THE PHYSIOLOGICAL EFFECTS OF HANDGUN BULLETS

The Mechanisms of Wounding and Incapacitation

Ken Newgard, M.D.

An examination of the effect of handgun bullets upon the human body shows that immediate incapacitation cannot be reliably expected even after disruption of vital organs.

When a law enforcement officer shoots a suspect, it is his or her purpose to stop the current activity of the suspect in order to prevent death or severe bodily harm to himself or other innocent persons. How many shots should an officer fire to achieve this objective? There is a large disparity in what is taught relative to this question in police academies, training schools, and military units. The range varies from one shot to the maximum cartridge capacity of the firearm. This paper attempts to answer this question using a physiological approach, and incorporating what is known about bullet wound trauma. Although much of this information applies to all types of weapons, I am referring here to handgun bullets because these are the most common weapons in use by police today.

A discussion of physiological effects of bullets would not be complete without a cursory review of terminal wound ballistics — although this discussion will be common knowledge to many readers of this Journal. I will then discuss the physiology of blood loss and shock and finally review the literature on length of survival times of fatal gunshot wounds.

TERMINAL BALLISTICS

A bullet causes injury primarily by crushing tissue as it penetrates. The space once occupied by the crushed tissue is called the permanent cavity. Injury of tissue may be augmented by bullet expansion — or bullet yaw in non-expanding bullets. These variables of projectile terminal performance expand the size of the permanent cavity.

Another cause of injury is by the radial stretching of tissue around the bullet path producing a temporary cavity. Because of tissue elasticity within the body, much of the temporary cavity potential for damage will be nullified by the stretching of the elastic fibers and will not contribute to tissue injury. Most often the temporary cavity of handgun bullets is too small to significantly contribute to the wounding mechanism. Certain organ tissue within the body are more susceptible to damage from the tempo-
WOUND BALLISTICS REVIEW
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Physiological Effects

TWO PHYSIOLOGICAL TYPES OF WOUNDS

The only method of reliably stopping a human with handgun bullets is to decrease the functioning capability of the central nervous system (C.N.S.) and specifically, the brain or cervical spinal cord. There are two ways in which to accomplish this goal: 1) direct trauma to the C.N.S. tissue resulting in tissue destruction and 2) lack of oxygen to the brain caused by bleeding and loss of blood pressure.

Bullet wounds to the brain are commonly thought to cause instant cessation of activity. Although this is true much of the time, there are cases where bullet wounds to the brain have not incapacitated the subject. In the experience of the author these usually involve injuries to the brain’s frontal lobe which controls the body’s non-critical functions such as memory, analytical thinking, etc. The only wounds which result in immediate cessation of activity are those that cause destruction of essential brain matter such as the brain stem or the cervical spinal cord which control the basic survival functions such as breathing and heart beat rhythm.

Non-central nervous system wounds are far more commonly seen and are variable in the amount of incapacitation they produce. Here, the disruption of blood vessels and organ tissue causes blood loss. The blood loss in turn leads to a lowering of blood pressure (hypotension) and when the blood flow is insufficient to deliver adequate amounts of oxygen to the brain, unconsciousness results. The rate of bleeding will depend on the size and shape of the wound, the number of vascular structures damaged, the size of the damaged vessel, the blood pressure within the vessel and the effects of surrounding tissue structures.

Instantaneous neutralization is impossible with non-central nervous system wounds. Even when bullets strike the heart or major blood vessels, the adversary may not be affected for many seconds or even minutes. Studies of civilian populations demonstrate that most persons with gunshot wounds to the heart survive if they reach a hospital in a reasonable amount of time. Table 1 shows the mortality rate in a civilian population of gunshot and knife wounds to the heart. A gunshot wound to the thoracic aorta would cause the greatest sudden blood loss and a relatively fast incapacitation. However, because the thoracic aorta is a long but very narrow target, it is not often hit and therefore has a low rate of injury, less than 10% in most studies.

How is a person able to survive wounds of major vessels or the heart? Controlled blood loss is only one half of the story. The other half is a phenomenon called “physiologic compensation.”

Table 1

<table>
<thead>
<tr>
<th>PENETRATING WOUNDS OF THE HEART</th>
</tr>
</thead>
<tbody>
<tr>
<td>NUMBER OF PATIENTS</td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>STAB WOUNDS</td>
</tr>
<tr>
<td>GUNSHOT WOUNDS</td>
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</tbody>
</table>


COMPENSATORY MECHANISMS IN HEMORRHAGIC SHOCK

In 1895 Warren described hemorrhagic shock as “a momentary pause in the act of death.” Shock, he wrote, is “a clinical syndrome involving widespread cellular dysfunction as a result of the inadequate delivery and use of oxygen, yielding the subsequent release of pharmacologically active cell metabolites.” Shock is not an all-or-nothing phenomenon but occurs over time with a progressive degree of detriment to the individual. For our purposes we are looking at the effect...
Physiological Effects

of hemorrhagic shock to the brain since this is the organ most sensitive to a reduction in oxygen supply.

There are a number of compensatory mechanisms that occur with the initiation of blood loss. The initial response and is by blood pressure sensors (baroreceptors) in the heart and great vessels. This results in an increase of two hormones: norepinephrine and epinephrine (adrenaline) in the bloodstream. The release of these hormones results in a faster heart beat and an increase in the heart muscle’s contractive force which causes an increase in cardiac output. The low volume of blood is detected by sensors in the carotid vessels (which carry blood to the brain,) and by sensors in the heart which send signals through the nervous system to initiate compensatory action. This action — the release of the two hormones into the blood stream — results in a constriction (narrowing) of the venous system. Since 60% of the circulating blood volume resides in the venous system (10), constriction of the veins will compensate for the mild blood loss without causing other changes in the body.

Because Cardiac Output (C.O.) equals Mean Arterial Pressure (M.A.P.) minus Central Venous Pressure (C.V.P.) divided by Total Peripheral Resistance (T.P.R.),

\[ C.O. = \frac{M.A.P.-C.V.P.}{T.P.R.} \]

and;

Total Peripheral Resistance equals Mean Arterial Pressure minus Central Venous Pressure divided by Cardiac Output,

\[ T.P.R. = \frac{M.A.P.-C.V.P.}{C.O.} \]

as T.P.R. increases, M.A.P. can be maintained by decreasing C.O. Maintenance of blood flow to the heart and brain is also protected by selective, sympathetic nervous system activity which constricts and reduces blood flow in vessels supplying the extremities and the non-critical (in terms of immediate survival) organs such as the liver, spleen, and bowels.

The forces governing fluid movement across peripheral capillary membranes were initially described by Starling. When bleeding causes blood pressure to fall, body fluid enters the capillaries from the surrounding tissue and replenishes the vascular volume. The amount of fluid transferred from tissue into the vascular system is proportional to the volume deficit and is significant. In Viet Nam, injured soldiers were shown to demonstrate transcapillary refill rates well in excess of 1000 ml/hr.

**HUMAN TOLERANCE OF BLOOD LOSS**

Because of the described mechanisms, the body can compensate for some blood loss. Healthy young persons can tolerate a sudden loss of approximately 25% of their blood volume blood loss in the supine (flat on the back) position without significant effect and without permanent injury. However with blood loss greater than 25% (which is about 1 liter) of total volume, the compensation mechanism described above will not be adequate to keep the brain and heart supplied with sufficient oxygen. The progression of this condition will lead to irreversible shock and death.

There are differences in the blood pressure requirements for a person laying flat and for a person in a standing position. In the standing position, a greater blood pressure is required for the blood to reach the brain and therefore a smaller amount of blood loss will be tolerated by a standing person. The exact quantity of blood loss that a person can tolerate before collapsing is difficult to determine and is dependent on age, health, activity, presence or absence of drugs and alcohol, and psychological state. However, testing of healthy, young persons by means of laying them on a flat board and then varying the tilt from horizontal to vertical has determined that symptoms and signs of hemorrhage are unpredictable until 1000 c.c.s of blood are lost. With this quantity of blood loss, a change in heart rate greater than 30 beats per minute or significant symptoms were observed when patients were...
WOUND BALLISTICS REVIEW

JOURNAL OF THE INTERNATIONAL WOUND BALLISTICS ASSOCIATION

Physiological Effects

For an average 70 kg male the cardiac output will be 5.5 L per minute. His blood volume will be 60 c.c.s per kg or 4200 cc. Assuming that his cardiac output can double under stress (as his heart beats faster and with greater force), his aortic blood flow can reach 11 L per minute. If one assumes a wound that totally severs the thoracic aorta, then it would take 4.6 seconds to loose 20% of his blood volume. This is the minimum time in which a person could loose 20% of his blood volume from one point of injury. How many shots could be fired in this 4.6 seconds? A marginally trained person can aim and fire at a rate of two shots per second. (unpublished data) In 4.6 seconds there could easily be nine shots of return fire before the assailant’s activity is neutralized. This analysis does not account for oxygen contained in the blood already perfusing the brain, that will keep the brain functioning for an even longer period of time.

Most wounds will not bleed at this rate because: 1) bullets usually do not transect (completely sever) blood vessels, 2) as blood pressure falls, the bleeding slows, 3) surrounding tissue acts as a barrier to blood loss, 4) the bullet may only penetrate smaller blood vessels, 5) bullets can disrupt tissue without hitting any major blood vessel resulting in a slow oozing rather than rapid bleeding, and 6) the above mentioned physiologic compensatory mechanisms.

Although the amount of time it takes for incapacitation to occur is difficult to predict, one point is perfectly clear, with wounds which do not disrupt the central nervous system, significant amounts of time can elapse between receiving the wound and unconsciousness. This correlates with what we observe in a trauma unit.

SURVIVAL TIMES OF FATAL GUNSHOT WOUNDS*

Survival time of fatal gunshot victims is difficult to determine with extreme accuracy due to the number of uncontrolled variables involved and the inherent observation inaccuracies of random events occurring in the field. For our purposes extreme accuracy is not needed. We only wish to determine if the person who was shot had enough time to shoot back. Two studies address this issue.

Levy[18] looks at the activity of the shotgun and knife victims who eventually died in Dade County in 1983. This obviously selects for the more severe injuries since only persons who died from their wounds were included in the study. The data in Table 3 shows the percentage of persons who survived longer than five minutes after being shot. The percentage of gunshot victims who survived five minutes or more after receiving ultimately fatal injuries was 64% with chest and abdominal injuries and 36% with head and neck injuries. In addition, they present individual cases of persons with severe injuries, including bullet wounds of the heart, undertaking strenuous physical activity before dying.

*Survival time relates only to persons who received fatal gunshot wounds; it should not be confused with gunshot victims who consciously fall down, faint, or otherwise surrender. Those reactions are based on psychological factors, not the physiologic factors discussed in this article.
TABLE 2

**Changes Seen in Acute Hemorrhage**

<table>
<thead>
<tr>
<th>Blood Loss</th>
<th>Vascular Response</th>
<th>Endocrine Response</th>
<th>Signs and Symptomatology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild (0% to 20%)</td>
<td>Contraction of capacitance system</td>
<td>Minimal</td>
<td>Narrowing of pulse pressure</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hypotension (90 to 100)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fast heart rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sweating</td>
</tr>
<tr>
<td>Moderate (20% to 30%)</td>
<td>Arteriolar constriction</td>
<td>Aldosterone</td>
<td>Decreased urine output</td>
</tr>
<tr>
<td></td>
<td>Narrowed pulse pressure</td>
<td>Antidiuretic hormone</td>
<td>Anxiety</td>
</tr>
<tr>
<td></td>
<td>Reduced cardiac output</td>
<td>Catecholamines (Epinephrine and</td>
<td>Hypotension (approx. 60 mm Hg)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Norepinephrine)</td>
<td>Cool, clammy skin</td>
</tr>
<tr>
<td>Severe (&gt; 30%)</td>
<td>Hypotension</td>
<td>Marked liberation of catecholamines</td>
<td>Shortness of breath</td>
</tr>
<tr>
<td></td>
<td>Drastic reduction of cardiac output</td>
<td></td>
<td>Coma</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Death</td>
</tr>
</tbody>
</table>


TABLE 3

**Survival Time of More Than 5 Minutes**

<table>
<thead>
<tr>
<th></th>
<th>With chest and/or abdominal injuries</th>
<th>With head and/or neck injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stab wound victims</td>
<td>6 (50%)</td>
<td>6 (50%)</td>
</tr>
<tr>
<td>Gunshot victims</td>
<td>53 (84%)</td>
<td>30 (36%)</td>
</tr>
</tbody>
</table>


Similar cases were presented by Spitz. Again, for a person to succumb from non central nervous system gunshot wounds takes a considerable length of time relative to the time it takes an assailant to return fire multiple times.

*Ken Newgard is an anesthesiologist and a reserve Deputy with the Orange County, CA Sheriff’s Dept.*

**CONCLUSION**

Instantaneous incapacitation is not possible with non central nervous system wounds and does not always occur with central nervous system wounds. The intrinsic physiologic compensatory mechanisms of humans makes it difficult to inhibit a determined, aggressive person’s activities until he has lost enough blood to cause hemorrhagic shock. The body’s compensatory mechanisms designed to save a person’s life after sustaining a bleeding wound, allow a person to...
continue to be a threat after receiving an eventually fatal wound, thus necessitating more rounds being fired in order to incapacitate or stop the assailant.

How many times is it necessary to shoot an assailant before he is incapacitated? Although shooting situations vary tremendously, the correct answer is clearly to continue shooting as long as an officer believes he is still threatened by his adversary. An officer in a life threatening situation should aim and fire as many rounds as tactically feasible. No absolute limit can be set since the officer has no way of knowing what organ tissue his rounds are disrupting and if compensatory mechanisms will allow the assailant to continue fighting. The officer has no way of determining if an assailant is about to immediately collapse or to continue his actions for 4, 5, 10 or more seconds. The only indicator he can use is the assailant’s response: as long as he continues to be a threat, the officer should continue to fire until he can perceive that the assailant is no longer capable of continuing his life-threatening actions.

The implications of the above information are not trivial. Persons writing police department policies on the use of lethal force, firearm instructors, forensic scientists, lawyers litigating shooting cases, police investigators, expert witnesses in criminal and civil cases and the news media must take the physiological response to bullet wounds into consideration when performing their respective duties or drawing judgmental conclusions. Also, a summary of this information should be part of every police officer’s education.

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