Int J Legal Med (1995) 108:117–126

REVIEW ARTICLE

B. Karger

Penetrating gunshots to the head and lack of immediate incapacitation

II. Review of case reports

Received: 16 May 1995 / Received in revised form: 10 July 1995

Abstract Because of the enhanced intracranial tissue disruption (see companion paper) and the functional significance of the central nervous system, penetrating gunshot wounds of the head commonly result in immediate incapacitation. However, in the last century numerous publications reported sustained capability to act following penetrating gunshot wounds of the head. These are reviewed. A large number of case reports had to be excluded from re-examination because of doubtful capability to act or lack of morphological documentation. There remained 53 case reports from 42 sources for systematic analysis. Favourable conditions for sustained capability to act are present in cases where the additional wounding resulting from the special wound ballistic qualities of the head (see companion paper) are minimized. Thus, more than 70% of the guns used fired slow and lightweight bullets: 6.35 mm Browning, .22 rimfire or extremely ineffective projectiles (ancient, inappropriate or selfmade). A centrefire rifle or a shotgun from close range were never employed in cases involving intracerebral tracts. A coincidence of several lucky circumstances made sustained capability to act possible in two cases of military centrefire rifle bullets passing longitudinally between the frontal lobes without direct contact with brain tissue. Only two large handguns resulting in intracerebral wounding were used: one firing a .38 special bullet, which solely wounded the base of the right temporal lobe and one firing a .45 lead bullet, which seriously injured the left frontal lobe but whose trajectory was limited to the anterior fossa of the skull.

Of the trajectories, 28% were outside the neurocranium. At least 70% of the craniocerebral tracts passed above the anterior fossa of the skull, wounding the frontal parts of the brain. Apart from a neurophysiological approach, this preference can be explained by the fact that the base of the anterior cranial fossa and the sella turcica area serve as a bony barrier protecting the parts of the brain located in its "shadow" relative to the trajectory against cavitational tissue displacement and associated overpressures. This is particularly true of the brain stem. Intracerebral trajectories not located above the anterior fossa were caused by slow and lightweight bullets preferring one temporal lobe. Additionally, one parietal and one occipital lobe were each injured once by a very ineffective projectile and by a 7.65-mm bullet reduced in velocity. Not a single case of injury to the brain stem, the diencephalon, the cerebellum or major paths of motor conduction and only one grazing shot of the anterior parts of the nucleus caudatus (basal ganglia) were described. Morphological signs of high intracranial pressure peaks (cortical contusion zones, indirect skull fractures, perivascular haemorrhages) and secondary missiles were poorly documented. It is suggested that these findings are at least very rare and not obvious in cases of sustained capability to act.

Key words Case reports · Penetrating gunshot wounds of the head · Physical activity · Incapacitation

Introduction

In the companion paper to this article, wound ballistics of the head and mechanisms of incapacitation were discussed. Incapacitation has been defined as a physiologically based inability to perform complex and longer lasting movements independent of consciousness and intention. The inelasticity of brain tissue, the generation of secondary missiles and, especially, the unyielding walls of the skull greatly augment the effect of temporary cavitation. Because of the enhanced intracranial tissue disruption and the functional significance of the central nervous system (CNS), craniocerebral gunshot wounds have a high early mortality rate of 90% and more (Kaufman et al. 1986; Siccardi et al. 1991) and are commonly followed by immediate incapacitation. However, exceptions with lack of immediate incapacitation following penetrating gunshots to

B. Karger
Institute of Legal Medicine, Westfälische Wilhelms-Universität, Von-Esmarch-Strasse 86, D-48149 Münster, Germany

Table 1 Summary of 28 individual cases of multiple suicidal gunshots to the head. Only the first gunshot, which did not cause incapacitation, is detailed for each case (*n* total number of gunshots to the head)

Author	Firearm/ammunition	Entrance wound	Exit wound	Wounded brain areas/trajectory	Special features	*n*
Naegeli 1884	Lefaucheux revolver	Right temporal	/	Right temporal cortex	/	2
Goroncy 1924	Revolver	Right temporal	Left temporal	Transtemporal	/	3
Mueller 1933	Walther pistol 6.35 mm FMJ	Right temporal	Frontal	Extraneurocranial	/	2
Strassmann 1935	6.35 mm pistol	Frontal	/	Frontal cortex	/	2
Rooks 1935	Browning pistol 6.35 mm	Right frontal	Frontal	Extraneurocranial	/	2
Killinger 1938	old revolver	Right temporal	/	Transtemporal	Called for second shot	2
Spoerl 1940	6.35 mm pistol FMJ	Right temporal	/	Right temporal lobe	/	3
	Walther pistol 7.65 mm	Right temporal	Left temporal	Base of both frontal lobes	/	3
Rommeney 1942	Dreyse-pistol 6.35 mm	Right temporal	Left temporal	Both frontal lobes	Indirect fracture ant. fossa	3
Krauland 1952	Rifle	Submental	Unknown	Face (extraneurocranial)	Walked after the shot	2
Mason et al. 1967	.32 revolver, improper ammunition	Right temporal	/	Extraneurocranial, no perforation	Fatal heart wound	4
Vallazza 1969	Pistol .22	Right temporal	Left temporal	Transtemporal	/	2
	Pistol .22	Right temporal	/	Transtemporal	/	2
Reh 1971	Pistol 7.65 mm	Right temporal	Right bulb of the eye	Extraneurocranial	/	2
	Pistol 6.35 mm	Right temporal	Left temporal	Cortex of both frontal lobes	/	4
Barz 1973	Mauser pistol 7.65 mm (7.63 mm?)	Right temporal	Left temporal	Extraneurocranial	Rose for second shot	2
Distelmeier 1977	Revolver, selfmade lead ball	Right temporal	/	Extraneurocranial, no perforation	Walked to hospital	3
Fryc et al. 1979	Military rifle	Submental	Frontal	Between (!) frontal hemispheres	Wrote after the shot	3
Lee 1980	Shotgun, contact range	Submental	Frontal	Face (extraneurocranial)	Reloaded	2
Missliwetz 1983	FN Browning Baby 6.35 mm	Right temporal	Left eye	Extraneurocranial	/	2
Krauland 1984	Pistol 6.35 mm	Retromandibular	Mouth	Extraneurocranial	Manual extraction of case	2
Maxeiner 1986	Modified blank pistol, 7.65 mm FMJ	Right temporal	/	Base of right temporal lobe	Reloaded	3
Sigrist et al. 1986	5.6 mm rimfire rifle (.22 short)	Frontal	/	Cortex of both frontal lobes	Reloaded, survival > 24 h	5
Cremer 1987	Percussion revolver Navy .44	Frontal	/	Extraneurocranial	Reloaded (muzzle loader)	2
Jacob et al. 1989	Modified 8 mm blank revolver	Mouth	/	Left frontal lobe	Bullet: 6.35 mm FMJ	2
	Rimfire rifle (.22 long rifle)	Mouth	/	Extraneurocranial	Reduced charge	3
Selway 1991	.22 rifle	Submental	/	Extraneurocranial	Fetched a second round	2
Faller et al. 1994	Walther PP pistol 7.65 mm	Submental	Below right eye	Extraneurocranial	/	2

Table 2 Summary of 25 individual cases of gunshots to the head followed by physical activity exceeding any attributable to reflexes or automatisms

Author	Firearm/ammunition	Entrance wound	Exit wound	Wounded brain areas/trajectory	Special features
Naegeli 1884	Small revolver	Right temporal	/	Transtemporal	Bullet in left temporal bone
	Small revolver	Right temporal	/	Extraneurocranial	Bullet in right temporal bone
	Terzerol (old primitive handgun)	Frontal	/	Both frontal lobes	Bullet inside left lateral ventricle
	Old pistol	Right temporal	/	Cerebral nerves (extracerebral)	/
	Old revolver	Left temporal	/	Left temporal cortex	/
	Small Lefaucheux revolver	Right temporal	Right temporal (fragment)	Right frontal lobe	Paralysis of legs
Puppe 1908	7 mm pointed bullet	Right temporal	/	Right frontal cortex	/
Goroncy 1924	7.5 mm bullet	Left temporal	Right frontal	Both frontal lobes	/
	Revolver	Frontal	/	Left frontal lobe	Walked 10 km
Sterba 1924	7 mm revolver	Right temporal	/	Transtemporal	Survival
Weimann 1928	Browning pistol (probably 6.35 mm)	Right temporal	Left temporal	Transtemporal	Walked 6 km
Leschmann 1932	Target rifle (most likely rimfire)	Right temporal	/	Transtemporal	Dissimulation for days
Rooks 1933	Browning pistol 7.65 mm	Right temporal	Left frontal	Both frontal lobes	Dissimulation, indirect fracture
Strassmann 1935	Handgun	Right temporal	Left cheek	Right temporal lobe	Homicide, walked several steps
Killinger 1938	Walther pistol 6.35 mm FMJ	Right temporal	Left temporal[a]	Both frontal lobes[a]	Multiple indirect fractures
	Browning pistol 6.35 mm	Right temporal	Left temporal	Transtemporal	Survival > 1 month
Smith 1943	Colt revolver .45	Submental	Frontal	Left frontal lobe	Communication, walked > 200 m
Krauland 1952	Military rifle World War II	Submental	Frontal	Between (!) frontal hemispheres	Walked to ambulance
Bartmann 1954	Pistol	Right temporal	Left temporal	Base of both frontal lobes	Walked more than 30 m
Herbich 1955	Pistol 7.65 mm	Right temporal	/	Both frontal lobes	Survival for 9 years
Zelder et al. 1972	6.35 mm pistol	Right temporal	Left fronto-parietal	Both frontal lobes	Aphasia
Klages et al. 1975	7.65 mm pistol FMJ	Right temporal	/	Right parietal lobe (most likely)	Left hemiplegia, recovery
Engel 1977	Walther 08 pistol, 6.35 mm	Left temporal	Right temporal	Transtemporal	Intentional activity in the room
Sellier 1982	7.65 mm pistol	Right temporal	Left temporal	Transtemporal	Conversation, walked
Bratzke et al. 1985	Revolver S+W .38 special	Right cygomatic	/	Base of right temporal lobe	Attempted homicide, walked

[a] Killinger recorded "high left fronto-parietal" for exit wound and "right temporal and left parietal lobe" for wounded brain areas; the author has corrected both statements in keeping with data supplied by Killinger, as they were obviously incorrect. No other details in the case reports reviewed have been changed

the head have been reported. These will be reviewed in the light of the theoretical basis presented already.

Selection of case reports

Results of animal experiments concerning incapacitation cannot be transferred to man. Every hunter is familiar with the fact that similar hits cause different reactions in different animal species. Therefore, publications reporting lack of instantaneous incapacitation in man will be examined with regard to several parameters.

The crucial factor in the selection of case reports was to guarantee lack of immediate incapacitation beyond any reasonable doubt. Therefore, only the following kinds of case reports have been included for evaluation:

1. Clearly defined cases of suicide involving two or more penetrating gunshots to the head (Table 1). When a second shot has been fired by the victim himself, incapacitation can definitely be excluded. Only if the second shot had been fired to the identical region of the head could it be argued that it was discharged by automatism. But in at least 3 out of only 6 cases with two entrance wounds in identical regions of the head, meaningful physical activity after the first shot has been documented by the person's walking purposefully (Krauland 1952), rising again to shoot (Barz 1973), or engaging in conversation (Killinger 1938). Positive proof of suicide had to be guaranteed by a reconstruction of the events. The determination of the first shot failing to cause incapacitation was also accomplished by a reconstruction of the events, at best supported by theoretical premises about the effects of the trajectory in question or by testimony.

2. Clearly defined cases of suicide involving a penetrating gunshot to the head and positive proof of lacking incapacitation (Table 2). These include, for example, cases of dissimulation of the injury, communication, walking up to 10 km following the gunshot or no incapacitation, testified to by persons not involved in the events. Furthermore, a conventional firearm shooting a free-flying projectile accelerated by a propellant had to be used.

Consequently, the following criteria of exclusion were established:

– The use of more than one firearm permitting simultaneous firing (Rommeney 1942, case 7; Fatteh et al. 1980; Hudson 1982; Sellier 1982; Marchiori 1983; Rogers 1989; Urban et al. 1994).
– The use of a humane killer for livestock slaughter (Liebegott 1949; Schiermeyer 1973), air rifle (Pollack 1978; Dittmann 1986; Cohle et al. 1987) or signal pistol (Cseh 1933).
– The use of a military rifle set on full automatic mode, so that it is not necessary to pull the trigger twice in order to fire a second shot (Walther 1970; Al-Alousi 1990).
– Lack of positive proof of suicide beyond any reasonable doubt (e.g. Maschka 1884; Winter 1932).
– Absence of satisfactory reconstruction of the sequence of shots (e.g. Schwarzacher 1921; Strassmann 1935, cases 6 and 8; Rommeney 1942, case 2; Greiner 1973).
– Lack of essential information as to the type of firearm used (e.g. Lewinski 1939), the location of the wounds (e.g. Händel 1968) or the direction of the trajectory (e.g. Naegeli 1884). Several collections of case reports were not considered because of inadequate documentation or repetition of cases published before (e.g. Foerster 1888).
– Restored capability to act after primary incapacitation (e.g. Cseh 1933). In a few cases included here, short initial periods of unconsciousness or incapacitation could not be excluded beyond any doubt. But the reconstruction of events, and especially the bloodstains, did not supply indications of primary unconsciousness in any of these cases.

Rigorous observation of these criteria meant that a large number of publications allegedly reporting lack of immediate incapacitation had to be rejected. A total of 53 case reports, taken from 42 sources, met these criteria and are thus regarded as reporting actual cases of lack of immediate incapacitation following penetrating gunshots to the head.

Table 3 Summary of the firearms used

Firearms used	53	
Pocket revolvers and old, low-energy handguns	10	(19%)
Modified blank handguns or selfmade/improper ammunition	5	(9%)
.22 pistol	2	(4%)
5.6 mm rimfire rifle	4	(7.5%)
6.35 mm pistol	13	(24.5%)
7.65 mm pistol	8	(15%)
.45 Colt revolver	1	(2%)
.38 special revolver	1	(2%)
Centrefire rifle	3	(6%)
Shotgun (contact shot)	1	(2%)
Not known precisely	5	(9%)

Table 4 Summary of brain areas injured or trajectories (where transtemporal is stated)

Wounded brain areas or trajectories	53	
One or both frontal lobes	17	(32%)
Transtemporal (no autopsy or no precise cerebral morphological findings)	11	(21%)
One temporal lobe	6	(11%)
Right parietal lobe	1	(2%)
Extraneurocranial	15	(28%)
Intraneurocranial but extracerebral	3	(6%)

Results

Tables 1 and 2 show the firearms used, the locations of entrance and exit wounds, the injured brain areas (location of permanent tract) or the trajectories (no autopsy or morphological documentation) and special features for each individual case. Tables 3 and 4 show the summarized results concerning the firearms and the wounded areas/trajectories.

Cortical contusion zones, indirect skull fractures and cerebral perivascular haemorrhages are important morphological signs of high intracranial overpressures (see companion paper). They were not included in the systematic analysis, however, for most case reports did not contain any information, either positive or negative, on these findings.

Discussion

When dealing with the capability to act following gunshots, Meixner (1931) and others regretted reporting a number of individual cases without being able to detect systematic correlations. Strassmann (1935) stated that the physical activity of a fatally injured victim may not be predicted. So far, there are only scattered annotations concerning the frequent use of low-energy firearms and the preference for the frontal brain in cases of sustained capability to act after penetrating gunshots to the head (Goroncy 1924; Meixner 1931; Sellier 1982; Krauland 1984; Bratzke et al. 1985; Sigrist and Patscheider 1986; Jacob et al. 1989). None of these statements has been supported by figures. This publication is an effort to provide actual figures and to establish systematic correlations between wounding and capability to act.

Epidemiology

By reviewing case reports it is of course not possible to collect epidemiological data on, for example, the incidence of sustained physical activity following gunshots to the head. Nevertheless, most authors justified publishing their case reports by pointing out their highly unusual features.

Old statistical studies reported multiple shots to account for 6–10% of all (!) suicidal gunshots (Schrader 1942), while more recent publications state 1.3% (Eisele et al. 1981), 1.4% (Missliwetz 1977) and 4.6% (Ropohl and Koberne 1990). In a large survey of 3522 suicides by firearms, Hudson (1981) determined 58 multishot firearm suicides (1.6%). Among them were 7 cases of multiple gunshots to the head, representing 0.2% of all firearm suicides and approximately 0.3% of all suicidal headshots. Of the 58 subjects firing twice or more, 29 used .22 caliber revolvers, and the three rifles used were .22 rimfire. Staak and König (1977) investigated 43 fatal gunshots to the head with regard to physical activity. According to the definition published by Petersohn (1967), they determined three cases of physical activity degree 2 (automatism) and one case in which degree 3 (instinctive reaction) could not be completely excluded. The four handguns used had calibres of 5.6–7.65 mm. Undisturbed consciousness did not exist in any case.

Firearms

The muzzle energy represents at most the maximum wounding potential of a bullet (see companion paper). For example, even bullets of identical mass and velocity but different construction can cause wounds differing quite substantially in severity (Fackler et al. 1988). Hence, energy figures should be regarded rationally. Impact energy and energy deposit are nothing more than indicators that may, together with other features of a bullet, help in an estimate of the resultant degree of wounding. This is how energy figures stated for bullets in the next section should be understood.

Among the firearms used (Table 3), small-calibre, low-energy handguns obviously predominate. In 10 cases (19%), so-called pocket handguns and other ancient small handguns were used. The propellant frequently consisted of fulminating mercury, and the biological effect has been compared to that of toys by contemporary writers (Schaefer 1900). In 2 cases (4%), pistol ammunition was fired from modified blank handguns with over-sized caliber barrels. In 3 more cases (6%), self-made or inappropriate ammunition was used, in 1 case lead balls fired from a replica of a black powder muzzle-loading revolver with a muzzle velocity of only 90 m/s (Cremer 1987).

Therefore, the ammunition used in 15 cases (28%) had a very low charge, resulting in extremely ineffective, low-energy projectiles not comparable to modern conventional handgun ammunition. In no case was there an exit wound, apart from a fragment exiting on the entrance side (Naegeli 1884). In 4 cases the penetration power was not sufficient to perforate the skull at the impact site (Naegeli 1884; Mason et al. 1967; Distelmeier and Vlajic 1977; Cremer 1987).

A 5.6-mm pistol or a 5.6-mm rimfire rifle was used in 6 cases (11%), once each with reduced charge (Jacob et al. 1989) and outdated ammunition barely penetrating the skull (Sigrist and Patscheider 1986). Most of the 5 firearms (9%) not exactly known were probably also shooting low-energy projectiles. These were all handguns, and the time of publication was 1924 in 3 cases. A total of 13 shots (25%) were fired by pistols of 6.35 mm calibre. By far the most common 6.35-mm ammunition is Browning, which has a mass of 3.2 g and a muzzle velocity of approximately 230 m/s. The muzzle energy is therefore only about 100 J, which ranks at the very bottom of conventional handgun ammunition. In 5 cases each the trajectories were extracranial and transtemporal. One or both frontal lobes were affected in 3 cases. Altogether, then, lightweight and slow conventional handgun bullets (Browning 6.35 mm), .22 rimfire bullets and extremely ineffective projectiles, which are much more innocuous than any modern bullet, account for 39 (74%) of the cases. Even when the 5 unknown firearms are excluded, the ratio (34 out of 48: 71%) remains the same.

Ammunition from 7.65 mm upwards was used in the other 14 cases. Therefore, they will be analysed in more detail:

A total of 8 shots (15%) were fired from a 7.65 mm pistol. Depending on mass and velocity, the different 7.65-mm ammunition has a muzzle energy of approximately 300–360 J. Extraneurocranial trajectories were present in 3 cases, one with contusions of the basal frontal cortex by the fragmenting roofs of the orbitae (Barz 1973). Both frontal lobes were perforated in 3 cases, and in 1 case the direction of the trajectory was transfrontal.

In an unusual case (Klages et al. 1975), the 7.65 mm bullet just about reached the falx of the cerebrum after impacting in the upper right temporal region. The resulting acute hemiplegia of the left side corresponded to the radiologically expected trajectory in the right parietal lobe. While age and condition of weapon and ammunition could not be traced, the strikingly short trajectory must have been due to a substantial reduction of velocity. Of the other 8 shots fired with 7.65 mm ammunition, 6 caused perforating wounds while 1 bullet lodged inside the bone at the exit side (Herbich 1955).

A Smith and Wesson .38 special revolver (Remmington lead bullet, 10.2 g, about 260 m/s and about 350 J) was used in 1 case (Bratzke et al. 1985). Lack of immediate incapacitation and survival were due to a very lucky trajectory: after impacting in the right cheek and perforating the zygomatic process and the relatively thick base of the skull in the middle cranial fossa, the bullet injured the base of the right temporal lobe before striking the anterior surface of the petrosus part of the temporal bone, which was severely fractured. The long extracranial trajectory including 2 bone contacts and the short intracranial track stopped by the massive petrosal bone made intentional physical activity (writing a note, crawling) possible.

In 3 cases, a centrefire rifle was used. Krauland (1952) reported on a submental contact shot from a military rifle (World War II). The trajectory passed through the floor of the mouth, hard palate, maxilla and sinus frontalis before entering the neurocranium. The bullet then passed through the longitudinal space between the frontal hemispheres causing only contusion bleedings in the cortex and slight subdural bleeding. The large frontal exit wound as well as a long radial fracture at the base of the skull demonstrate that the bullet still had a considerable amount of residual energy left. The man survived for 4 h, during which he walked around and went downstairs. Considering the rather mild brain lesion, sustained capability to act was not a surprising finding. It was surprising, however, that a contact shot from a military rifle resulting in an intracranial trajectory did not cause more serious brain damage. Several factors contributed to this extraordinary event: first, a long extracranial trajectory including the hard palate and maxilla was located in front of the neurocranium. This caused a substantial decrease in velocity. Secondly, there was no direct contact with brain tissue, so that crushing of the tissue did not take place. Thirdly, the intracranial trajectory was very short, at most 4 cm according to the photograph. This short distance would not have allowed a huge intracranial temporary cavity to be formed, even if the diameter had been large. Last but not least, the bullet passed through the ventral part of the anterior fossa of the skull. This location enabled the base of the anterior cranial fossa and the sella turcica area to act as a barrier against cavitation-caused tissue displacement and associated overpressures directed downwards. This phenomenon will be discussed in more detail in the next section. Thus, as in the case of the aforementioned .38 special bullet, a coincidence of several fortunate circumstances led to mild intracranial effects despite a potentially powerful projectile.

In an almost identical case (Fryc and Krompecher 1979) a submental contact shot from an unspecified military rifle resulted in an intracranial longitudinal trajectory between the frontal lobes without direct contact with brain tissue. The same factors as described above were responsible for delayed incapacitation. The third shot from a centrefire rifle (not specified at all) caused partial destruction of the skull of the face, but the neurocranium was not affected (Krauland 1952).

In a very exceptional case a .45 Colt revolver (bullet approx. 16 g, 260 m/s, 570 J) was used for a submental contact shot (Smith 1943). After perforating the floor of the mouth the tract passed into the skull through the dorsal part of the roof of the left orbita and exited through the frontal bone. The left frontal lobe was lacerated, and the left temporal lobe was also affected. Nevertheless, the man was able to communicate and to walk more than 200 m. Unfortunately, the morphological description was sparse. Extracranial bone contact probably took place, but was not mentioned. Again, a long extracranial trajectory and the location of the intracranial tract above the anterior cranial fossa mitigated the intracranial effect of a powerful bullet to a certain degree. Nevertheless, the extent of intracranial wounding was the most extensive described in the case reports reviewed. Sustained capability to act could possibly be explained by the fact that wounding was essentially limited to the frontal lobe above the anterior cranial fossa. It is the author's opinion, however, that the vast majority of similar bullet wounds will result in immediate incapacitation.

Because of pellet dispersion and rapid decrease in velocity only shotgun wounds from close range are comparable. A submental contact shot from a single-barrelled shotgun caused severe destruction of the lower skull of the face without intraneurocranial injury (Lee 1980).

Altogether, the majority of firearms (39/53: 74% or 34/48: 71%) were ancient handguns firing ineffective projectiles, modified blank pistols, handguns firing self-made or inappropriate ammunition and firearms firing 5.6 mm rimfire or 6.35 mm Browning bullets. In 8 cases (15%), a 7.65 mm pistol was used. The remaining 6 cases (11%) were made up of a .38 special lead bullet which only wounded the base of the right temporal lobe, a .45 lead bullet passing through the left frontal lobe above the anterior fossa, 2 hits from centrefire rifles without direct contact to brain tissue and 2 extraneurocranial hits, one from a centrefire rifle and one from a shotgun at contact range.

Wounded brain areas

Obviously, bullet injuries of the head may cause brain damage or they may not. The significance of differentiating penetrating craniocerebral missile wounds from gunshots to the head in general is stressed by Table 4. 15 hits (28%) did not result in cerebral wounding because the trajectory remained outside the neurocranium, most frequently in the skull of the face or inside the bulbus of the eye. Lack of incapacitation was not surprising, since there is no such thing as commotio cerebri in penetrating shots to the head (see companion paper).

The largest group (17 = 32%) with regard to location of cerebral wounding was formed by injuries to one or both frontal lobes, thus supporting the remarks from other authors (e.g. Goroncy 1924; Meixner 1931; Sellier 1982).

From a functional or neurophysiological point of view this preference for the frontal brain in cases of delayed incapacitation is easy to understand: the frontal brain does not include areas immediately essential to acting or consciousness. But there is also a ballistic or anatomical approach to this phenomenon. The frontal brain is located in the anterior fossa of the skull. The base of the anterior cranial fossa together with the sella turcica area can be regarded as an almost horizontal bony plate acting as a barrier against radial tissue displacement and associated overpressures directed downwards. A trajectory inside the frontal lobes has to pass over this plate, which will thus protect those parts of the brain located in its "shadow" by diminishing the effects of temporary cavitation. Depending on the height of the trajectory in the anterior cranial fossa, at least the caudal and possibly the central and dorsal parts of the brain will be protected to a certain extent. This bony protection will reduce the magnitude of the mechanical forces acting upon those parts of the brain. In particular, the brain stem will be pushed with less violence into the foramen magnum and against its rims and edges. The central and dorsal parts will be protected if the bullet does not pass too high above the base of the anterior cranial fossa.

The protective function of the anterior cranial fossa and the sella turcica area will be even more obvious if the 11 cases of transfrontal trajectories (21%) are considered. In these cases, either an autopsy was not performed or cerebral morphological findings were lacking. Instead of the wounded brain regions, therefore, the trajectory was determined from the wounds of entrance and exit, which were located temporally in all cases, or from the direction of the trajectory in the case of the shots not exiting. In the majority of injuries to the frontal lobes, and even in some of the extracranial trajectories, temporal sites were given for the entrance wound. According to Sellier (1982), a typical temporal suicidal gunshot will usually result in wounding of the frontal instead of the temporal lobes. Consequently, a high percentage of the transtemporal trajectories must actually have been located in the frontal lobes or even outside the neurocranium. Furthermore, the 2 cases of trajectories between the frontal lobes (Krauland 1952; Fryc and Krompecher 1979) were also located in the anterior cranial fossa. Therefore, a minimum of 19 out of 38 (50%) craniocerebral gunshot wounds were located in or above the anterior cranial fossa. Considering the transtemporal trajectories, however, 30 out of 38 intracranial trajectories (79%) most probably passed above the anterior cranial fossa. If the transtemporal trajectories are excluded, 19 of the remaining 27 intracranial trajectories (70%) were located above the anterior fossa.

Among the remaining 8 cases of intracranial injury not located in the anterior cranial fossa (15%), there was 1 case each of isolated injury to brain nerves (Naegeli 1884) and of wounding to the ventral part of the right parietal lobe (Klages et al. 1975). The other 6 cases involved only one temporal lobe. In no case was there wounding of both temporal lobes, probably because most such trajectories would also have to transit central parts of the brain. This further supports the assumption that transtemporal trajectories not causing immediate incapacitation must traverse in front of the temporal lobes above the anterior cranial fossa.

Apart from the .38 special bullet with its fortunate trajectory (Bratzke et al. 1985) and possibly the unspecified handgun resulting in an exit wound (Strassmann 1935), the remaining 6 bullets causing intracranial lesions not located in the anterior cranial fossa must have been of rather low energy. This can be concluded from the descriptions of the firearms (small revolver, Lefaucheux revolver, modified blank pistol, etc.) as well as from the fact that the transversal tracts were restricted to one hemisphere. It must also be true for the 7.65 mm bullet that caused damage to the parietal lobe at the entrance side (Klages et al. 1975).

Interesting in this context is the second shot from a two-barreled blank pistol (barrels enlarged to 10 mm) firing 7.65 mm FMJ bullets (Maxeiner et al. 1986). The man was able to manually reload even after the second shot impacting in the right temporal region had perforated the right temporal and occipital lobes. A ballistic reconstruction showed a muzzle velocity of only 90 m/s.

In no case did the trajectory pass through the brain stem, the diencephalon, major motor paths of conduction or the cerebellum. The motor cortex was injured once by a 7.65 mm bullet of reduced velocity (Klages et al. 1975). The central grey matter was never hit directly, but the most anterior parts of the caput of the left nucleus caudatus were grazed once by a 7.65 mm bullet (Herbich 1955).

Altogether, then, the vast majority of gunshots to the head missed the brain or the trajectory was located in the anterior cranial fossa, wounding one or both frontal lobes. In the remaining 8 cases, bullets with a low velocity or a very fortunate trajectory caused injuries to isolated lobes of the brain, favouring one temporal lobe. Because of the low velocity resulting in markedly diminished temporary cavitation, the extent of injury inside these lobes was small and well defined.

Craniocerebral signs of intracranial peak pressure

Indirect skull fractures are an excellent measure for intracranial peak pressures in relation to the individual skull (see companion paper). The vast majority of case reports did not contain any information on skull fractures, though three publications clearly denied and seven affirmed fractures. The character of these seven fractures with regard to their origin (direct/indirect) was not clearly stated, but according to the sometimes sparse morphological description, four of them were direct fractures caused by the impact of the bullet. Therefore, a systematical analysis was not possible.

Definite secondary fractures as a result of high intracranial overpressures (see companion paper) have been described in three case reports. All three tracks perforated both frontal lobes and the pistols used were caliber 6.35 mm (Killinger 1938; Rommeney 1942) and 7.65 mm (Rooks 1933). Indirect fractures were located in the roofs of the orbits and in the ethmoidal plates. These preferential sites in the anterior fossa have been described before in a large study (Klaue 1949). Surprisingly, there were additional small indirect fractures of the middle and posterior cranial fossa in 1 case (Killinger 1938). But the generation of indirect fractures always depends on the relationship between intracranial overpressure and individual resistance of the skull to stretch forces. Unfortunately, Killinger (1938) did not remark on the constitution of the skull.

Even if the information on skull fractures was fragmentary it can be assumed that obvious fractures, especially indirect ones, would have been reported at least in the majority of cases. Therefore, it can be cautiously concluded that indirect skull fractures are a very rare finding in penetrating craniocerebral gunshots lacking incapacitation. Furthermore, in two out of three cases describing indirect fractures (Rooks 1933; Rommeney 1942) these were restricted to the orbital roof at the entrance side, which represents a point of mechanical weakness as well as the point of greatest pressure effect in cases of tracts traversing the anterior cranial fossa.

The findings in the present series therefore support the interpretation of indirect skull fractures as signs of high intracranial overpressure. Specifically searching for indirect fractures in cases without incapacitation as well as in a large number of craniocerebral gunshots resulting in immediate incapacitation would help in further quantification of the significance of indirect fractures for the capability to act. Klaue (1949) reported 140 indirect fractures (18%) out of 777 cases of penetrating gunshots sustained during World War II. But considering the field conditions under which the autopsies were performed, a considerable number of indirect fractures might have eluded detection.

Compared with skull fractures, the case reports contained even less information on cortical contusion zones, intracerebral petechial haemorrhages and intracranial haematomas. Rooks (1933) and Killinger (1938), for example, described petechial haemorrhages in the vicinity of the permanent tract, which is a logical finding (Freytag 1963; Oehmichen et al. 1985; Finnie 1993). In no case were petechial haemorrhages remote from the tract reported. The same applies to notable cortical contusion zones and intracranial haematomas. Thus, although some authors might not have specifically been searching for these findings, they must at least be very rare and not obvious in cases of sustained capability to act. Whether they occur at all can only be determined by a systematic search.

Even massive intracranial haemorrhages commonly do not contribute to immediate incapacitation (see companion paper). This is illustrated by a case where the second gunshot to the head caused profuse bleeding from the sinus sagittalis (Goroncy 1924). Nevertheless, the man was able to change the position of the revolver and fire a third and fatal shot.

Miscellaneous

Secondary missiles in the form of bone chips or bullet fragments or resultant secondary tracts were hardly mentioned in any of the case reports. Bratzke et al. (1985) described an intracerebral fragment of a lead bullet. Intracerebral secondary missiles frequently escape demonstration by macroscopic observation or digital palpation (Kirkpatrick and DiMaio 1978). But with regard to wound ballistics, prerequisites for the generation of secondary missiles are fracture zones at the impact site or fast or suitably constructed projectiles. This did not apply to the vast majority of cases. So at least multiple or massive intracerebral secondary projectiles can be ruled out indirectly in most cases.

Cushing (1918) and others regarded transventricular gunshot wounds to be a serious complication resulting in very high mortality and rapid unconsciousness. Apart from a tamponade of the ventricular system, however, there is no direct pathophysiological mechanism capable of causing rapid incapacitation. But the brain tissue forming large parts of the walls of the ventricular system is of functional significance for consciousness and activity. Direct injury to these brain areas, possibly aggravated by augmented temporary cavitation in the ventricle as a liquid-filled cavity, rather than the perforation of the ventricle itself is probably responsible for the reported poor prognosis of these hits. The anterior parts of the lateral ventricles, however, are not surrounded by essential brain regions. Therefore, a transventricular trajectory in this region has been demonstrated to be compatible with lack of incapacitation (Herbich 1955).

Staak and König (1977) proposed using the physical data of the projectile and the location of the trajectory to construct a projected image of the temporary cavity to determine the brain regions injured. To accomplish this, they assumed a fixed numerical ratio of 1:3:5 between the diameter of the permanent tract, the zone of extravasation and the temporary cavity. This assumption is not valid. The temporary cavity itself does not injure anything, it is the tissue displacement caused by cavitation that causes additional wounding (see companion paper). Most importantly, there is no fixed relationship concerning the extent of different zones of wounding. Even otherwise identical projectiles that are of different construction will produce very distinct wounds differing for example in diameter of permanent tract and zone of extravasation (Fackler et al. 1988). A range of variable parameters, comprising angle of impact, skull thickness, intermediate targets, generation of secondary missiles, fragmentation, deformation or yawing of the bullet, ricocheting from the inner table of the skull, etc., will interfere with general theoretical considerations concerning the extent of injury. Therefore, this approach is not practicable. Unless each case is investigated individually and manually there is no way that statements on the extent of injury and its effects can be made. The basis of this investigation will always be an autopsy.

Conclusion

Favourable conditions for sustained capability to act following penetrating gunshots to the head are present in cases where the additional wounding resulting from the special wound ballistic qualities of the head are minimized. This is best fulfilled by slow and lightweight projectiles: more than 70% of the guns used fired 6.35 mm Browning bullets, .22 rimfire bullets or extremely ineffective projectiles not comparable to any modern bullet.

In the literature reviewed, there is not a single case of missing incapacitation following an intracerebral hit from a centrefire rifle or a shotgun from close range. The 2 military centrefire rifle bullets passed longitudinally between the frontal lobes with no direct contact with brain tissue. Only 2 large handguns were used: a coincidence of several lucky circumstances made sustained capability to act possible in one case of a .38 special bullet that wounded the base of the right temporal lobe exclusively and in one case of a .45 lead bullet that lacerated the left frontal lobe but whose trajectory was limited to the anterior fossa of the skull.

Of the trajectories, 28% were outside the neurocranium, thus not affecting the brain. At least 70% of the craniocerebral tracts passed above the anterior cranial fossa, wounding the frontal parts of the brain. This preference can be explained from both a neurophysiological and a wound ballistic point of view. The base of the anterior cranial fossa and the sella turcica area serve as a bony barrier protecting those parts of the brain located in its "shadow" relative to the trajectory against cavitational tissue displacement. This is particularly true of the brain stem. Intracerebral trajectories not located above the anterior fossa were caused by low-energy bullets preferring one temporal lobe. One parietal and one occipital lobe were each injured in one case, by a very ineffective projectile and by a 7.65-mm bullet reduced in velocity. Therefore, sustained capability to act following craniocerebral gunshots is very unlikely if even one of the followig two conditions is fulfilled:

1. Use of a firearm from about 9 mm Parabellum upwards in terms of penetration power and wounding potential (large handguns, centrefire rifles). To increase the probability of incapacitation further, intracerebral trajectories above the anterior cranial fossa or very short ones should be excluded.
2. Definite presence of signs of high intracranial overpressures: indirect skull fractures, intracerebral petechial hemorrhages remote from the tract, and cortical contusion zones.

Incapacitation can be determined beyond any doubt if central nervous centres essential for physical activity are wounded directly. In the literature reviewed, not a single case of injury to the brain stem, the diencephalon, the cerebellum or major paths of motor conduction has been described. The central grey matter can also be included, for there was only one "grazing" shot of the most ventral parts of the caput of the caudate nucleus. The motor cortex was injured in one case by a slow projectile, probably restricting wounding to the permanent tract and resulting in acute hemiplegia.

Acknowledgements The author would like to thank M. Fackler and F. Unterharnscheidt for a critical review of the manuscript.

References

Al-Alousi LM (1990) Automatic rifle injuries: suicide by eight bullets. Am J Forensic Med Pathol 11:275–281

Bartmann F (1954) Dubiose Fälle. Schmidt-Römhild, Lübeck, pp 24–25

Barz J (1973) Selbsttötung durch zwei Kopfschüsse. Z Rechtsmed 73:61–63

Bratzke H, Pöll W, Kaden B (1985) Ungewöhnliche Handlungsfähigkeit nach Kopfsteckschuß. Arch Kriminol 175:31–39

Cohle SD, Pickelman J, Connolly JT, Bauserman SC (1987) Suicide by air rifle and shotgun. J Forensic Sci 32:1113–1117

Cremer U (1987) Rekonstruktionsversuch einer ungewöhnlichen suicidalen Mehrfachschußverletzung. Beitr Gerichtl Med 45: 109–115

Cseh I (1933) Rückkehr der Handlungsfähigkeit nach ungewöhnlich ausgedehnter Hirnzerstörung durch Schußverletzung. Dtsch Z Gerichtl Med 22:185

Cushing H (1918) A study of a series of wounds involving the brain and its enveloping structures. Br J Surg 5:558–684

Distelmaier P, Vlajic I (1977) Lage eines Geschosses in einem Hirnventrikel. Fortschr Röntgenstr 126:71–72

Dittmann W (1986) Gehirnschußverletzungen durch Luftdruckwaffen. Z Rechtsmed 96:119–131

Eisele JW, Reay DT, Cook A (1981) Sites of suicidal gunshot wounds. J Forensic Sci 26:480–485

Engel F (1977) Handlungsfähig trotz tödlicher Kopfschußverletzung. Kriminalistik 31:272–273

Fackler ML, Bellamy RF, Malinowski JA (1988) The wound profile: illustration of the missile-tissue interaction. J Trauma Suppl 28(1):S21–S29

Faller-Marquardt M, Pollak S (1994) Zweimalige suizidale Schußabgabe mit submentaler und parietaler Einschußlokalisation. Arch Kriminol 193:129–138

Fatteh A, Gore SB, Mann GT, Garvin K (1980) Suicide with two guns: a unique case. J Forensic Sci 25:883–885

Finnie JW (1993) Pathology of experimental traumatic craniocerebral missile injury. J Comp Pathol 108:93–101

Foerster G v (1888) Ueber Doppelschädelschüsse bei Selbstmördern. Dissertation, Berlin

Freytag E (1963) Autopsy findings in head injuries from firearms. Arch Pathol (Lond) 76:215–225

Fryc O, Krompecher T (1979) Überlebenszeit und Handlungsfähigkeit bei tödlichen Verletzungen. Beitr Gerichtl Med 37: 389–392

Goroncy C (1924) Handlungsfähigkeit Kopfschußverletzter. Dtsch Z Gerichtl Med 4:145–164

Greiner H (1973) Zur Handlungsfähigkeit nach Schrotschußverletzungen. Arch Kriminol 152:33–36

Händel K (1968) 47. Jahrestagung der Deutschen Gesellschaft für gerichtliche und soziale Medizin. Kriminalistik 22:655–658

Herbich J (1955) Neun Jahre überlebte Gehirn- und Herzschußverletzung mit Einheilung beider Geschosse, nach Selbstmordversuch. Beitr Gerichtl Med 20:22–34

Hudson P (1981) Multishot firearm suicide. Examination of 58 cases. Am J Forensic Med Pathol 2:239–242

Hudson P (1982) Suicide with two guns fired simultaneously. J Forensic Sci 27:6–7

Jacob B, Barz J, Haarhoff K, Sprick C, Wörz D, Bonte W (1989) Multiple suicidal gunshots to the head. Am J Forensic Med Pathol 10:289–294

Kaufman HH, Loyola WP, Makela ME, Frankowsky RF, Wagner KA, Bustein DP, Gildenberg PC (1986) Gunshot wounds to the head: a perspective. Neurosurgery 18:689–695

Killinger H (1938) Bemerkenswerte Fälle von langem Überleben und längerer Handlungsfähigkeit nach schwerem Schädelschuß. Dissertation, Munich

Kirkpatrick JB, DiMaio VJM (1978) Civilian gunshot wounds of the brain. J Neurosurg 48:185–198

Klages U, Weithoener D, Frössler H, Terwort H (1975) Überlebenszeit, Handlungsfähigkeit und röntgenologische Diagnostik bei Schußverletzungen des Schädels. Z Rechtsmed 76: 307–319

Klaue R (1949) Die indirekten Frakturen der vorderen Schädelgrube beim Schädeldachschuß. Dtsch Z Nervenheilkd 161: 167–193

Krauland W (1952) Zur Handlungsfähigkeit Kopfschußverletzter. Acta Neurochir 2:233–239

Krauland W (1984) Zur Beurteilung von tödlichen Schußverletzungen (Die Waffe in der Hand). Arch Kriminol 174:1–22

Lee K (1980) A single barrelled shotgun. Med Sci Law 20:198–199

Leschmann W (1932) Über einen Fall von Dissimulation einer schweren Kopfschußverletzung. Dtsch Z Gerichtl Med 19:82–84

Lewinski W (1939) Selbstmord durch zweifachen Gehirnschuß. Dtsch Z Gerichtl Med 31:322

Liebegott G (1949) Seltener kombinierter Selbstmord und seine versicherungsrechtliche Auswirkung. Dtsch Z Gerichtl Med 39: 351–355

Marchiori A (1983) Eccezionale caso di suicidio mediante il contemporareo uso di due pistole (in Italian). Zaccia 56:409–414

Maschka (1884) Gerichtsärztliche Mittheilungen. 3. Mit mehrfachen Verletzungen vorgefundene beraubte Leiche. Mord oder Selbstmord? Vjschr Gerichtl Med 40:11–15

Mason MF, Rose E, Alexander F (1967) Four non-lethal head wounds resulting from improper revolver ammunition: report of a case. J Forensic Sci 12:205–213

Maxeiner H, Schneider V, Betsch J, Piefke K (1986) Suizid mit drei Kopfsteckschüssen. In: Eisenmenger W, Liebhardt E, Schuck M (eds) Medizin und Recht. Springer, Berlin Heidelberg New York, pp 211–216

Meixner K (1931) Die Handlungsfähigkeit Schwerverletzter. Dtsch Z Gerichtl Med 16:139–165

Missliwetz J (1977) Über die Häufigkeit von Schußfällen im Untersuchungsgut des Wiener Instituts (Eine statistische Übersicht). Beitr Gerichtl Med 35:55–59

Missliwetz J (1983) Phänomenologie von Selbsttötungen mit mehrfachen Schußverletzungen. Arch Kriminol 171:143–150

Mueller B (1933) Eigenartige Befunde an den Händen bei Selbstmord durch Erschießen nebst Bemerkungen über die kriminalistische Untersuchung der Patronenhülsen. Dtsch Z Gerichtl Med 21:190–201

Naegeli O (1884) Zwei perforirende Hirnschüsse. Mord oder Selbstmord? Vjschr Gerichtl Med 40:231–264

Oehmichen M, König HG, Staak M (1985) Morphologie des Hirnschusses. Beitr Gerichtl Med 43:55–61

Petersohn F (1967) Über die Aktions- und Handlungsfähigkeit bei schweren Schädeltraumen. Dtsch Z Gerichtl Med 59:259–270

Pollak S (1978) Statistik und Phänomenologie kombinierter Selbsttötungen und anderer suizidaler Mehrfachschädigungen im urbanen Bereich (II). Arch Kriminol 161:68–81

Puppe G (1908) Atlas und Grundriss der Gerichtlichen Medizin. Lehmann, Munich

Reh H (1971) Selbstmord durch zwei Kopfschüsse. Arch Kriminol 148:36–40

Rogers DR (1989) Simultaneous temporal and frontal suicidal gunshots. Am J Forensic Med Pathol 10:338–339

Rommeney (1942) Mehrere Schußverletzungen bei einem Selbstmörder und Kombination mit Erhängen. Dtsch Z Gerichtl Med 36:232–244

Rooks G (1933) Zur Handlungsfähigkeit Kopfschußverletzter. Dtsch Z Gerichtl Med 20:201–206

Rooks G (1935) Die Lage der Einschußwunde bei Selbstmord und Mord. Arch Kriminol 96:156–161

Ropohl D, Koberne F (1990) Tödlicher Schußwaffengebrauch in Friedenszeiten. Beitr Gerichtl Med 48:339–348

Schaefer (1900) Ueber den Tod durch Erschiessen vom gerichtsärztlichen Standpunkt. Vjschr Gerichtl Med Sanitätswesen 19: 63–125

Schiermeyer H (1973) Suicid durch zweimaligen Bolzenschuß in den Kopf. Arch Kriminol 151:87–90

Schrader G (1942) Selbstmord durch 5 Herzschüsse. Beitr Gerichtl Med 16:117–120

Schwarzacher W (1921) Ueber Fälle von Selbstmord mit mehreren tödlichen Schußverletzungen. Wien Klin Wochenschr 34:375–377, 391–392

Sellier K (1982) Schußwaffen und Schußwirkungen I. Schmidt-Römhild, Lübeck, p 299, p 347

Selway R (1991) Gunshot suicides in Victoria, Australia, 1988. Med Sci Law 31:76–80

Siccardi D, Cavaliere R, Pau A, Lubinu F, Turtas S, Viale GL (1991) Penetrating craniocerebral missile injuries in civilians: a retrospective analysis of 314 cases. Surg Neurol 35:455–460

Sigrist T, Patscheider H (1986) Suizid durch fünf Kopfschüsse. in: Eisenmenger W, Liebhardt E, Schuck M (eds) Medizin und Recht. Springer, Berlin Heidelberg New York, pp 317–325

Smith S (1943) Voluntary acts after a gunshot wound of the brain. Police J 16:108–110

Spoerl W (1940) Ein kriminalistisch interessanter Raubmordversuch und Selbstmord des Täters durch drei Pistolenschüsse (7,65 mm) in den Schädel. Dissertation, München

Staak M, König HG (1977) Handlungsfähigkeit und Verletzungsmuster bei Opfern von tödlichen Schuß- und Stichverletzungen. Beitr Gerichtl Med 35:273–280

Sterba O (1924) Der Selbstmordversuch eines Schülers. Beitr Gerichtl Med 6:106–113

Strassmann G (1935) Über Lebensdauer und Handlungsfähigkeit Schwerverletzter. Dtsch Z Gerichtl Med 24:393–400

Urban R, Ogbuihi S, Pötsch L, Riepert T, Rittner C (1994) Rekonstruktion zweier außergewöhnlicher Schußfälle mit Mehrfachverletzungen – Kombinierter Suizid oder Fremdbeibringung? Rechtsmedizin 5:24–28

Valazza JL, Arauz LF (1969) Das gerichtsmedizinische Gutachten in Selbstmordsachen – seine Bedeutung in der Kriminalistik. Kriminalistik 23:443

Walther G (1970) An unsual repeated gunshot injury of the head. Zentralbl Rechtsmed 1:170

Weimann W (1928) Zur Frage der Handlungsfähigkeit Kopfverletzter. Arch Kriminol 82:178–180

Winter R (1932) Beitrag zur Frage der Handlungsfähigkeit eines tödlich Verletzten. Med Welt 6:988

Zelder O, Koch H (1972) Schußverletzungen großer Körperhöhlen und des Schädels. Monatsschr Unfallheilkd 75:168–179