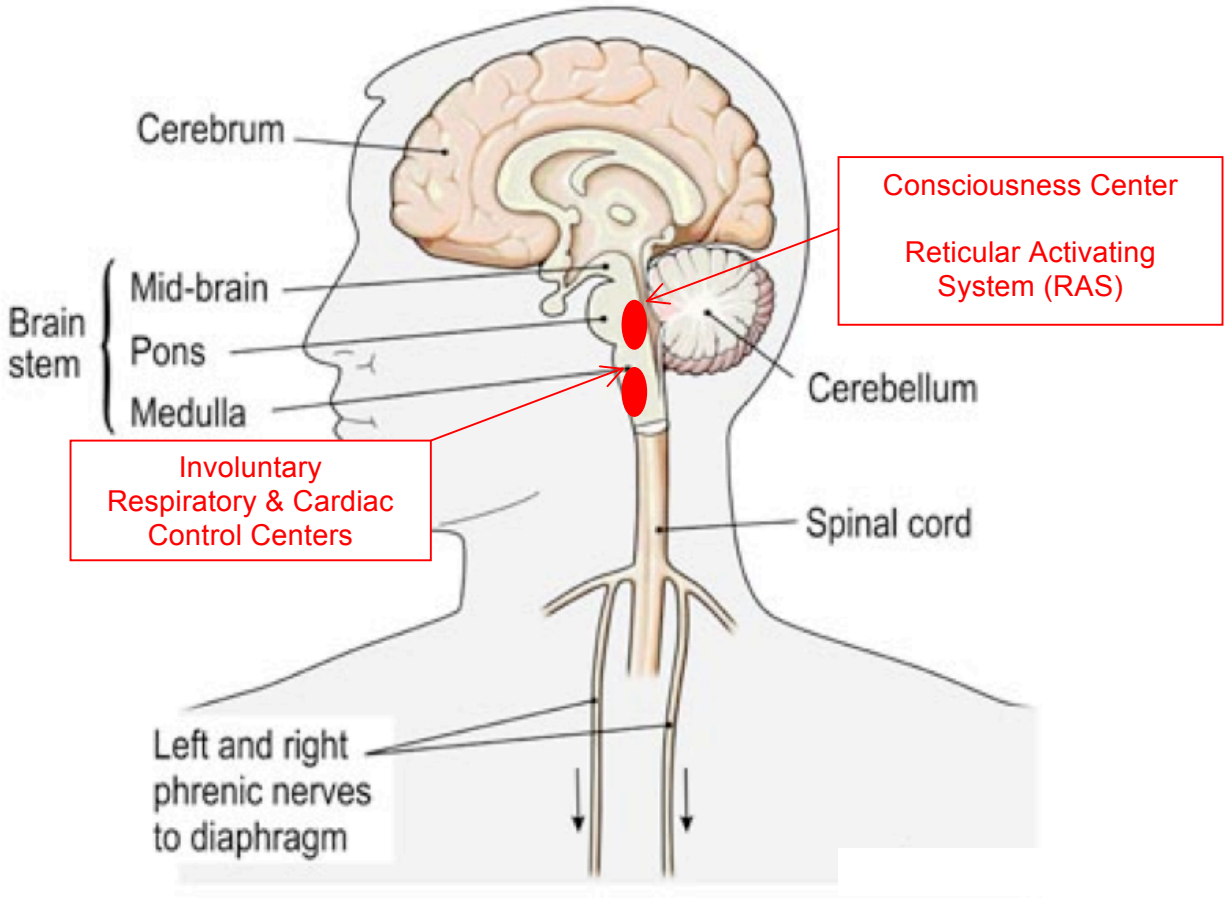
Penetrating injuries of the cranium, such as bullet wounds may result in only focal cerebral dysfunction without loss of consciousness IF no cranial displacement / brain tissue shearing occurs.

Incapacitation due to gunshot wounds to the head; the wounds may be penetrating (entrance wound only) or perforation (entrance and exit wounds present). The observed rapidity of incapacitation due to a head gunshot wound is variable, with a clear relationship to the location of brain tissue injury.

The following relates to the mechanism of incapacitation resulting from a penetrating gunshot wound to the head.



Whether a person is awake i.e. conscious, is controlled by the upper part of the brain stem through a system of nerve cells and fibers (the reticular activating system-RAS). The reticular activating system resides in the brain stem that extends from the top of the spinal column to the midbrain. The RAS is activated by input from surrounding sensory tracts and transmits this excitation to the cerebral cortex to induce generalized arousal behavior. **In the absence of input from the RAS, consciousness is impaired.**

The right and left side cerebral hemispheres (the largest part of the brain) interacts with the upper part of the brain stem to maintain consciousness and alertness.

The brain's ability to adjust its activity and consciousness levels are incapacitated when
1. Both cerebral hemispheres malfunction, particularly when they are suddenly and severely damaged.
2. The reticular activating system malfunctions.

Incapacitation

Determining a person's capability to act following a gunshot wound can be of major importance in crime scene reconstruction and in differentiation between homicide and suicide. If a person who has been shot is not able to shoot back, attack or escape, i.e. incapacitated, possible forensic events can be ruled out. This can assist the identification of the person who fired the gun and the reconstruction of the sequence of shots and activities. Therefore, forensic questions concerning the possibility of physical activity following a given gunshot wound are repeatedly raised.

Firearms are often lawfully employed to stop the momentary activity of a person by causing an immediate incapacitation. "Stopping power" is a term popularly used interchangeably with incapacitation, however with the former term the point of view has changed to one from behind the trigger. For the purposes of this discussion it is agreed the observed stopping power and its effective human incapacitation will result from the same physiological phenomenon.

There are a variety of definitions related to the temporal onset of incapacitation, mostly concentrating on the one's inability to act in a conscious and purposeful manner such as escaping or attacking. Others have used complex definitions primarily based on the degree of consciousness and on underlying neuro-physiological processes.

In this Tactical Professor
(http://tacticalprofessor.wordpress.com/2014/09/20/a-lesson-from-jimmy-cirillo-and-the-stakeout-squad/)

context of a news story about a mother shot in the head,
(http://www.ktvu.com/news/news/national/hero-mom-dies-protecting-her-baby-daughter/nhQp9/)

a functional definition of capability to act independent of the state of consciousness or intention will be used: capability to act is the ability to participate in the interaction between victim and perpetrator or victim and environment, resulting in discernible events or forensic stains. Thus, incapacitation is an early and necessarily occurring inability to perform complex and longer lasting movements. *The activity does not have to be appropriate in the situation at hand.* For example, pocketing or storing the firearm following a suicidal gunshot is not always achieved intentionally or purposefully. Incapacitation is based on physiological effects independent of psychological mechanisms such as pain or fright because it has to be independent of the victim's ''cooperation''.

Incapacitation Definitions and Mechanisms
1. Reliable
2. Immediate
3. Rapid
4. Commotio Cerebri and Cerebral Pressure
5. Delayed

Reliable incapacitation based on physiological effects, according to the above definition, is closely connected to death and can only be produced by decreasing the functioning capability of the central nervous system (CNS). The two sole mechanisms to accomplish this are:
1. direct disruption of brain tissue or
2. indirect elimination of the CNS by cerebral hypoxemia (lack of blood oxygen) from bleeding, both causing unconsciousness

There is no other way to prevent a determined person from further action. Many victims will collapse immediately when struck by a bullet as will some who were missed but think they were hit. They do so on a psychological basis but this is inconsistent and erratic. The only thing to count on is that it will not work in the case of determined and highly motivated persons or in the case of those under the influence of drugs or adrenalin. Excessive pain, for example, must first be perceived and then this perception of pain must cause an emotional reaction. **So reliable incapacitation is solely based on physiological effects independent of any unpredictable psychological factors**.

Another alleged mechanism of incapacitation is so-called high energy-transfer or high energy deposit. Energy deposit is an abstract value, considering neither the way (crush/stretch) or location energy is transferred nor the type of tissue involved. Therefore, the amount of energy is of limited value in predicting effects in an actual shooting. The momentum transferred to the target does not knock the human body down or drive it significantly backwards, even if shown so a thousand times on television. The impulse transferred to an adult from a .45 ACP round results in a negligible backwards motion of approximately 5 cm / sec. Injury or even incapacitation from shock waves or a mysterious ‘‘nerve shock’’ postulated especially in hunting are not supported by a single experiment or by theoretical considerations.

Hampered physical activity but not incapacitation may be produced by injuries to sensory or optic brain areas, the spinal cord and large peripheral nerves, static structures such as long bones or joints and by pneumothorax (collapsed lung).

Immediate Incapacitation

Instantaneous incapacitation can only be produced by direct disruption of brain tissue. In the case of gunshot injuries causing acute bleeding, the speed of blood loss is too slow and compensation mechanisms are too effective for immediate loss of consciousness and incapacitation. **So the only way to immediately cease the activity of another person are penetrating / perforating gunshots to the head.**

Because of the enhanced intracranial tissue disruption and the functional significance of the CNS, cranio-cerebral gunshot wounds result in a high early mortality rate of 90% and commonly in immediate incapacitation. However, in the last century, numerous publications reported sustained capability to act following penetrating gunshot wounds of the head. Since these were case reports or small case series, no systematic correlations between wounding and capability to act could be detected. Therefore, all accessible cases have been reviewed (see Karger B (1995) Penetrating gunshots to the head and lack of immediate incapacitation. II. Review of case reports. Int J Legal Med 108:117–126) A large number of case reports had to be excluded from this re-examination because of doubtful capability to act or lacking morphological or ballistic documentation; there remained 53 case reports from 42 sources for systematical analysis. **Favorable conditions for sustained capability to act are present in cases where the additional wounding resulting from the special wound ballistic qualities of the head are minimized.** Thus, more than 70% of the guns used fired slow and light-weight bullets: 6.35-mm Browning, .22 rimfire or extremely ineffective projectiles such as ancient, improper, or self-made missiles.

Firearms used	$N = 53$
Pocket-revolvers and old, low-energy handguns	$n = 10$ (19%)
Modified blank handguns or selfmade/improper ammunition	$n = 5$ (9%)
.22 pistol	$n = 2$ (4%)
5.6-mm rimfire rifle	$n = 4$ (7%)
6.35-mm pistol	$n = 13$ (25%)
7.65-mm pistol	$n = 8$ (15%)
.45 Colt revolver	$n = 1$ (2%)
.38 special revolver	$n = 1$ (2%)
Centerfire rifle	$n = 3$ (6%)
Shotgun (contact shot)	$n = 1$ (2%)
Not exactly known	$n = 5$ (9%)

Only two large handguns resulting in intra-cerebral wounding were used: A .38 spec. bullet which solely wounded the base of the right temporal lobe and a .45 lead bullet which seriously injured the left frontal lobe but whose trajectory was limited to the anterior fossa of the skull. A center-fire rifle or a shotgun from close-range was never employed in cases of intra-cerebral tracts. *A coincidence of several lucky circumstances made sustained capability to act possible in two cases of military center-fire rifle bullets passing longitudinally between the frontal lobes without direct contact with brain tissue.* *A possibility in the case under discussion?*

Therefore, sustained capability to act following cranio-cerebral gunshots is very unlikely if one of the following two conditions are fulfilled:
1. Use of a firearm from about 9-mm Parabellum upwards in terms of penetration power and wounding potential (large handguns, center-fire rifles). To increase further the probability of incapacitation, intra-cerebral trajectories above the anterior cranial fossa or very short ones can be excluded.

2. Definite forensic signs of high intracranial overpressures: indirect skull fractures, intra-cerebral petechial (small) hemorrhages remote from the tract and cortical contusion zones.

Incapacitation can be determined beyond any doubt if central nervous centers essential for physical activity are wounded directly. *In the literature reviewed, not a single case of sustained capability to act AFTER injury to the brain stem, the cerebellum, or major paths of motor conduction has been described.*

Immediate incapacitation, therefore, can only be produced reliably by injury to the upper cervical spinal cord, brain stem including the mid-brain, cerebellum, and major paths of motor conduction.

Rapid Incapacitation

Acute cerebral hypoxemia (lack of oxygen carrying blood to the brain) can be caused by massive blood loss (or a double-sided pneumothorax i.e. traumatic lung collapse). **Injuries associated with acute and massive bleeding will cause circulatory depression and reduced perfusion of the CNS with subsequent unconsciousness. However, immediate circulatory arrest is very rare in cardiac or vascular gunshot wounds and even if this occurs, the oxygen stored in the CNS ensures a potential for physical activity for about 10 seconds.** This is illustrated by numerous case-reports. Marsh et al. described two six-shot suicides, one of which involved three .22 bullets striking the heart. A young man had been conscious for several minutes after receiving two perforating and one grazing gunshot wound of the heart from .22 bullets. The highest number of suicidal gunshots recorded is nine including a complete disruption of the apex of the heart from seven .25 FMJ bullets. Other cases of physical activity following penetrating gunshot wounds to the heart have been published by Spitz et al. and Levy and Rao. In a ‘‘worst-case’’ scenario described by DiMaio, a man was able to walk 20 meters after sustaining a hit from a 12-gauge shotgun from a range of 3–4 m which destroyed his entire heart.

Missliwetz reported a similar close range shotgun case with laceration of the posterior wall of the heart and complete transection of the thoracic aorta where the young man still walked a distance of 6 m. These very rare examples of immediate circulatory arrest from gunshot wounds demonstrate without any doubt that a potential for physical activity is present in such cases.

Therefore, direct trajectories involving the heart, the aorta (especially the thoracic part) or the truncus of the pulmonary artery can cause rapid incapacitation but they cannot be relied upon to terminate the physical activity of the victim immediately.

Commotio Cerebri and Cerebral Pressure

Theoretically, incapacitation from gunshots to the CNS can result from primary or from secondary effects of the bullet. The major primary effect is disruption of brain tissue resulting in focal disturbances or loss of consciousness and has been discussed above. Commotio cerebri where the major symptoms are immediate unconsciousness and loss of muscle tone may be another primary effect. The generation of commotio cerebri has been discussed in cases of penetrating ballistic head injury for a long time and was thought to originate from the momentum transferred from the impacting projectile to the skull. However, the mechanogenesis of commotio cerebri is a matter of sudden acceleration of the skull, which by means of inertia results in wounding of the brain. The crucial physical parameter in this is the change of impulse per unit time or in other words the product of mass and acceleration of the head. A maximum acceleration of the skull will be achieved when the mass of the impacting object is equivalent to that of the head and when the velocity of the object is relatively high. (i.e. boxing glove to head resulting in K.O.)

A projectile has a very small mass but a very high velocity resulting in an ultra- short time span during which the projectile is acting upon the skull. Because of inertia, the skull as a whole will not really move during transfer of the impulse. Instead, during impact there will be a high transfer of momentum and energy locally but no direct load on the entire skull. The result is the perforation of the skull without marked acceleration of the head. The penetrating character of gunshots to the head thus does not allow a substantial transfer of impulse to the head as a whole. In accordance with these theoretical considerations are observations from battlefields reporting lack of commotio cerebri in penetrating gunshots to the head. Cerebral pressure is the major secondary effect of ballistic brain injury. However, the latent period in the range of minutes until the intracranial pressure rises substantially in animal experiments is too long to produce immediate or very rapid incapacitation following a head shot, although during the further course elevated intracranial pressure can of course become symptomatic. So immediate incapacitation, loss of consciousness and muscle control, can only be the result of disruption of specific brain tissue control centers by the bullet.

Delayed Incapacitation

Vital Function Demise After Brain Injury

Delayed incapacitation, pathophysiological processes that eventually end in the mortal condition may initially engage the central nervous system with delayed (minutes, hours, days !) negative influences to the circulatory and respiratory systems of the human body.

For many years it was not well understood that the Central Nervous System (CNS), comprising the brain and the spinal cord, plays a crucial role in maintaining an organism's vital functions. The involuntary contraction of the muscles of respiration are brought about by a signal sent from the respiratory center of the CNS; that control center is located at the base of the brainstem in a structure known as the medulla oblongata.

When sensors in the respiratory center detect a relatively high level of carbon dioxide, CO_2, in the blood, a nerve signal is sent to the muscles of respiration, spurring them to contract. Each of the normal adult eight to twelve inhalations per minute is the body's response to the accumulation of the waste products of metabolism; for life to continue, the CO_2 must be expelled and new oxygen must be brought in.

Changes in the depth and pace of breathing can be brought about without conscious effort: the rate of breathing will quicken, for example, during physical exercise or in response to a “fight or flight” situation. These changes are directed by changing metabolic needs (current or anticipated) throughout the body's organs and tissues.

In what is called “conscious breathing,” man can deliberately control the depth and pace of breathing, during which time other parts of the brain are involved in controlling the muscles of respiration.

For the purposes of our inquiry, the crucial fact about the mechanics of breathing is this: When the brainstem's respiratory centers are incapacitated, the organism will not make or display any respiratory effort. The chest will remain absolutely still and the body's need for oxygen will go unanswered. If the death of the organism is to be prevented, some external “driver” of the breathing process—a rescue CPR breather or a mechanical ventilator must be used.

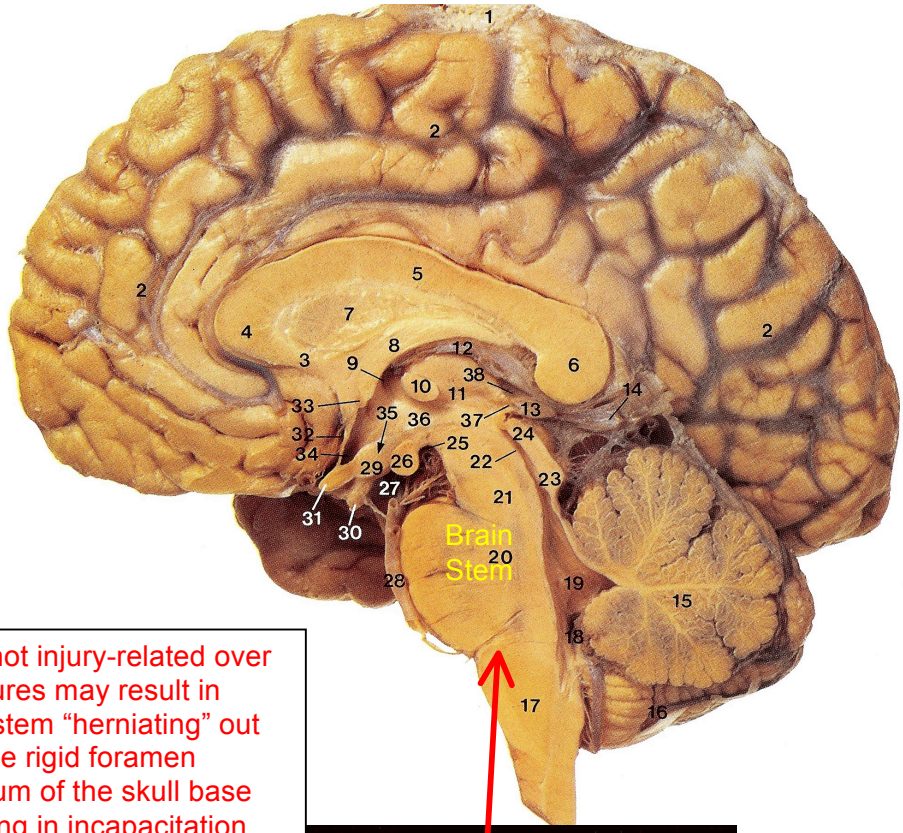
Likewise, the action of the circulatory system is analogous to the controlled actions of the respiratory system; the mechanism of circulatory action is the periodic contraction of muscle—the heart muscle in circulation, the muscles of respiration in breathing. However, unlike the respiratory system there is no part of the CNS that is *absolutely indispensable* for heart contractions in the way that the respiratory center in the brainstem is absolutely indispensable for the muscular contractions involved in breathing.

In healthy circumstances, stimuli from the CNS will alter the rate and strength of cardiac contractions: the heart rate will change in response to danger, excitement, or other stimuli. But even when there is no stimulus whatsoever from the CNS, the heart can continue to beat. This property of the heart, known as its “inherent rhythmicity,” has been demonstrated dramatically by experiments in which an animal's heart is taken out of its body and stimulated to begin beating rhythmically again. It is also demonstrated by the heartbeat of an embryo, which begins before the CNS has developed.

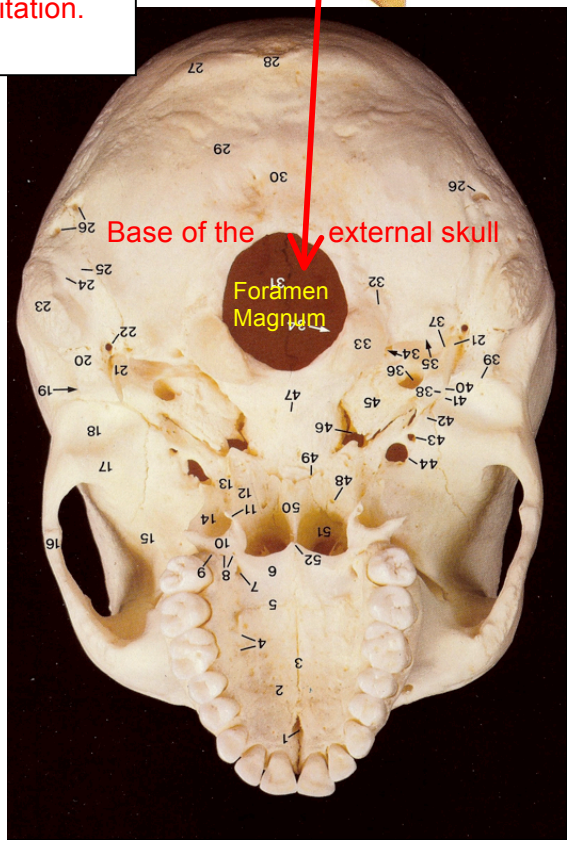
Additional Mechanisms of Incapacitation Explained

Frequently, bullet impacting the cranium causes additional secondary missiles in the form of bone fragments. The accelerated bone fragments travel in different directions in the vicinity of the bone, to a small extent even against the line of fire (forensic back spatter). The effect of secondary bone fragment missiles is analogous to bullet fragments including secondary shot channels enhancing the severity of the wound. In intracranial gunshot wounds, several of the above-mentioned factors enhance the degree of tissue disruption. The inelastic quality and the high water content of brain tissue make it per se very vulnerable to cavitation and stretch injury mechanisms.

Intracranial trajectories impart alternative mechanisms of injury, by the rigid skull functioning as a non-yielding wall. Because brain tissue is almost incompressible, intracranial temporary cavitation and surrounding overpressure meet counter-pressure from the skull. The skull will, so to speak, try to overcome the principle of non-confinement of the cranial cavity by denying the free space necessary for a gradual decrease of radial tissue displacement and associated overpressure. The volume of the intracranial temporary cavity will consequently stay smaller than a cavity formed under identical conditions in tissue not confined in a casing (e.g. gelatin-based terminal ballistics). Intracranial overpressures around the expanding temporary cavity, however, clearly exceed the pressures found in non-confined tissue. These high dynamic pressures, the asymmetric shape of the temporary cavity, and unilaterally fixed tissue structures lead to shear forces within brain tissue. The unyielding skull does not allow the brain to expand, so the brain will transfer the overpressures to the skull. In other words, the brain’s surface gets pushed with great force against the inner table of the neuro-cranium, importantly the brain stem gets forced down into path of least resistance, the foramen magnum (largest opening of the cranium at the base of the skull (see related diagrams below).



Gunshot injury-related over pressures may result in brain stem “herniating” out thru the rigid foramen magnum of the skull base resulting in incapacitation.

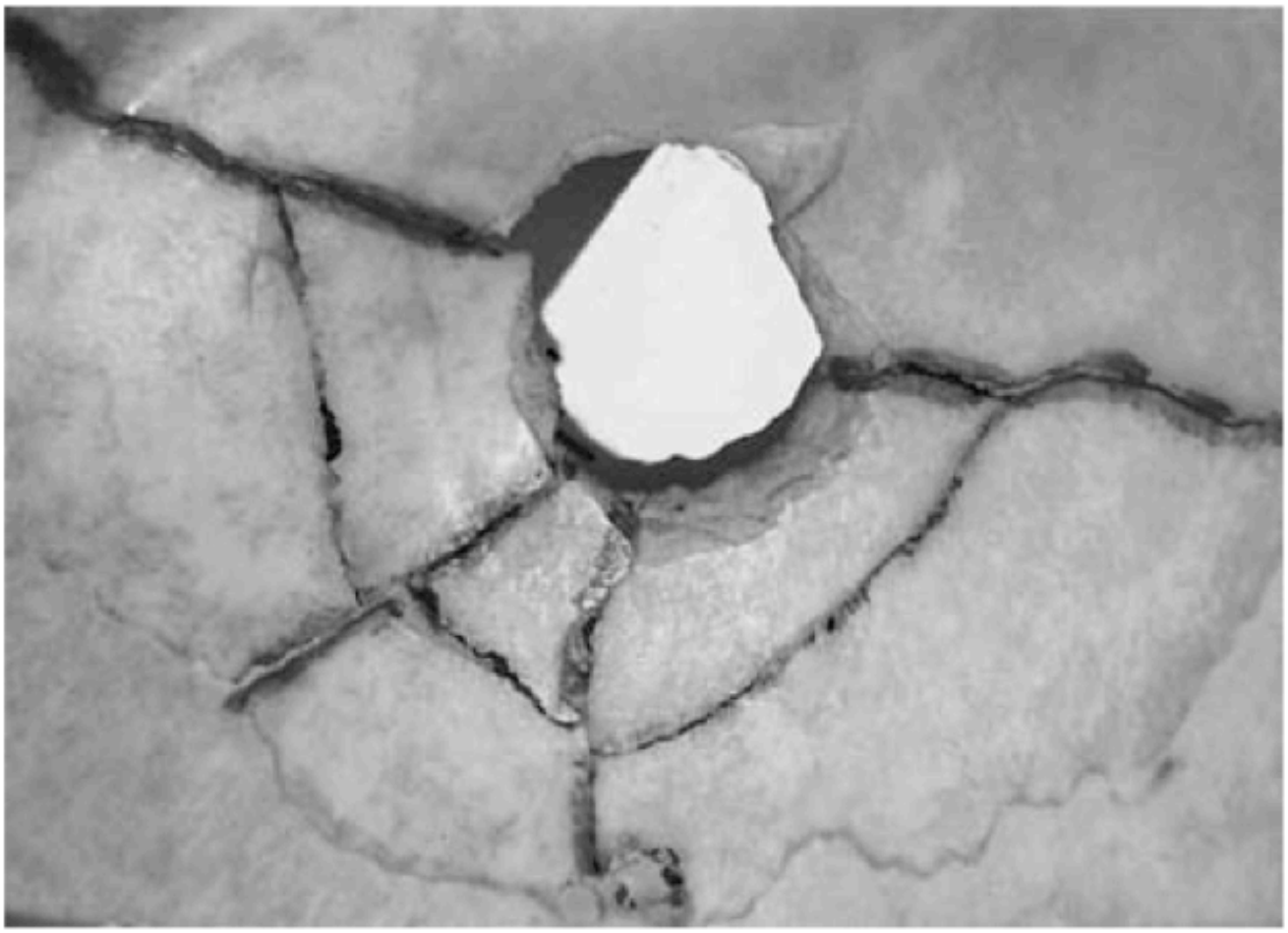


The skull will at first be slightly stretched by intracranial overpressures. If the skull’s capacity to elastically stretch is surpassed, there will be indirect skull fractures, i.e., fracture lines without contact to the primary bony entrance and exit defects. Because the base of the skull is inhomogeneous and less resistant to stretching than the remaining boney cranial vault, preferential locations are the thin bone orbital (eye-socket) roofs. While secondary radial fractures originating from the gunshot defects are induced by the

bullet's impact, tertiary concentric fractures connecting the radial fracture lines are indirect heaving fractures functioning as additional stress relief for internal overpressures. If the internal pressures are high enough, indirect skull fractures will combine to an ''explosive'' type of head injury with comminuted fractures of the skull and laceration of the brain.

So the rigid skull, which protects the brain from most blunt trauma, also makes the brain by far the most susceptible organ in the body to penetrating ballistic injury. Intracranial pressure peaks and its effects vary greatly, depending on ballistic and anatomical parameters. Mathematically, the peak pressures recorded vary in direct proportion to the projected cross-sectional area of the missile and the square of its velocity but in inverse proportion to the distance from the point of origin. In more practical terms, bullet wounds from handguns and rifles differ considerably with regard to their effect in penetrating gunshots to the head. Bullets from conventional handguns can produce indirect skull fractures and pronounced cerebral tissue disruption. Center-fire rifles, whether military or hunting, almost invariably cause a strong ''explosive'' effect with comminution of bone and laceration of at least part of the brain. Hits from shotguns differ substantially depending on the range of fire. Close range shots have a tremendous effect similar to center-fire rifles by literally riddling brain tissue and blasting the skull.

Below, Indirect (concentric) heaving fractures around an exit wound in the left temple after gunshot with a .44 lead projectile. The concentric fracture lines are produced indirectly by intracranial overpressure while the radial fracture lines are caused directly by impact of the projectile



Lateral View of Cadaver Anatomy
IDPA Target Neck Zones