TECHNICAL NOTE

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Characteristics of Gunshot Wounds in the Skull

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ABSTRACT: The analysis of trauma to the skeleton is an important aspect of forensic case work, but most pathology references devote limited attention to this topic. This paper describes various aspects of gunshot wounds, including entrance and exit patterns, angle and path, range of fire and velocity, and caliber of the bullet, based on observations of a series of known cases. Skeletal remains of 21 victims of gunshot wounds were studied. In most cases, there was documentation of the investigation, autopsy, and victim's identity. Each case was analyzed in terms of wound location, shape, size and exit/entry surface area ratio, beveling, and direction of shooting. Skull entry wounds were most often round or oval. Unusual shapes were observed in bones like the mandible and mastoid process, but were also found to be triangular, nearly rectangular or irregular. Tunneling was observed in the mastoid process. The expected internal beveling was obvious in all but one skull. External beveling of an entry wound was only observed in one case (parietal bone). Exit wounds were roughly round, oval, square, and rectangular and were always more irregular than entry wounds. External beveling of exit wounds was observed in most vault bones, but there was none in the orbit, maxilla, greater wing of the sphenoid, temporal, or left occipital bone. Tangential gunshot wounds were seen in a mastoid process, zygomatic process, mandibular ramus and condyle, and occipital condyle. Most of the exit to entry surface area ratios (cm^2) varied from 1.4 to 2.0. In four cases the ratio indicated that entrances were larger than exists. In conclusion, understanding of gunshot wound characteristics is an important matter to interpret distance, velocity, direction and sometimes caliber size. Assessment of this nature of gunshot wounds helps reconstruct events surrounding the death.

KEYWORDS: forensic science, forensic anthropology, bones, gunshot wounds, entrance and exit wounds

Most major pathology references devote limited attention to the analysis of trauma to the skeleton (1–5). Among anthropological publications, few deal with gunshot wounds, and most of these only describe specific cases demonstrating the importance of this assessment (6–17). To date, few studies have focused on size and shape variation in gunshot entry and exit wounds in bones (10,17–20). Data based research on gunshot wounds in the dry skeleton are very few and yet skeletonized remains are expected to show differences resulting from taphonomic factors, loss of bone, small or large, after death or during recovery, and fragmentation as a result of bullet damage. This may affect, for example, the interpretation of the severity of the wound. Therefore the aim of this paper is to address these issues by describing entrance and exit shapes, and various patterns of the bullet lesions using a series of documented skeletonized forensic cases with gunshot wounds.

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Materials and Methods

The skulls of 21 individuals with gunshot wounds (C1–C21) were studied. Age, sex, and race were available for most cases, as well as autopsy reports including cause and manner of death, photographs, and crime scene and other investigation reports. Most of the files did not have specific information about weapons and ammunition responsible for the wounds. When the identity of the victim was unknown, age, race, and sex, were assessed using standard forensic anthropological methods (21). Of the 21 cases, 8 were unidentified. Each wound was described in terms of its shape, beveling, and location. Dimensions of both entrance and exit wounds were measured to the nearest millimeter. Surface area was calculated using the necessary formula for its geometric shape. An exit/entry surface area index was computed from these surface areas. The trajectory of the bullet was estimated when possible and the caliber of the bullet was noted when available. The path of the projectile was determined by noting its general direction (e.g., from right or left). When there was no exit, direction was estimated from the wound shape and autopsy report.

Results

Table 1 shows the demographic characteristics of the sample. Of the 21 individuals, majority were white males (N = 16; 76%). Overall age range was from 18 to 53 years. Manner of death was homicide for 18 and suicide for 2 individuals (both males). The caliber of the bullet was known in 5 cases and estimated from autopsy findings in 4 others. Location, size (cm), and surface area (cm^2) of entrance and exit wounds and exit to entrance surface area ratio are given in Table 1. Of the 21 cases 10 multiple gunshot wounds were seen (C2-C4, C9, C10, C12, C14-C16, C18). In 10 cases there was no exit wounds. Of these "no exit" cases, 8 had single gunshot entry wounds. Of the 10 multiple gunshot cases, 3 cases (C2, C12, C15) displayed 2 exits each; 3 cases (C4, C9, C16) one exit, and 4 cases (C3, C10, C14, C18) no exit. In cases C9 and C12, and C15 the exit holes are smaller than the entrances. The exit was also small in C16 in which there were two entries and one exit. In both suicide cases (C5, C21), the bullet entered from one side of the head and exited exactly from the same bone of the other side. There were 5 female victims with an age range of 18 to 23 years. They were all shot from the lateral side of the head. Two female victims (C2, C4) had multiple gunshot wounds, one (C2) of whom had two

TABLE 1—*Demography, manner (Manner) of death (H, homicide; S, suicide), bullet caliber (Cal), entrance (En) and exit (Ex) wound location, shape, size (cm), surface area (cm^2), and exit to entrance surface area ratio.*

Case No	Sex	Race	Age	Manner	Cal		Wound Location	Shape	Size	Surface Area	Ratio
C1	M	W	28	H	357 Mag	En	Right frontal	Round	2	3.14	
						No ex					
C2	F	W	19	H	0.25	En	L. cor.suture	Round	0.5	0.20	8.01
						Ex	Right parietal	Oval, irregular	1 × 0.5	1.57	
						En	Right parietal	Oval	0.7 × 0.5	1.10	1.43
						Ex	Left occipital	Oval, irregular	1 × 0.5	1.57	
C3*	M	W	50	H	Small	En	Right occipital	Round	1	0.79	
						No ex					
						En	Right occipital	Oval	1.8 × 1.3	7.35	
						No ex					
C4	F	W	18	H	0.38	En	Post. to right mastoid, junction of the 3 sutures	Triangle	1.5 ×1.3 × 1.3	0.80	
						No ex					
						"En"†	L. zygoma. process				
						then†	Mand. condyle, occipital condyle				
C5	M	W	42	S		En	Right temporal	Semi-lunar‡	1.2	1.13	2.01
						Ex	Left temporal	Very irregular	1.7	2.27	
C6	M	W	53	H		En	Left temporal	Round, irregular‡		0.5	0.20
						No ex					
C7	F	B	23	H		En	Left temporal	Round	1.2	1.13	
						No ex					
C8*	M	W	27	H		En	L. parieto-occ.	Semi-lunar‡	0.8	0.50	1.56
						Ex	Left frontal	Round	1	0.79	
C9	M	W	35	H	Large	En	Left temporal	Oval	1.2 × 0.8	3.02	0.51
						Ex	Right temporal	Irregular, round with 2 extensions	1.4	1.54	
						"En"†	Left zygoma	oval	0.3 × 0.1		
						Ex	Post. max. wall	Very irreg.	2 × 1		
						then	L. orbit, r. orbit				
C10	F	W	20	H		En	Right occipital	Triangle	1 × 1 × 0.6		0.29
						No ex					
						Depressed† fracture	L. occipital	Oval	1 × 0.7	2.20	
C11	M	W	20	H		En	L. mand. ramus	Round, irregular	0.8	0.50	
						then	R. occ. condyle†				
						and	r. mastoid§	Irreg. rectangle	1.2 × 1	1.20	
C12*	M	W	45	H		En	Left parietal	Oval	1 × 0.9	2.83	1.89
						Ex	Right parietal	Oval	1.7 × 1	5.34	
						En	Left post. parietal	Oval	1.2 × 1	3.77	0.66
						Ex	R. greater wing	Rectangle	2.5 × 1	2.50	
C13*	M	W	28	H		En	Left parietal	Round	0.5	0.20	45.92
						Ex	Right orbit	Square, irregular	3 × 3	9.00	
C14*	M	W	30	H	Small	En	R. occipital	Round	0.9	0.64	
						No ex					
						"En"†	L. mand. coron. process	Semi-lunar nick	0.5		
						then	Lat. maxil. sinus wall	Irreg.	1 × 1		
C15	M	W	24	H		En	Left maxilla	Oval	1.2 × 1.7	6.41	1.76
						Ex	L. post. maxilla wall toward	Oval, irregular	3 × 1.2	11.31	
						then§	Left mastoid	Irreg.	1 × 1		
						En	Occipital	Oval	2.3 × 2	14.45	1.74
						Ex	Left frontal	"8" shape	2.5 × 1.7 & 2.5 × 1.5		25.13
C16	M	W	21	H		En	Right frontal	Oval	1.6 × 1.3	6.53	
						No ex					
						En	Left parietal	Oval	1.5 × 1.2	5.65	0.66
						Ex	L. temporal fossa	Rectangle down and triangle up	2.5 × 1.5		3.75
C17*	F	W	23	Unk.		En	R. parieto-occ.	Oval	1.7 × 1.6	8.55	
						No ex					

continued

exits. In the rest of cases the bullet remained inside after damaging the internal surface of the cranium.

Table 2 summarizes various pathways of the projectile as mentioned in Table 1. Almost all of the facial entry wounds were followed with exit holes. Only those bullets that entered through the thick bones like the frontal, parietal, and occipital showed higher frequency of "no exits." For example, of the 2 cases entering the frontal bone, and of the 6 cases entering the parietal bone, none exited. The same situation was 50% (3 of 6 bullets) when the bullet penetrated the occipital bone. Most of the bullets were fired left to right side (41.9%) of the victim. The opposite direction was seen in 22.6%.

Table 3 lists the frequency of occurrence of different shapes of entry and exit wounds. The following fairly regular shapes were identified in entry wounds: round (C2, Fig. 1A), oval (C16, Fig. 1B), semi-lunar (C5, Fig. 1C), and roughly triangular (C4, Fig. 1D). Several holes were very irregular, as in the mandibular ramus (C11, Fig. 1E and 1I). Unusual shapes appeared in certain locations, as for example, when the defect impinges on the rim of the

TABLE 1—*Continued*

Case No	Sex	Race	Age	Manner	Cal		Wound Location	Shape	Size	Surface Area	Ratio
C18*	M	W	40	H		En	L. post. temp.	Oval	0.9 × 0.7	1.98	
						No ex					
						"En"†	Tooth 15	Tiny nick			
						then†	C1-C2, 1. occ. condyle	Nick, then small groove			
C19	M	W	26	H	0.38	"En"†	R. mastoid	Tunnel	3 × 1.2	3.60	
						"Ex"†	R. mastoid				
C20*	M	Mix	45	H	0.22	En	Right temporal	Oval	0.9 × 0.6	1.70	103.53
						Ex	Left temporal	Oval‡	8.1 × 6.9	175.58	
C21	M	W	45	S	0.38	En	Right parietal	Round‡	1.2	1.13	5.53
						Ex	L. post. parietal	Square, irregular	2.5	6.25	

* Unknown remains; only the average of estimated age is indicated.
† Tangential wound.
‡ These shapes appear along the edge of a larger defect created by extensive bone loss.
§ The projectile impacts into the mastoid process.

TABLE 2—*Pathways of the Projectile.*†

Entrance Wounds	Exit Wounds	Case No.
Frontal	No exit	C1, C16
Temporal	Temporal	C5, C9, C20, C21
	Parietal	C2
	Occipital	C18
	No exit	C6, C7, C18
Parietal	Temp. fossa	C16
	Parietal	C12, C21
	Occipital	C2
	Sphenoid	C12
	Orbit	C13
Occipital	Frontal	C15
	Petrous	C17
	Posterior fossa	C14
	No exit	C3, C10, C14
Others		
Coronal suture	Parietal	C2
Temporoocc.	No exit	C4
Parietoccipital	Frontal	C8
	No exit	C17
Asterion	No exit	C10
Maxilla	Orbit	C9
	Mastoid	C15
Zygomatic process	Occipital condyle	C4
	Orbit	C9
Mandible	Mastoid	C11
	Tangential	C11
	Maxillary sinus	C14
Malar	Maxillary sinus	C14
Mastoid	Mastoid (groove)	C19
Tooth	Occipital condyle	C18

† Direction of shooting:

	N	%
Right to left	7	23
Left to right	13	42
Horizontal/sagittal	1	3
Unknown	10	32

foramen magnum (C15, Fig. 1F). In the mastoid process, a partial fracture resulted, because the bone fragment acted as a secondary missile (C15, Fig. 1G) or a tunnel formed through the mastoid by a tangential shot (C19, Fig. 1H). In the right occipital, a pseudo-keyhole shape defect was composed of an entrance connected to an exit, and one of the entries displayed external erosion along the edge (C3, Fig. 1J). Internal beveling (beveling on the inner surface in the direction of the shot) was obvious in almost all skulls (C16, Fig. 1K), and a similar beveling of the internal surface was seen in the mandible (C11, Fig. 1I). Beveling also occurred in the direction of the shot in the margin of the orbit (C9, Fig. 1L). Only one case (C9)—a thin temporal bone—did not exhibit any visible beveling. External beveling (beveling on the outer surface) of an entry wound is rare. It was only observed in one case (C12, Fig. 1M), on the left posterior parietal bone. Exit wounds were roughly round (C9, Fig. 2A), triangular, oval (C12, Fig. 2B), square, rectangular (C21, Fig. 2C) or irregular (C2, Fig. 2D). Sometimes the shape was unusual such as a figure "8" (C15, Fig. 2E). Of bullets holes, 19 (59%) of entrance and 8 of exit wounds (57%) were round and oval. Seven (22%) of 31 cases showed tangential damages to the skulls. Tangential gunshot wounds were seen in the mandibular condyle (C4) and ramus (C11, Fig. 2G), gonial angle (C11), mastoid process (C19), zygomatic arch (C4), and occipital condyle (C4, C18, Fig. 2H).

Table 4 shows cases with external beveling in exit wounds. This phenomenon was observed in 7 cases of thick vault bones including the frontal, temporal, and parietal (C2, Fig. 2F). There was no beveling in 4 cases. These were usually thin bones as in the orbits, posterior wall of left maxilla, right greater wing of the sphenoid, and occipital bone near the foramen magnum.

Discussion

Since homicides and suicides frequently result from gunshot wounds, it is essential to derive as much details as possible about both the cause and manner of death. This is especially true when the only evidence consists of skeletonized or decomposed bodies. This study not only revealed typical patterns that are commonly associated with trauma from firearms but also and more importantly pointed out cases with unexpected findings.

Entrance and Exit Wounds

Entrance wounds were normally round or oval, and sharp-edged, with a "punched-out" appearance and internal beveling. Occasionally, triangular (Fig. 1D) and irregular (Fig. 1E) shapes were also noted. Rhine and Curran (14) reported a rectangular entrance wound of the left sphenotemporal region. Various factors can modify the shape of the entry wound, such as the yawing and the tumbling of the missile, and its deformation at impact prior to or dur-

TABLE 3—*Shapes of the entry and exit wounds.*

Shape	Entry Wounds N†	%	Case Numbers	Exit Wounds N	%	Case Numbers
Oval	11	35.4	C3, C9, C12, C12, C15, C15, C16, C16 C17, C18, C20	5	35.7	C2, C2, C12, C15,* C20
Round	8	25.8	C1, C2, C3, C6, C7, C13, C14, C21	3	21.4	C5, C8, C9
Semi-lunar	2	6.4	C5, C8			
Triangular	2	6.4	C4, C10			
Rectangular	1	3.2	C18	1	7.1	C11*
Square				3	21.4	C12, C13, C21
Tangential	7	22.6	C4, C9, C10, C11 C14, C18, C19	2	14.3	C9, C18
Irregular	1	3.2	C6†	All	100.0	
Total	31	103		14	100.0	

*Ending into the mastoid.
†The total is affected because C6 is counted both as round and irregular.

TABLE 4—*External beveling in exit wounds.*

Beveling	N	Case Numbers
Present		
Frontal	2	C8, C15
Temporal	3	C5, C16, C20
Parietal	2	C2, C21
Total	7	
Absent		
Occipital	1	C2
Orbits	1	C13
Maxilla	1	C15
Sphenoid	1	C12
Total	4	

ing perforation of the bone. Intermediate targets can also alter the bullet. In this study, thin segments of bone (e.g., maxilla or thin regions of the temporal bone) tended to exhibit more atypically shaped entrance wounds, whereas it is usually considered more common for the thin squamous region of the temporal bone to show a round hole approximately the size of the bullet when struck perpendicularly.

Internal beveling is one of the most important signs of an entrance wound to the skull. It occurs on the internal surface in the direction of the shot (Fig. 1K), and is also seen in other thick bones like the mandibular corpus (Fig. 1I). Dixon (7) observed that in thin areas, beveling may not always be discernible. Outward beveling may also be seen at entrances (Fig. 1M). In this case, however, examination of the internal surface revealed characteristic beveling that is all but diagnostic of an entry wound. This conclusion was confirmed here by the presence of a definitive exit wound on the right parietal bone. Coe (6) collected a few examples of external beveling in non-tangential shots, usually involving contact wounds produced by handguns, and observed that external beveling of the entrance is generally less pronounced than the internal beveling, as in case C12.

The explanation of this phenomenon is not always clear. In contact shots of the head, chipping off of the outer layer of the bone around the defect may be produced by the forceful return of gases through the bullet hole (22). When the shooting occurs at a distance, the twisting force of the rotating bullet has also been suggested as a factor (22), but this explanation has to be ruled out. More precisely, it is the twist of the rifling that determines the bullet spin. A rifling twist of one turn in nine inches means that the bullet has to travel nine inches for its spin to make one revolution: at any locus in its pathway the rotation of the bullet is nil. Another explanation is the blowback from pressure associated with temporary cavity formation (16). Chips of bone can flake off the edge of an entrance defect, producing an effect resembling outward beveling, but not as marked as the truly beveled surface (C2, Fig. 1A).

A pseudo-keyhole defect was observed in the right occipital (C3, Fig. 1J). Actual keyhole defects can be observed both with handgun ammunition of a variety of calibers and with shotgun pellets (7). They are usually circular or oval entries with internal beveling, and triangular or oval exits with external beveling. One portion of the bullet enters the cranial vault while the second portion is deflected outward exiting the bone almost immediately after penetrating the outer table. When the skin is present, it shows typical grazing that clearly indicates the trajectory; but when the skin is altered by decomposition, fire damage, or surgical intervention, this bony defect is a reliable indicator of the line of fire. Keyhole defects are rarely discussed in forensic literature. Spitz (23) noted that the "entrance" and "exit" portions exhibited beveling of the inner and outer tables respectively. Dixon (7) reported 5 cases of keyhole defects. In one case, the entire bullet entered the skull, the total defect therefore represented the entrance hole. The arrangement of the beveling, nevertheless, indicated a tangential shot and the direction of fire. Adelson (2) described a keyhole defect in an exit wound with no mention of the tangential nature of the shot. Keyhole entrances are also reported as tangential gunshot wounds (7,9). Figure 1J shows the difficulty of diagnosis in keyhole shaped defects. In this case, two entry wounds were connected, and one displayed external erosion along the edge. Superficial analysis can lead to misinterpretation of the true nature of these types of wounds. But in this case, internal beveling was visible on both holes, and the skin displayed two holes as well.

Most wounds produce defects within the range of shapes noted previously. Other patterns, such as tunneling, are rare, as in the case characterized by a semi-tunnel inside the mastoid (Fig. 1H). The bullet can penetrate into the mastoid process without shattering the bone and thus a groove is created. Some shootings result in atypical features more characteristic of blunt trauma (13). Perforation of the skull and associated fractures and defects may lead to a very different morphology.

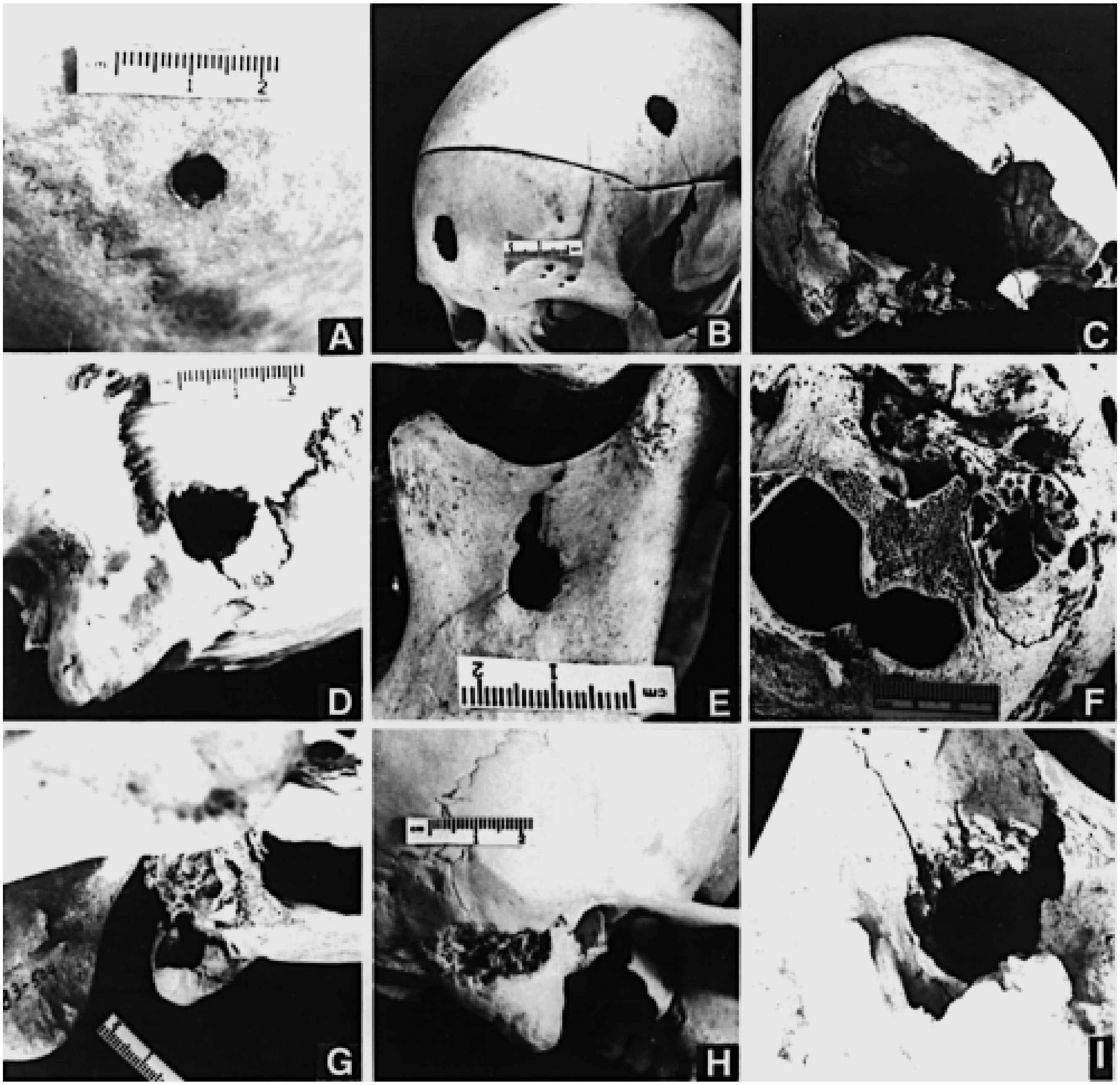

FIG. 1—*Entry wounds. In plate 1A, C2 exhibits typical round entry in right parietal with punched-out appearance. Note slight flaking at the edge. 1B (C16) shows oval-shape entries with punched-out appearance in right frontal and left parietal. In C5 (1C), there is a punched out, semicircular notch in the bone (indicating the point of entry of the bullet) along the edge of a large defect. C4 illustrates a rough triangular entrance posterior to the right mastoid (1D), and 1E (C11) has a round entry with associated bone loss creating an irregular defect in the left mandibular ramus. C15 (1F) with entry wound shows impinging on the foramen magnum. C15 displays partial loss of mastoid process (1G), and 1H (C12) with superficial tunneling in the right mastoid from a tangential shot. Figure 1I (C12) shows the internal beveling on the medial surface of the mandibular ramus.*

External beveling, the hallmark of an exit wound, was observed in this series, but was not always present, especially in thin bones (orbital bones, maxilla, sphenoid) as is also the case for entrance wounds (Table 4). Keyhole defects as exit holes are rare (2,8,14). Internal beveling of non-keyhole exit wounds has also been reported (24).

Size of the Gunshot Wounds

Exit wounds show significant variation; yet two consistent features were encountered in this series. They were always irregular, and nearly larger than entrances (Table 1) as was also seen in other studies (2,4,22,23). Light (25) demonstrated that this can result from yawning, tumbling, and deformation of the projectile, which often mushrooms. In his experiments on goats, he used non-deforming missiles (steel spheres) with relatively high impact velocities, and found that exit wounds in the skin were always smaller than the entrances. He explained this fact by the absence of deformation of the projectile, and the loss of velocity between entrance and exit.

In this series, only 11 cases of pairs entrance/exit wounds, out of 10 forensic cases, were available (in the other cases there were ei-

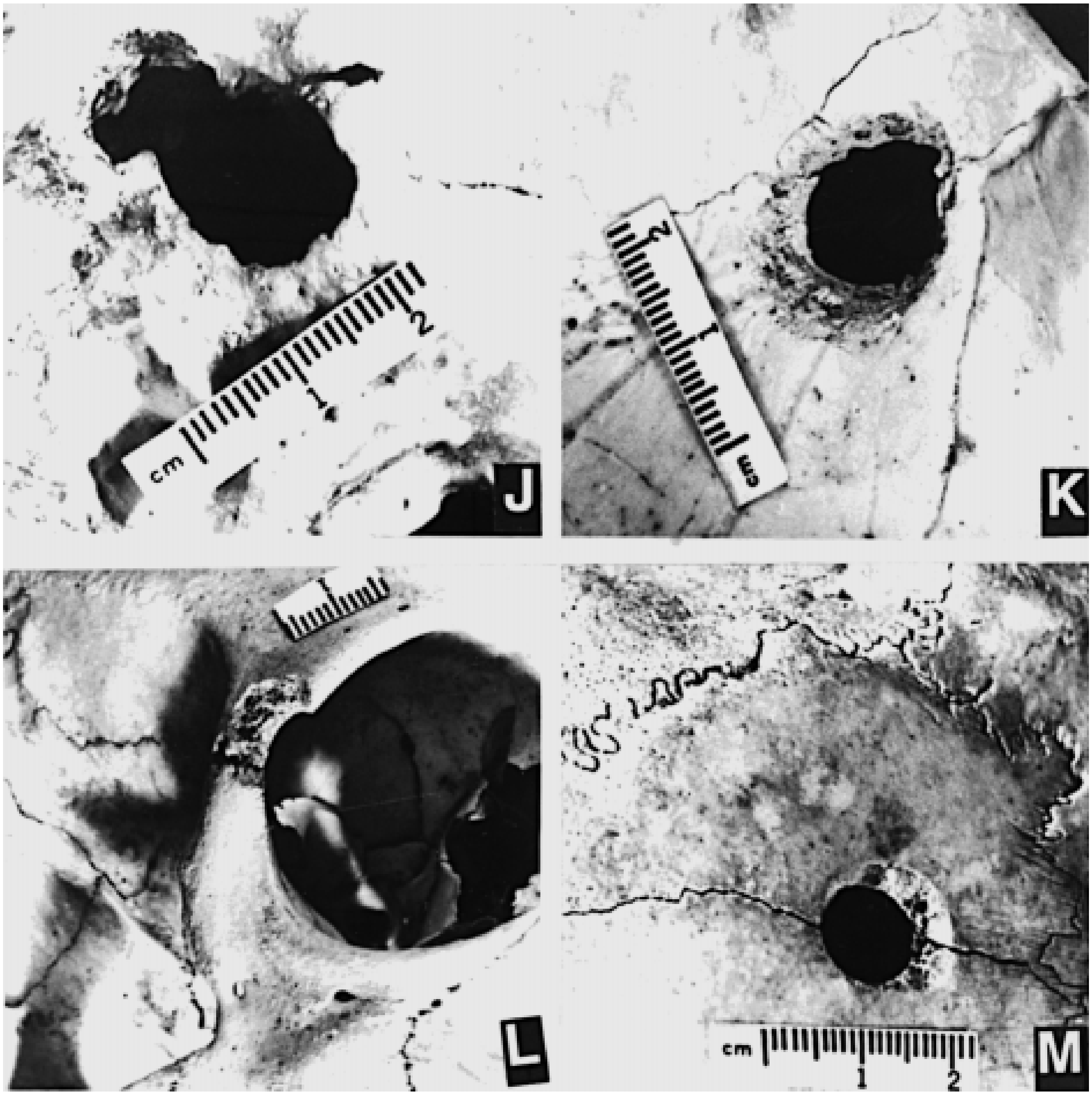

FIG. 1—*Entry wounds (continued). Figure 1J (C3) depicts a pseudo-keyhole-shape defect of the occipital bone: entrance wound (punched-out appearance) connected with the exit wound (beveling). Figure. 1K (C16) is an example of classical internal beveling of an entrance wound in the left parietal, and Fig. 1L (C9) beveling of the margin of the orbit where the shape is punched out in the other side. These two characteristics indicate clearly the direction of shooting. Figure 1M (C12) shows a rare external beveling of an entrance wound in the left posterior parietal bone.*

ther tangential shot, or no exit) (Table 1). Usually, the exit to entrance ratio confirms the trends for the exits to be larger than the entrances. In 8 cases the exit/entrance figure ranges from 1.43 to 8. In 2 cases the exit to entrance ratio was very high because of broken and missing fragments. For example, the ratio in C13 was 45.9 probably because the exit wound was in the thin and fragile orbit. In C20 (ratio: 103.5), the entrance wound was in the right temporal, and the exit wound in the left temporal with a large piece of bone missing. These two cases illustrate that exit wounds in a dry specimen may not be similar to that in an intact body. However the sample is too small to state definitive conclusions. The ratios are high (5.5 and 8 respectively) in 2 cases (C2, C21), when the bullet perforated thick parts of the bone. The 4 cases where the exit is smaller than the entrance are difficult to explain. In C9 (ratio: 0.51), the bullet entered the left temporal before exiting the right temporal: this has to be compared with C20 (see above). In C12 and C16, the entry wound was in a thick parietal bone, but the exit wound was in a less resistant bone (sphenoid and temporal fossa). This phenomenon was difficult to understand because one may assume that the bullet could be much altered after perforating a thick bone. In C15 (ratio 0.57) the bullet entered the occipital and exited the frontal bone. It is however observed that in the 4 cases all were smaller than entrance. Although the sequence of the bullets fired in these cases was not known, it is very likely that before the second bullet entered, the first bullet may already exploded the skull and thus making the exit for the second bullet smaller. These few ex-

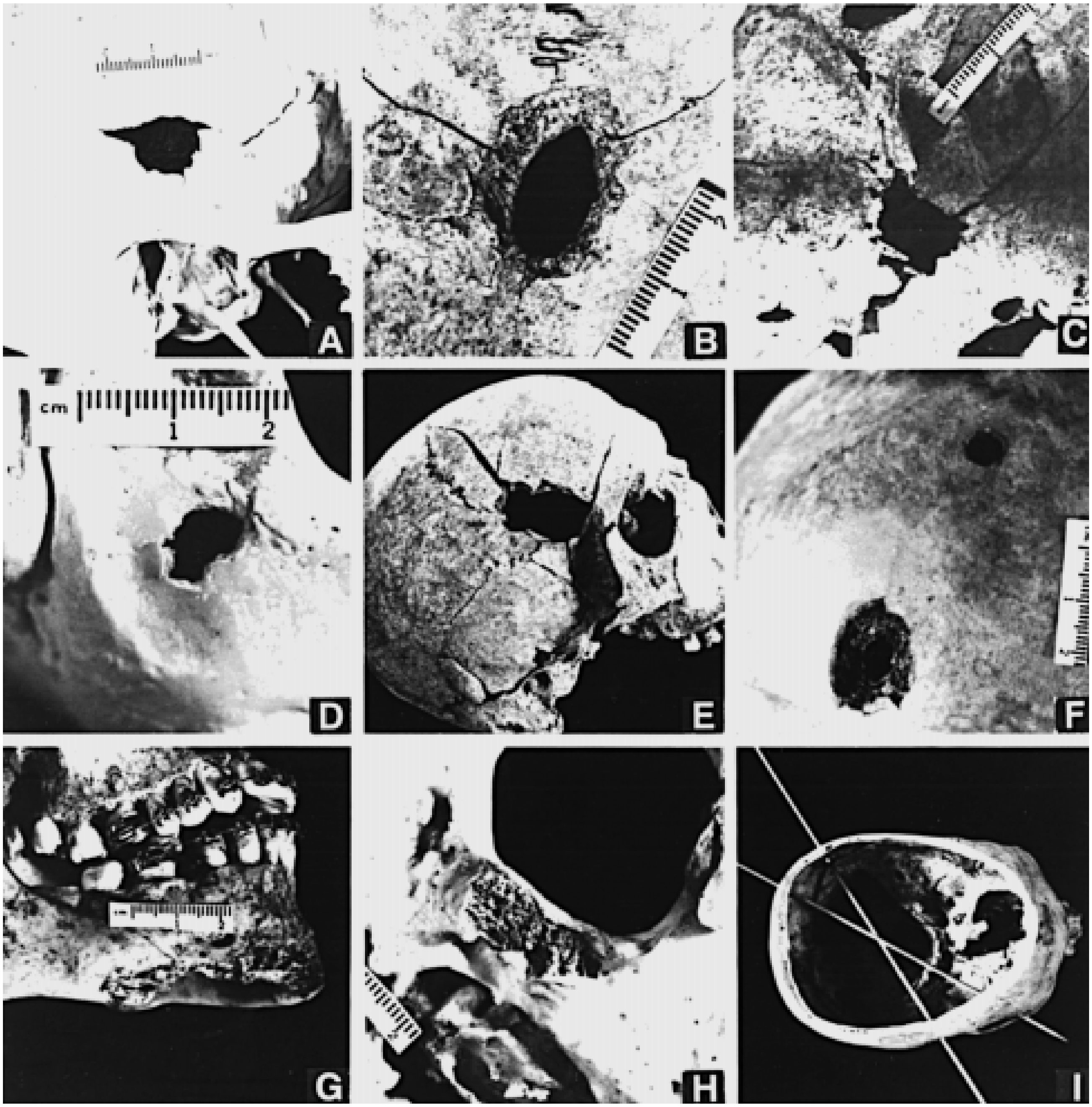

FIG. 2—*Exit wounds, tangential gunshot wounds and assessment of trajectory. Exit wound of C9 (2A) is roughly round in the right temporal bone with slight external beveling. Typical oval-shape exit wound with important external beveling is illustrated in right parietal bone of C12 (2B). Roughly rectangular-shape exit wound is seen in the right wing of the sphenoid of C21 (2C). Exit wound in 2D of C2 is irregular in the left occipital. Number "8" shape exit wound in the left frontal bone (C15) is very rare (2E). Typical external beveling of an exit wound in the right parietal bone (C2) is illustrated in 2F. The smaller wound in this figure is an entrance wound as already shown in Fig. 1A. Figure 2G shows tangential shot in the left ramus of a mandible (C11) and Fig. 2H (C4) in the left occipital condyle. Figure 2I of C12 illustrates reconstruction of the path with slim metal rods (e.g., knitting needles) from left to right parietal bone, and left parietal bone to the right greater wing of the sphenoid.*

amples confirm that the thickness of the bone is only one of the factors that may explain the large ranging of the exit to entrance wounds area ratio. Other factors that affect the exit/entry surface area ratio include age, sex, body size, race, and pathology affecting bone biology and thus its reaction to the bullet. The bullet itself also go through a range of change in its direction, tumbling and yawing before and during its bone penetration.

Angle and Pathway

Usually, the angle of the shot can be deduced from the shape of the entrance wound and beveling (4,19,20,23). A circular opening (as in C2) (Fig. 1A) should indicate a perpendicular entrance; while an oval aperture (as in C9) (Fig. 1B) suggests an oblique shot. A keyhole defect suggests a tangential shot, as does a cortical defect

(Fig. 2G), and a semi-tunnel, for example, in the mastoid (C19) (Fig. 1H). Symmetrical beveling usually indicates that the bullet struck the skull at a right angle (14). Asymmetry of the crater is usually associated with angulation of the missile, and the elongation of the bevel implies the direction of the trajectory (Fig. 1K) (23). However, there may be a deviation from this generality (19).

The direction of the shot is determined by establishing the relationship of the entrance and exit wounds—the path is usually straight between the two (although it may follow the curvature of the skull for a considerable distance or make a turn after striking bone or the dermal undersurface (2,23). A slim metal rod (e.g., knitting needle) spanning the entrance and exit reveals the line of fire (Fig. 2I) and also eliminates impossible pathways. This simple method is useful especially in multiple gunshot wounds with several entries and exits, as in case C12 (Fig. 2I). Table 2 shows that the pathways observed in this series are from one temporal to the other in 4 cases, and that the temporal bone showed the greater number of bullet wounds (9 cases). The parietal and occipital entrances were not rare (6 cases each); in contrast the frontal entrance was observed only in 2 cases in this series. The face was targeted in 6 cases.

Various pathways were observed, whatever the entrance location. The general direction of the pathways was from left to right in most cases (41.9%). In both suicide cases, the bullet entered and exited laterally. Suicides with a gun may vary and it is not unusual to see other entrance and exit locations, e.g., through the mouth or under the chin or even very unusual pathways (4,23).

Range and Velocity

Although the forensic case reports did not provide information, the range of fire and velocity of the missile are another important issue. Every forensic anthropologists must observe these characteristics to express an opinion on the matter of distance and velocity by interpreting fracture size, damage and patterns. The velocity of the missile can be estimated by the quantity and severity of the damage produced. A minimum velocity of 70 m/sec is necessary for a bullet to break through the surface of bone (26), but it obviously depends on the thickness of the bone. The production of fractures is dependent on the distance from the weapon at the time of discharge and kinetic energy (velocity) of the bullet (4), as well as the weight and shape of the missile when it perforates the skull, and the direction and site of impact (27). Skull fractures mechanisms can be compared to glass fractures mechanisms (28). The primary fracture is the entrance hole. Secondary fractures radiate from the point of impact of the bullet. These radial fractures are common (2,29,30), even in a low velocity shooting, although sometimes they are very superficial (Fig. 1E). The absence of these fractures indicates that the kinetic energy was totally absorbed by the primary fracture (the entry wound) (Fig. 1A). In other cases, massive fractures result when the energy is not totally absorbed by the primary fracture, creating secondary (radial) fractures (Fig. 1M), and even tertiary (concentric) fractures. High speed projectiles, as well as contact handgun wounds of the head, produce multiple severe fractures with open edges, large defects (Fig. 1C), or opening of the sutures. Sometimes the skull is badly fragmented (as in case C21), and must be reconstructed in order to establish the entrance, exit, and path of the bullet. This outcome is frequent in contact gunshot wounds, especially with a rifle, and strongly suggests suicide (case C21), or an execution-style murder (23). It should be noted that entrance fractures propagate across the skull faster than the bullet passes through the brain (27), and the exit fractures cannot cross the entrance fractures (31).

In conclusion, using forensic skeletal series shows that gunshot wounds in the skull have a number of commonalities. This study differs from those using recently deceased remains. It lacks many of the advantages that a forensic pathologist observes in a recently deceased case. It has been shown that the exit wounds were usually larger than the entry. Yet, there may be several factors that may make the entrance larger than the exit wounds. Beveling can be best assessed when it is on a thick bone. Most of the observed shapes of the entry wounds were round or oval. However these shapes partly depend on whether the bullet hit the target perpendicular or oblique. Exit wounds are more varied and nearly all are irregular. The shape and size of thin and fragile bones are very difficult to assess. The same is true about the direction of the bullet. It is imperative that anthropologists who are consultant to a medical examiners office are familiar with the crime scene where remains are found and complete recovery of remains are made.

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