse plane*: downward (D), upward (U), or without downward or upward deviation (/);
- C) *Coronal plane*: backward (B), frontward (F), or without backward or frontward deviation (/).

The bullet trajectories were recorded from the autopsy report and checked against the autopsy photographs. In each case, three directions were recorded (one for each anatomic plane), and the final data were combined, obtaining a total of 26 possible bullet trajectories (Table 1).

Range of fire was classified based on the examination of the skin/clothes surrounding the gunshot wound of entrance/body surface. Wounds were classified as:

- *contact-range* if there was a muzzle imprint, soot surrounding the skin/clothes or involving the underlying bone, stellate appearance to the wound, and or thermal change on the skin about the gunshot wound of entrance. Contact wounds included both *hard contact*, *loose contact* and *near contact* (close) *wounds* (Fig. 2A–B).
- *intermediate-range* when stippling was present (Fig. 2C).
- *indeterminate-range* when there was no soot or stippling present on the skin surrounding the entrance wound (Fig. 2 D).

Finally, the data collected from the autopsy reports were used to create a graphic reconstruction of the anatomical distribution of the gunshot wounds on the body surface for each manner of death.

2.1. Statistical analyses

Frequencies and percentages were used to describe the demographic and wound characteristics of the subjects, as well as the anatomical plane and trajectory characteristics of the bullet pathway. Comparisons between the suicide and homicide groups were made using Chi-square tests and Fisher's Exact tests, as appropriate. Binary logistic regression with indicator variables was used to estimate odds ratios for the associations between the individual trajectories and manner of death. Statistical significance was defined as $p < 0.05$. All statistical analyses were conducted using SAS® version 9.4. Statistical analyses results are reported in Tables 4–9.

3. Results

A total of 3491 deaths due to gunshot wounds were identified. After the first round of review, deaths due to complication from delayed fatal gunshot wounds, subjects who received hospital care prior to death, and decomposed bodies were excluded. The remaining 3214 cases have been classified as deaths due to MGSW (n = 1702) and deaths due to SGSW (n = 1512). The groups were then subcategorized as to the manner of death. The results showed: MGSW homicides (n = 1688) and suicides (n = 14); SGWS homicides (n = 873), suicides (n = 614), accidents (n = 4), and undetermined (n = 21). (Table 2).

After initial review, only 14 cases of the 1702 MGSW cases were found to be suicides. Accordingly, the number of suicides in the MGSW group was considered too small compared to the MGSW homicides to permit a reliable comparison. Therefore, only the SGSW group was investigated for a potential association between specific gunshot wound autopsy features and the manner of death.

Similarly, although drug and alcohol level may be very useful in a particular case, we did not find a significant enough distinction in these

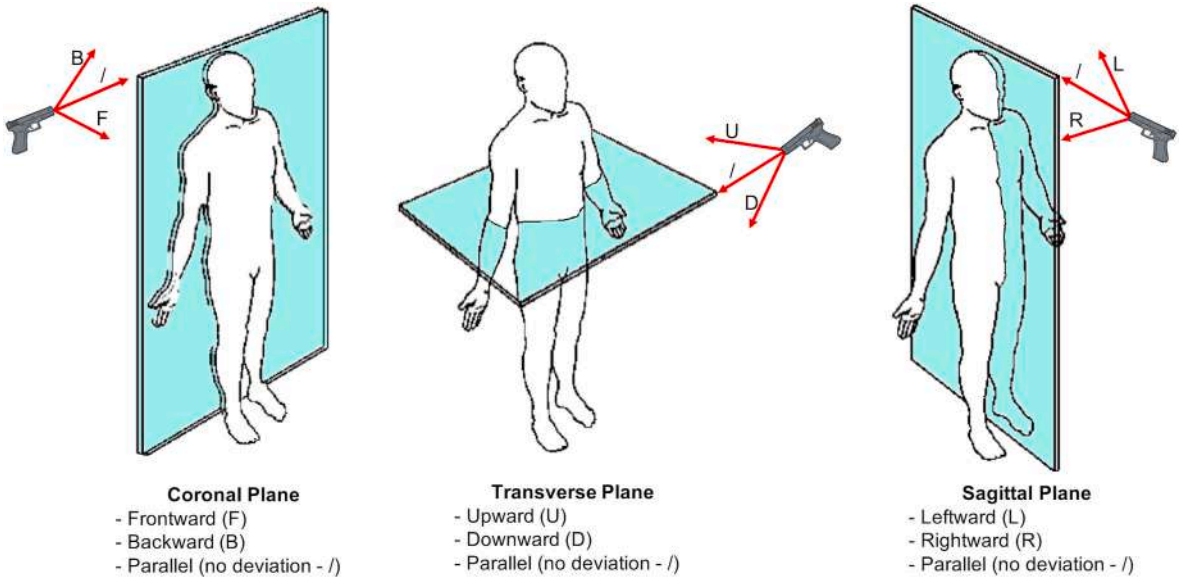

Fig. 1. Bullet trajectories according to the anatomic planes of the body.

Table 1
Possible bullet trajectories according to the autopsy data.

Anatomic planes			Description
Sagittal	Transverse	Coronal	
L	D	B	Leftward – downward – backward
L	D	F	Leftward – downward – frontward
L	D	/	Leftward – downward – without backward/ frontward deviation
L	U	B	Leftward – upward – backward
L	U	F	Leftward – upward – frontward
L	U	/	Leftward – upward – without backward/ frontward deviation
L	/	B	Leftward – without downward/upward deviation – backward
L	/	F	Leftward – without downward/upward deviation – frontward
L	/	/	Leftward – without downward/upward deviation – without backward/frontward deviation
R	D	B	Rightward – downward – backward
R	D	F	Rightward – downward – frontward
R	D	/	Rightward – downward – without backward/ frontward deviation
R	U	B	Rightward – upward – backward
R	U	F	Rightward – upward – frontward
R	U	/	Rightward – upward – without backward/ frontward deviation
R	/	B	Rightward – without downward/upward deviation – backward
R	/	F	Rightward – without downward/upward deviation – frontward
R	/	/	Rightward – without downward/upward deviation – without backward/frontward deviation
/	D	B	Without leftward/rightward deviation – downward – backward
/	D	F	Without leftward/rightward deviation – downward – frontward
/	D	/	Without leftward/rightward deviation – downward – without backward/frontward deviation
/	U	B	Without leftward/rightward deviation – upward – backward
/	U	F	Without leftward/rightward deviation – upward – frontward
/	U	/	Without leftward/rightward deviation – upward – without backward/frontward deviation
/	/	B	Without leftward/rightward deviation – without downward/upward deviation – backward
/	/	F	Without leftward/rightward deviation – without downward/upward deviation – frontward

levels between homicides and suicides to establish a reliable marker as to manner of death.

4. Deaths due to single gunshot wound (SGSW)

4.1. Demographics

Among the 1512 subjects of the SGSW group, the ages ranged from 0 to 96 years. Males accounted for 91% while females for 9%. A summary of the demographic data is reported in Table 3.

4.2. Weapons and calibers

Information regarding weapons and calibers was reported only in <10% of cases of homicide, where generic terms such as “handgun” or “unknown handgun” were used.

In suicide cases, the type of weapon was frequently described (90% of the cases) as well as the caliber (71%). The most commonly used weapons were: pistols (59% - semi-automatic, derringer), revolvers (39%), rifles (2%), others (<1% - assault pistol, flare gun, etc.). The 0.38 caliber was the most common caliber used, followed by 9 mm, 0.357 magnum, 0.45, 0.22, 0.380, and others.

Anatomic distribution of gunshot wounds: suicide group (n = 614, Fig. 3).

The *head* (including *face*) was involved in 547 cases (89.1%): right temporal (n = 256, 46.8%); intraoral (n = 117, 21.4%); right parietal (n = 56, 10.2%); right frontal (n = 25, 4.6%); chin (n = 21, 3.8%); left temporal (n = 20, 3.7%); midline forehead (n = 17, 3.1%); left frontal (n = 9, 1.6%); right ear (n = 7, 1.3%); left parietal (n = 5, 0,9%); right upper face (n = 5, 0.9%); right occipital (n = 4 0.7%); vertex (n = 2, 0.4%); left upper face (n = 1, 0.2%); midline face (n = 1, 0.2%); left ear (n = 1, 0.2%).

The *chest* was involved in 47 cases (7.6%): left upper chest (n = 36, 76.6%); midline anterior (n = 5, 10.6%); right upper (n = 4, 8.5%); left lower (n = 2, 4.3%).

The *neck* was involved in 16 cases (2.6%): right anterior (n = 6, 37.5%); midline anterior (n = 6, 37.5%); left anterior (n = 3, 18.7%); right posterior (n = 1, 6.3%).

The *abdomen* was involved in 4 cases (0.6%): epigastrium (n = 2, 50%); right upper quadrant (n = 1, 25%); left upper quadrant (n = 1, 25%).

The *back*, and *upper* and *lower* extremities were not involved.

Anatomic distribution of gunshot wounds: homicide group (n = 873, Figs. 4–6).

The *head* (including *face*) was involved in 334 cases (38.3%): left parietal (n = 40, 11.9%); left occipital (n = 36, 10.8%); right temporal (n = 35, 10.5%); left frontal (n = 32, 9.6%); right occipital (n = 29, 8.7%); right parietal (n = 28, 8.4%); left temporal (n = 28, 8.4%); right frontal (n = 27, 8.0%); right upper face (n = 21, 6.3%); left upper face (n = 12, 3.6%); left ear (n = 11, 3.3%); right ear (n = 10, 3.0%); right lower face (n = 7, 2.1%); left lower face (n = 7, 2.1%); midline anterior face (n = 4, 1.2%); mouth (n = 3, 0.9%); chin (n = 2, 0.6%); midline forehead (n = 1, 0.3%); midline posterior head (n = 1, 0.3%).

The *chest* was involved in 194 cases (22.2%): left upper chest (n = 74, 38.1%); right upper chest (n = 52, 26.8%); left lateral chest (n = 27, 13.9%); right lateral chest (n = 17; 8.8%); left lower chest (n = 12; 6.2%); right lower chest (n = 7; 3.6%); midline anterior chest (n = 5; 2.6%).

The *back* was involved in 175 cases (20.0%): left upper back (n = 52, 29.7%); left lower back (n = 50, 28.6%); l right upper back (n = 42, 24.0%); right lower back (n = 30, 17.1%); midline back (n = 1, 0.6%).

The *abdomen* was involved in 69 cases (7.9%): left flank (n = 14; 20.2%); right upper quadrant (n = 11; 16.0%); right lower quadrant (n = 10, 14.5%); left upper quadrant (n = 10; 14.5%); left lower quadrant (n = 10; 14.5%); right flank (n = 8; 11.6%); periumbilical area (n = 4; 5.8%), epigastrium (n = 2,9%).

The *neck* was involved in 43 cases (4.9%): left anterior neck (n = 15; 34.9%); right anterior neck (n = 14; 32.6%); left posterior neck (n = 6; 13.9%); right posterior neck (n = 5; 11.6%); midline anterior (n = 3, 7.0%).

The *left upper extremity* was involved in 18 cases (2.1%): left arm (n = 10, 55.6%); left shoulder (n = 8; 44.4%).

The *right upper extremity* was involved in 16 cases (1.8%): right shoulder (n = 7, 43.7%); right arm (n = 7; 43.7%); right forearm (n = 2; 12.6%).

The *right lower extremity* was involved in 13 cases (1.5%): right hip (n = 9, 69.3%); right thigh (n = 4; 30.7%).

The *left lower extremity* was involved in 11 cases (1.3%): left hip (n = 7, 63.7%); left thigh (n = 4; 36.3%).

4.3. Range of fire

In the suicide sample, contact-range gunshots wound of entrance were observed in 612 cases out of 614 (99.6%), and intermediate-range

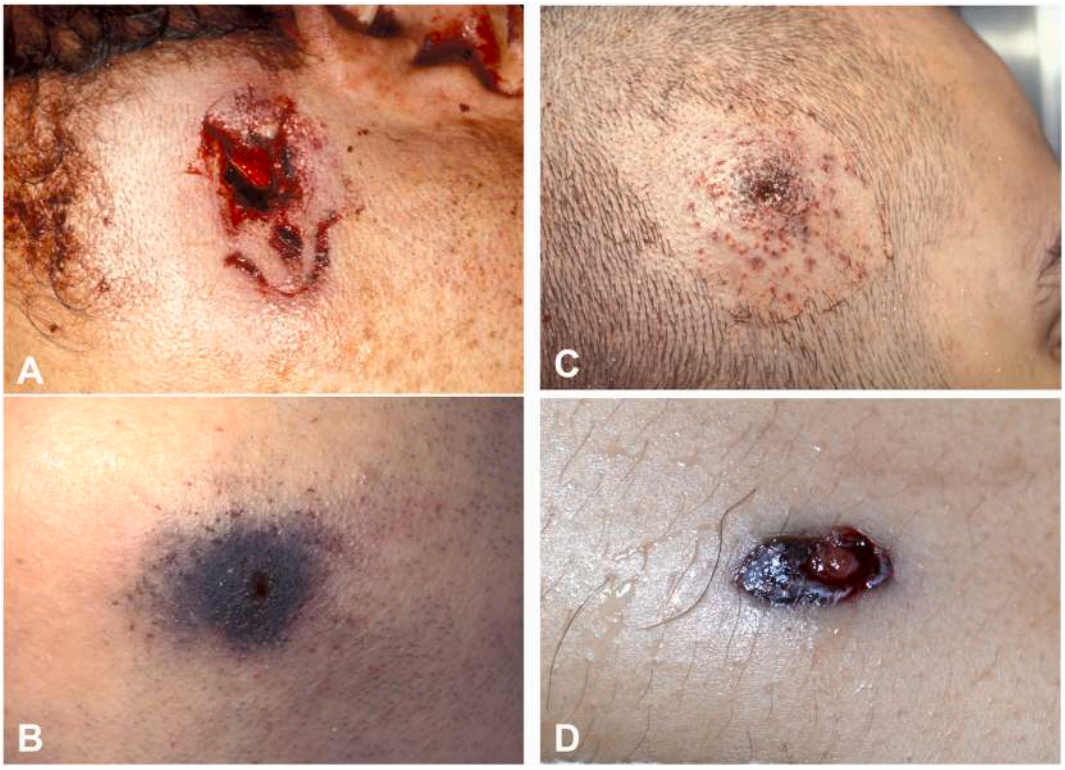

Fig. 2. Range of fire. A) Contact-range. B) Close-range. C) Intermediate-range. D) Indeterminate-range.

Table 2
Overview of the study population (n = 3384) and subcategorization.

Group	*n* =
MGSW TOT	1702
HOM	1688 (99.2%)
SUI	14 (0.8%)
Group	***n* =**
SGSW TOT	1512
HOM	873 (58.0%)
SUI	614 (40.6%)
ACC	4 (0.1%)
UND	21 (1.3%)

MGSW: deaths due to multiple gunshot wounds; SGSW: deaths due to single gunshot wound; HOM: homicide; SUI: suicide; ACC: accident; UND: undetermined.

Table 3
Demographic characteristics by manner of death.

	Homicide (N = 873)		Suicide (N = 614)		P-value
	N	%	N	%	
Age Group (years)					
≤20	249	28.5	36	5.9	<0.0001
21-40	506	58.0	209	34.0	
41-60	99	11.3	183	29.8	
61-80	17	2.0	141	23.0	
≥81	2	0.2	45	7.3	
Race					
Caucasian	187	21.4	460	74.9	<0.0001
African-American	666	76.3	142	23.1	
Other	20	2.3	12	2.0	
Gender					
Male	798	91.4	549	89.4	0.19
Female	75	8.6	65	10.6	

gunshot wounds were observed in 2 cases (0.4%).

In the homicide sample, indeterminate-range gunshots wounds of entrance were observed in 811 cases out of 873 (92.9%), followed contact-range gunshot wounds in 32 cases (3.7%), and by intermediate-range gunshot wounds in 30 cases (3.4%). Figs. 3–6 show the graphical distribution and the range of fire of the gunshot wounds in the suicide and homicide samples.

4.4. Presence and features of exit wounds

In the suicidal sample, a gunshot wound of exit was observed in 398 out of 614 cases (64.8%). In 216 cases (54.2%) the exit wound was larger the entrance wound, in 159 cases (40.0%) the exit wound was smaller than the entrance wound, while in 23 cases (5.8%) both entrance and exit wounds showed the same size. The most frequent exit sites were: left temporal (35.1%), left parietal (20.6%), left back (7.5%), left occipital (5.0%), right parietal (4.5%), right occipital (3.8%) other sites (23.5%).

In the homicide sample, a gunshot wound of exit was observed in 314 out of 873 cases (35.9%). In 227 cases (72.3%) the exit wound was larger the entrance wound, in 39 cases (12.4%) the exit wound was smaller than the entrance wound, while in 48 cases (15.3%) both entrance and exit wounds were the same size. The most frequent exit sites were right chest (10.8%), left chest (8.9%), left back (6.4%), right back (6.0%), right parietal (5.1%), left occipital (4.5%), left parietal (3.2%), other sites (54.3%).

A summary of data regarding range of fire, features of gunshot wounds of exit, and anatomic distribution of entrance wounds is reported in Table 4.

4.5. Additional relevant injuries

Other injuries were observed in 31 suicides, most often consisting of incised wounds predominantly on the wrist and neck areas, consistent with suicide attempts, and in 115 homicides, predominantly multiple

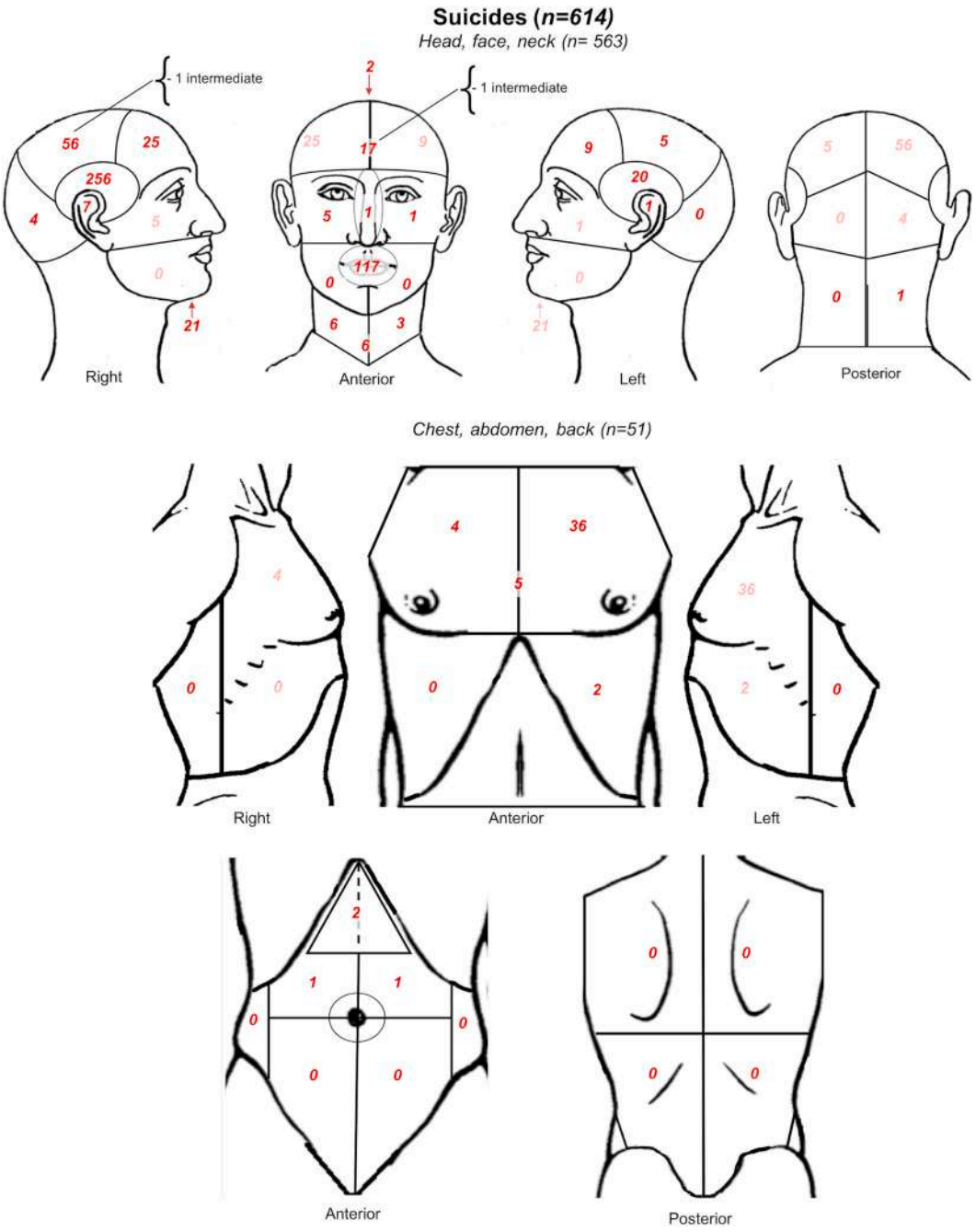

Fig. 3. Anatomic location of gunshot wounds in suicides. If not specified, the range of fire is contact.

lacerations and/or bruises on different body areas.

4.6. Bullet trajectory

The following single bullet trajectories were observed in suicides:

- on the sagittal plane: leftward, 66.8%; rightward, 15.0%; without leftward/rightward deviation, 18.2%; - on the transverse plane: downward, 24.9%; upward, 51.2%; without upward/downward deviation, 23.9%; - on the coronal plane: backward, 63.6%; frontward, 10.5%; without backward/frontward deviation, 25.9%.

The following single bullet trajectories were observed in homicides:

- on the sagittal plane: leftward, 40.5%; rightward, 51.4%; without leftward/rightward deviation, 8.1%; - on the transverse plane: downward, 41.2%; upward, 38.6%; without upward/downward, 20.2%; - on the coronal plane: backward, 44.7%; frontward, 43.3%; without backward/frontward, 12.0%.

The combined (3 planes) bullet trajectories observed in suicides and homicides are reported in detail in Table 8.

5. Discussion

In this study, females constituted approximately 10% of the suicides, and the 9% of the homicides in the SGSW group. This finding is consistent with previous research.[9] Statistical analyses showed that compared to those who died by suicide, subjects who died by homicide

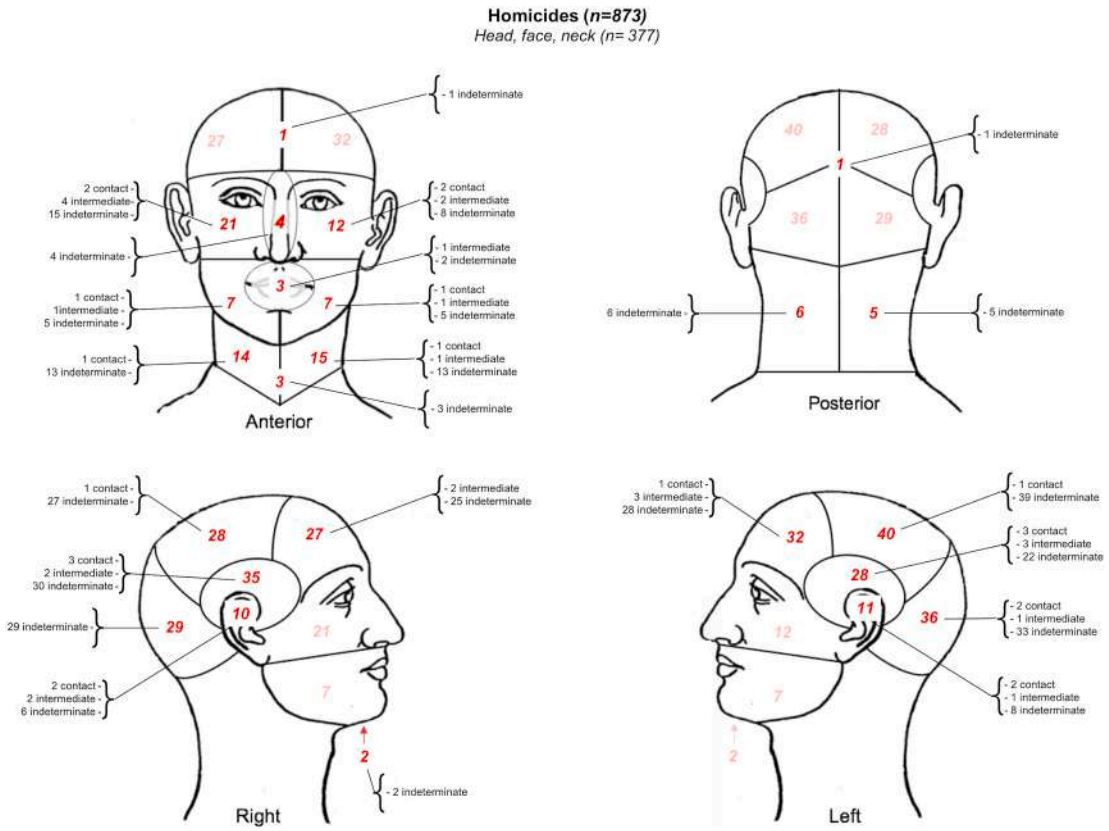

Fig. 4. Anatomic location of gunshot wounds in homicides: head, face, and neck areas.

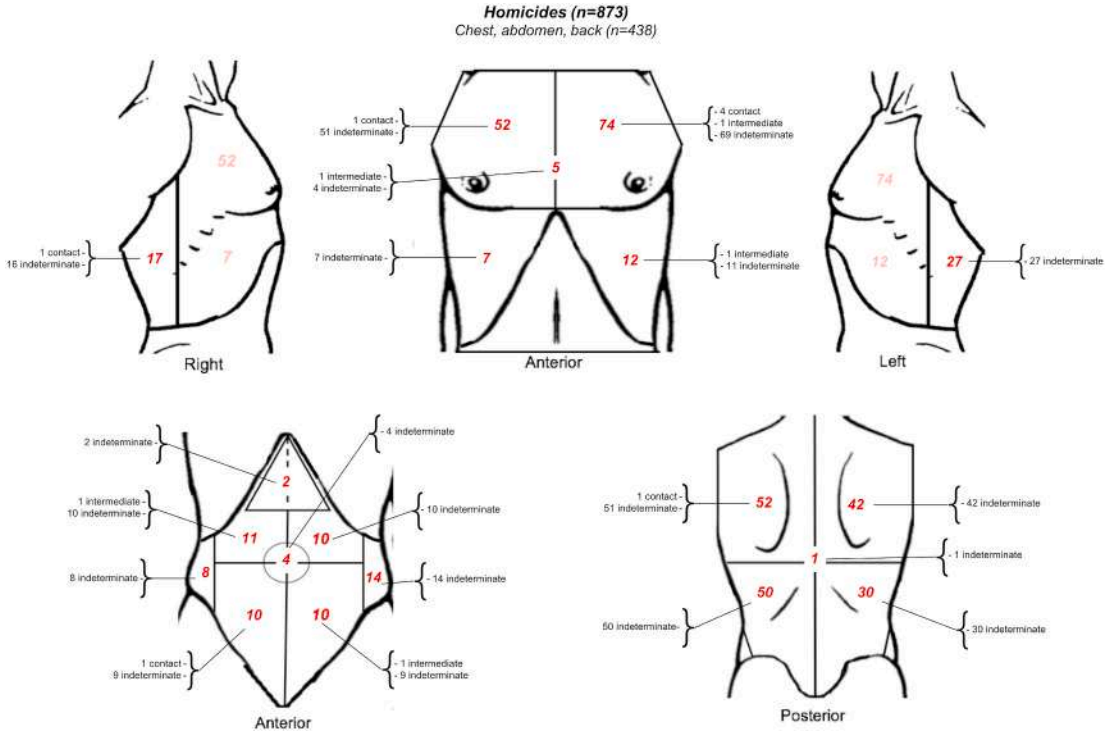

Fig. 5. Anatomic location of gunshot wounds in homicides: chest, abdomen, and back areas.

were generally younger (Table 3).

As expected, most of the weapons were unknown in the homicide group or were generically described as "handgun." This is a common scenario since the perpetrator tends to carry a weapon and dispose it after the homicide.[10] Conversely, the weapon was reported in 90% of suicides. In the remaining cases, the weapon was not reported,

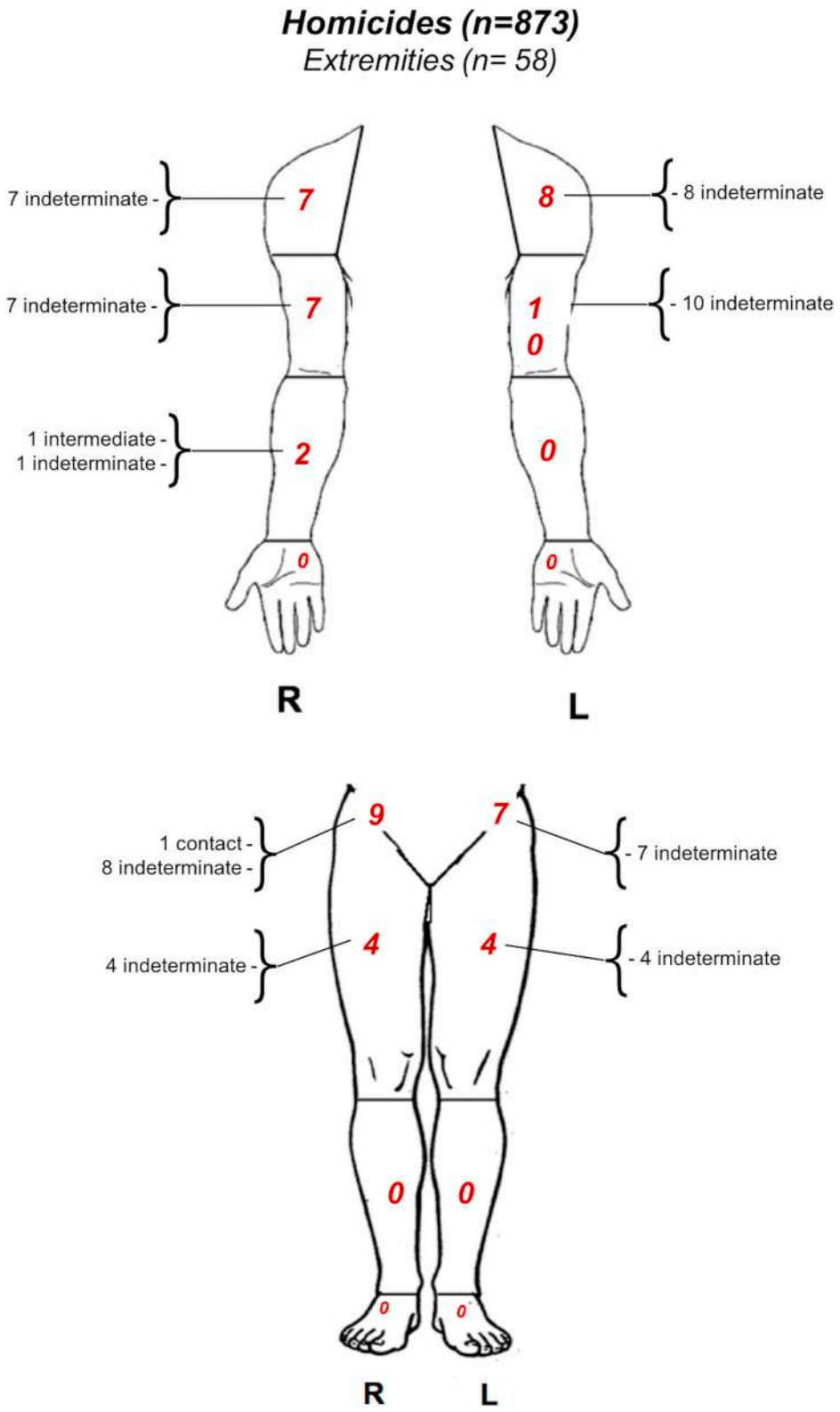

Fig. 6. Anatomic location of gunshot wounds in homicides: extremities.

suggesting that information about the weapon may not have been correctly included in the investigative reports. In previous research[11], in suicide cases, the weapon has been always found on the scene. Thus, the presence of the weapon on the death scene is an important indicator of suicide. However, there can also be circumstances in which the weapon is actually not found on the scene. For example, in the present study, in one case of suicide, the victim shot themselves close to the lake, and the weapon fell into the water; even after careful search, it was not recovered. The location in which the body is found can give information about the dynamic of the event.[12]

In both groups, short-barreled weapons were used, with pistols and revolvers being the most commonly reported. Compared to the bulkier

long-barreled weapons which can be more difficult to operate single-handedly, the concealability, portability and manageability of handguns make them easy to use also in homicides. Availability is also an important factor. Studies have found a variation in the prevalence of the type of weapon can be observed in different geographical areas. While in metropolitan areas long-barreled weapons are rarely used, in rural areas such weapons are frequently encountered because they are mainly used for hunting. In these areas, a higher prevalence of suicides, homicides, or accidents due to shotgun wounds can be observed.[13]

Statistically significant differences in the anatomic distribution of the wounds were found between suicides and homicides (Table 4). The main body area involved in suicides in the SGSW group was the head/face (89.1%), followed by the chest (7.6%). The right temporal region was by far the most affected head region (46.8%), followed by the intraoral area (21.4%). Surprisingly, the chin was affected in <4% of cases: this is in contrast with previous data,[14] but it can be related to the largest use of short-barreled weapon found in this study. The preference for the right side of the head compared to the left side may suggest that most of the victims were right-handed. Involvement of the right temporal region was also observed in homicides in the present study, but there was a higher prevalence in the suicidal group (256 suicides vs. 35 homicides). Moreover, the most frequent bullet trajectory in suicidal gunshot wounds to the right temple was leftward-upward-backward (59 cases), but it was observed in only 3 cases of homicide. Both findings suggest that the involvement of the right temple can be suggestive of a suicidal manner of death.

Similar to the suicide group, the main body area involved in homicides in the SGSW group was the head/face (38.3%). The occipital areas of the head were frequently involved in homicides (65 cases), while they were affected only in 4 cases of suicides. This finding is in line with previous literature.[15] Although not pathognomic for homicide, the involvement of the occipital areas suggests a homicidal manner of death. It is hard for the victim to aim a weapon at certain anatomical regions; thus, these areas of the head are less accessible for suicidal purposes.

Among the face lesions, the intraoral location was exclusive for suicides, indicating that this region is highly specific for this manner of death. Three cases of homicides showed an entrance gunshot wound on the mouth area, but the range of fire was intermediate or indeterminate, excluding a direct intraoral contact shot. However, careful evaluation of the investigative findings is necessary since homicidal shooting through the mouth does rarely occur, and can be mistaken for a suicide.[16]

The most frequent involved chest region in suicides was the left upper chest. The left upper chest region, however, was also the most commonly affected area in homicides, preventing any reliable conclusion. More useful are injuries located to the lateral sides (left and right) of the chest that were observed exclusively in homicides in this case series. These findings suggest that in suicides victims try to hit body areas that contain critical organs, while in homicides the shot is directed generally to the victim's central body mass.

The back was never involved in suicides, while it was frequently involved in homicides (175 cases), with the upper areas of the back being the most involved sites. The exclusive involvement of the back in homicides indicates that this body area is highly specific for this manner of death, as previously reported.[17]

The abdomen was involved in 69 homicides vs. 4 suicides, suggesting that an abdominal location of the gunshot wound is suggestive of a homicidal manner of death. This finding confirms again that self-inflicted injuries preferentially involve body areas that contain vital organs (head, chest). Thus, easily accessible but potentially less lethal targets, such as the abdomen, are usually uninvolved in suicides.

The extremities were also exclusively involved in homicides. A total of 58 homicide cases in the SGWS group showed involvement of one of the extremities. In these cases, death was caused by damage to major blood vessels such as the femoral artery, or by the extension of the bullet path into the chest with subsequent damage to vital organs.[17]

Regarding the range of fire, in this study, statistically significant differences in range of fire were found between suicides and homicides (Table 4). Indeterminate-range gunshot wounds were limited to homicides and thus can be considered highly specific for this manner of death. Contact-range gunshot wounds were observed almost exclusively in suicides, but they were occasionally seen in homicides (612 cases vs. 32 cases). The presence of contact range wounds in the homicide group may indicate that the victim was surprised or incapacitated before the shot, that there was a struggle for the weapon or that the victim was shot "execution" style. Although there are rare instances of contact-range wounds in homicides, contact-range wounds should nevertheless be considered highly suggestive of suicide.[18]

Regarding gunshot wounds of exit, they may show different shape (round, oval, stellate, irregular, etc.) and can be larger or smaller than the entrance wound. A common misconception is that an exit wound is always bigger than the entrance wound. Actually, the exit wound size is determined primarily by the amount of energy retained by the bullet as it exits the skin, the bullet size and configuration, and the amount of energy transferred to underlying tissue. The size of the wound has not been well studied as an indicator of an exit vs. entrance gunshot wound.

In the present study, statistically significant differences in exit wound presence and size were found between suicides and homicides (Table 4). A gunshot wound of exit was observed most commonly in the suicidal group compared to the homicidal group (64.8% vs. 36.2%). When present, an exit wound larger than the entrance wound was seen more commonly in homicides (227 cases, 72.3%), but it was also frequent in suicides (216 cases – 54.2%).

A potential explanation of the latter finding can be that while in suicides the bullet is usually fired in contact with the skin, the vast majority of homicides show a distant range of fire, leading to a possible increase in the instability of the projectile. It is recognized that multiple variables can cause bullet instability, including atmospheric factors such as air density (lower the air density, greater is the stability). If the bullet becomes destabilized, it will more readily lose its kinetic energy after the impact with tissue, accentuating its yaw within the body and transferring more energy to the tissue after the impact, thus contributing to a larger size of the exit wound. Conversely, in contact-range wounds, there is a direct pathway from the weapon to the tissue, avoiding any possible atmospheric effect that could affect the bullet stability.

The study of the trajectory of the bullet as a sign of suicide versus homicide has rarely been investigated.[19,20] Homicidal gunshot wounds can affect the same body areas involved in suicides. Therefore, the sole examination of the location of the wound is insufficient for distinguishing between these two manners of death. The analysis of the bullet direction with respect to the anatomical planes can be an

Table 4
Wound characteristics and anatomic location by manner of death.

	Homicide (N = 873)		Suicide (N = 614)		P-value
	N	%	N	%	
Range					
Contact/Close	32	3.7	612	99.7	<0.0001
Intermediate	30	3.4	2	0.3	
Indeterminate	811	92.9	0	0.0	
Exit Wound					
Present	316	36.2	398	64.8	<0.0001
Not Present	557	63.8	216	35.2	
Exit Wound Size					
Larger than Entrance	227	72.3	216	54.2	<0.0001
Smaller than Entrance	39	12.4	159	40.0	
Same Size	48	15.3	23	5.8	
Anatomic Distribution					
Head/Face	334	38.3	547	89.1	<0.0001
Neck	43	4.9	16	2.6	
Chest	194	22.2	47	7.6	
Back	175	20.0	0	0.0	
Abdomen	69	7.9	4	0.7	
Extremities	58	6.7	0	0.0	

additional parameter that could help in determining the manner of death. In theory the offender or the victim would fire the bullet aiming for a location that would ensure a fatal shot. The major difference, however, between gunshots fired in homicides and in suicides lies in the stability of the shot. In suicides the victims tend to shoot themselves in a secluded location and in a relatively stable position. In contrast, in homicides, the event is characterized by unpredictable movements and actions of the victim that reduce the ability of the offender to target a specific area of the body.

In the present study, statistically significant differences between the groups were also found for the bullet pathway according to all three anatomical planes. These differences were also found among the subset of head/face wounds and among the subset of chest wounds (Tables 5–7).

Binary logistic regression of the associations between combined trajectories and manner of death identified several trajectories that were statistically associated with manner of death. Leftward-downward-backward (LDB) was arbitrarily chose as the referent trajectory since in the studied population the proportion of suicides and homicides showing a LDB trajectory was relatively even and of good size. Relative to the LDB trajectory, several trajectories (LUB, LU/, L/B, L//,/UB) were more likely to occur among suicide than homicide, while several trajectories (RDB, RD/, RUF, R/B, R/F,/UF) were less likely to occur among suicide than homicide. For example, relative to a LDB trajectory, a LUB trajectory is 6.4 times as likely to occur among suicide than homicide.

Details of the combined trajectories and the odds ratios of suicides compared to homicides are showed in Tables 8 and 9

Summarizing, the analyses of the combined bullet trajectories in respect to the anatomical planes showed the following:

- A course leftward-upward-backward was the most frequent observed trajectory in suicides.
- A course rightward-upward-frontward was the most frequent observed trajectory in homicides.
- A course right-downward-backward was observed more in homicides than in suicides.
- A course leftward-without any downward/upward/backward/frontward deviation was observed more in suicides than in homicides.
- A course without leftward/rightward deviation-upward-backward was commonly observed more in suicides than in homicides.

The analyses of the combined bullet trajectories in respect of the anatomical planes and reference to the specific most affected body areas showed:

- Right temporal: suicides - leftward-upward-backward; homicides – rightward-without downward/upward deviation-backward or frontward.
- Left upper chest: suicides – leftward-without downward/upward deviation-backward; homicides – rightward-upward-backward.

Table 5
Single bullet pathway by manner of death.

	Homicide (N = 873)		Suicide (N = 614)		P-value
	N	%	N	%	
Sagittal Plane					
Leftwards	354	40.6	410	66.8	<0.0001
Rightwards	449	51.4	92	15.0	
Parallel	70	8.0	112	18.2	
Coronal Plane					
Frontwards	378	43.3	65	10.6	<0.0001
Backwards	390	44.7	390	63.5	
Parallel	105	12.0	159	25.9	
Transverse Plane					
Upwards	338	38.7	314	51.1	<0.0001
Downwards	359	41.1	153	24.9	
Parallel	176	20.2	147	23.9	

Table 6
Single bullet pathway by manner of death among head/face wounds (n = 881).

	Homicide (N = 334)		Suicide (N = 547)		P-value
	N	%	N	%	
Sagittal Plane					
Leftwards	143	42.8	387	70.8	<0.0001
Rightwards	155	46.4	68	12.4	
Parallel	36	10.8	92	16.8	
Coronal Plane					
Frontwards	128	38.3	62	11.3	<0.0001
Backwards	170	50.9	329	60.2	
Parallel	36	10.8	156	28.5	
Transverse Plane					
Upwards	83	24.9	295	53.9	<0.0001
Downwards	143	42.8	114	20.8	
Parallel	108	32.3	138	25.2	

Table 7
Single bullet pathway by manner of death among chest wounds (n = 241).

	Homicide (N = 194)		Suicide (N = 47)		P-value
	N	%	N	%	
Sagittal Plane					
Leftwards	81	41.8	15	31.9	<0.0001
Rightwards	104	53.6	17	36.2	
Parallel	9	4.6	15	31.9	
Coronal Plane					
Frontwards	27	13.9	1	2.1	<0.0001
Backwards	132	68.0	46	97.9	
Parallel	35	18.0	0	0.0	
Transverse Plane					
Upwards	56	28.9	4	8.5	0.0002
Downwards	116	59.8	35	74.5	
Parallel	22	11.3	8	17.0	

Table 8
Details of the combined bullet trajectories.

Homicides (n = 873)		Combined bullet trajectories (see Table 1 and Fig. 1 for details)	Suicides (n = 614)	
Cases	%		Cases	%
105	12.0%	L – D – B	68	11.1%
43	4.9%	L – D – F	17	2.8%
17	1.9%	L – D –/	20	3.3%
27	3.1%	L – U–B	112	18.2%
83	9.5%	L – U–F	33	5.4%
13	1.5%	L – U –/	44	7.2%
33	3.8%	L –/– B	44	7.2%
13	1.5%	L –/– F	9	1.5%
20	2.3%	L –/–/	63	10.3%
100	11.5%	R – D – B	28	4.5%
45	5.2%	R – D – F	0	0.0%
27	3.1%	R – D –/	2	0.3%
49	5.6%	R–U–B	40	6.5%
127	14.5%	R–U–F	3	0.5%
14	1.6%	R–U –/	4	0.7%
39	4.5%	R –/– B	7	1.1%
35	4.0%	R –/– F	1	0.2%
13	1.5%	R –/–/	7	1.1%
15	1.7%	/– D – B	16	2.5%
6	0.7%	/– D – F	1	0.2%
1	0.1%	/– D –/	1	0.2%
9	1.0%	/– U–B	59	9.6%
16	1.8%	/– U–F	1	0.2%
0	0.0%	/– U –/	18	2.8%
12	1.4%	/–/– B	16	2.6%
11	1.3%	/–/– F	0	0.0%

Leftward: L; rightward: R; downward: D; upward: U; backward: B; frontward: F; parallel:/.

Table 9
Odds ratios of suicides compared to homicides for combined trajectories.

Trajectory	Odds Ratio	P-value
LDB	Referent	Referent
LDF	0.6	0.13
LD/	1.8	0.1301
LUB	6.4	<0.0001
LUF	0.6	0.0587
LU/	5.2	<0.0001
L/B	2.1	0.0094
L/F	1.1	0.8848
L//	4.9	<0.0001
RDB	0.4	0.0015
RDF	[a]	[a]
RD/	0.1	0.0038
RUB	1.3	0.3803
RUF	0.04	<0.0001
RU/	0.4	0.1640
R/B	0.3	0.0035
R/F	0.04	0.0024
R//	0.8	0.7086
/DB	1.6	0.2026
/DF	0.3	0.2136
/D/	1.5	0.7601
/UB	10.1	<0.0001
/UF	0.1	0.0249
/U/	[a]	[a]
//B	2.1	0.0799
//F	[a]	[a]

[a] Too few occurrences to estimate.

- Intraoral: suicides – without leftward/rightward deviation-upward-backward.
- Back: homicides – leftward or rightward-upward-frontward.

The present study reports a comprehensive analysis of the gunshot features that can be helpful in discriminating between suicides and homicides. The specific anatomic location of the entrance gunshot wound and the internal bullet trajectory can provide helpful information to support the manner of death, but they must be considered in the context of a thorough medicolegal death investigation, including scene findings, investigations, witnesses' statements, range of fire, presence and size of exit wounds, and any other additional findings useful to support a specific manner of death.

In conclusion, although there were several statistically significant differences between suicidal and homicidal gunshot wounds, these features alone should not be used in determining the manner of death. When the wound location and the internal trajectory of a bullet are interpreted in the light of all available evidence they can impeach or corroborate witness statements and highlight consistencies as well inconsistencies in investigative reports and scene examinations. Thus, they can be additional factors to consider in the assessment of firearm fatalities.

Ethical approval

Not applicable: only data collected in the process of routine medicolegal investigations are described in this paper.

Informed consent

As above.

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Authors contribution

Dr. Gitto conceived and supervised the project and wrote the manuscript. Dr. Serinelli wrote the manuscript. Drs. Arunkumar, Segovia, and Filkins collected data and wrote the manuscript. M. Formica performed statistical analyses. All authors collectively proofread the manuscript and approved the final version.

Declaration of competing interest

The authors declare no conflicts of interest.

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References

1. Hardt-Madsen M, Simonsen J. Firearms fatalities in Denmark 1970–1979. *Forensic Sci Int.* 1983;23:93–98.
2. Selway R. Firearm fatalities in Victoria, Australia 1988. *Med Sci Law.* 1991;31:167–173.
3. Thomsen JL, Albrektsen SB. An investigation of the pattern of firearm fatalities before and after the introduction of the new legislation in Denmark. *Med Sci Law.* 1991;31:162–166.
4. Chapman J, Milroy CM. Firearm deaths in Yorkshire and Humberside. *Forensic Sci Int.* 1992;57:181–191.
5. Riddick L, Wanger GP, Fackler ML, et al. Gunshot injuries in Mobile County, Alabama: 1985-1987. *Am J Forensic Med Pathol.* 1993 Sep;14(3):215–225.
6. Hougen HP, Rogde S, Poulsen K. Homicide by firearms in two Scandinavian capitals. *Am J Forensic Med Pathol.* 2000;21:281–286.
7. Denton JS, Segovia A, Filkins JA. Practical pathology of gunshot wounds. *Arch Pathol Lab Med.* 2006;130(9):1283–1289.
8. Desinan L, Mazzolo GM. Gunshot fatalities: suicide, homicide or accident? A series of 48 cases. *Forensic Sci Int.* 2005;147S:S37–S40.
9. Solarino B, Nicoletti EM, Di Vella G. Fatal firearm wounds: a retrospective study in Bari (Italy) between 1988 and 2003. *Forensic Sci Int.* 2007 May 24;168(2-3):95–101.
10. Pecino-Latorre MDM, Pérez-Fuentes MDC, Patró-Hernández RM, Santos-Hermoso J. Expressiveness and instrumentality of crime scene behavior in Spanish homicides. *Int J Environ Res Publ Health.* 2019;16(22):4526.
11. Garavaglia JC, Talkington B. Weapon location following suicidal gunshot wounds. *Am J Forensic Med Pathol.* 1999 Mar;20(1):1–5. https://doi.org/10.1097/00000433-199903000-00001. PMID: 10208326.).
12. Byard R, Payne-James J, eds. *Encyclopedia of Forensic and Legal Medicine.* San Diego, CA: Academic Press; 2005.
13. Thoreson S. Fatal head injuries from firearms: an autopsy study of 270 cases. *Z Rechtsmed.* 1984;93(20):65–69.
14. Cina SJ, Ward ME, Hopkins MA, Nichols CA. Multifactorial analysis of firearm wounds to the head with attention to anatomic location. *Am J Forensic Med Pathol.* 1999;20(2):109–115.
15. Blumenthal R. Suicidal gunshot wounds to the head: a retrospective review of 406 cases. *Am J Forensic Med Pathol.* 2007 Dec;28(4):288–291.
16. Berens S, Ketterer T, Kneubuehl BP, Thali MJ, Ross S, Bolliger SA. A case of homicidal intraoral gunshot and review of the literature. *Forensic Sci Med Pathol.* 2011 Jun;7(2):209–212.
17. Molina DK, DiMaio VJ, Cave R. Handgun wounds: a review of range and location as pertaining to manner of death. *Am J Forensic Med Pathol.* 2013 Dec;34(4):342–347.
18. Stone IC. Characteristics of firearms and gunshot wounds as markers of suicide. *Am J Forensic Med Pathol.* 1992;13(4):275–280.
19. Druid H. Site of entrance wound and direction of bullet path in firearm fatalities as indicators of homicide versus suicide. *Forensic Sci Int.* 1997;88(2):147–162.
20. Karger B, Billeb E, Koops E, Brinkmann B. Autopsy features relevant for discrimination between suicidal and homicidal gunshot injuries. *Int J Leg Med.* 2002;116:273–278.