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MISSILE-CAUSED WOUNDS

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DIVISION OF MILITARY TRAUMA RESEARCH

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PREFACE

This paper was submitted to the Office of the Surgeon General of the Army in September 1986 in response to a request by COL Thomas Bowen MC USA of the Surgeon General's staff that Dr. Fackler revise/rewrite "Missile-Caused Wounds" (Chapter II from the 1975 edition of the NATO HANDBOOK - EMERGENCY WAR SURGERY), for the upcoming revised edition. The chapter has been completely rewritten, and none of the wording or figures from the previous Chapter II have been included. Since COL Bowen felt that the wording in the submitted chapter was too blunt or "confrontational," he and Dr. Fackler worked together to edit the chapter for publication.

The purpose of this Institute Report is to preserve the chapter in the form it was submitted (and thus distinguish it from the edited chapter) and to clearly establish authorship, since authors' names will not be included with their contributions in the NATO HANDBOOK.

ABSTRACT

Wound profiles made under controlled conditions in the wound ballistics laboratory using gelatin tissue simulant that has been calibrated against living animal soft tissue show the location along the tissue path and amount of both crush (permanent cavity) and stretch (temporary cavity) caused by the penetrating projectile. Characteristic wound profiles are presented for a variety of penetrating projectiles, including rifle, pistol, shotgun. The data on these profiles is used to correct common fallacies and lay the groundwork for better understanding and more effective treatment doctrine.

key words: gunshot wounds, penetrating wounds, military medicine, high velocity misssile

CHAPTER II : MISSILE-CAUSED WOUNDS

Missiles that penetrate the human body disrupt, destroy, or contuse tissue, and the resultant wound is invariably contaminated. Triage and treatment decisions are based on the estimation of the location, type, and amount of tissue disruption. Objective data from the physical examination and appropriate roentgenographic studies of the wounded individual provide the information needed to make these decisions.

MECHANISMS OF WOUNDING

The penetrating object crushes and destroys tissue as it bores a hole through it (Fig. 1). This hole is the permanent cavity. Its size is limited by the presenting area of the missile causing it, and its dimensions are roughly the same for all soft tissues.

After passage of the projectile the walls of the permanent cavity are stretched radially outward. The maximum lateral tissue displacement delineates the temporary cavity. Any damage inflicted by temporary cavitation results from stretching of the tissue. Resistance to stretch damage depends mostly on tissue elasticity. The same stretch that causes a moderate contusion and little interference with function in muscle can cause massive disruption if it occurs in the liver. The temporary displacement of tissue is actually a localized area "blunt trauma" surrounding part of the projectile path, and it is useful to keep this in mind in assessing relative vulnerability to disruption.

The sonic shock wave shown at the far right of Fig. 1 preceeds the passage of the projectile through tissue. Although the sonic wave generated by penetrating projectiles may range up to 100 atmospheres, its duration is so brief (circa 2 microseconds) that it does not displace tissue. It has no detectable harmful effect on tissue.

The typical wounding potential of a given missile can be assessed by measuring the two types of tissue disruption it produces. A method developed at the Letterman Army Institute of Research captures the entire path of the fired missile in gelatin tissue simulant.

path of the fired missile in gelatin tissue simulant. Measurements taken from the gelatin are used to depict the location and extent of both crush and stretch types of tissue disruption on a drawing or "Wound Profile". Figures 2 through 12 illustrate selected "Wound Profiles". The scale included on each profile can be used to measure the extent of tissue disruption at any point along the projectile path. It also facilitates comparisons between wound profiles.

GUNSHOT WOUNDS

Figures 2 through 7 show profiles of bullets that do not deform on striking soft tissue.

45 AUTOMATIC - This full-metal-jacketed military bullet (Fig. 2) is one of few that does not yaw (turn the long axis in relation to direction of travel) significantly in soft tissue. Lack of yaw, coupled with the large mass of this bullet, results in deep penetration. The crush tissue disruption remains nearly constant throughout the bullet path. Temporary cavity stretch is maximal near the surface, gradually diminishing with penetration, but with this bullet type and velocity the temporary cavity is too small to show a wounding effect.

22 LONG RIFLE - This commonly used rimfire bullet (Fig. 3) yaws through 90 degrees and ends up traveling base forward for the last half of its tissue path. The crush tissue disruption increases with yaw angle, reaching its maximum when the bullet is traveling sideways. Temporary cavity stretch increases with increasing bullet yaw, as a diver hitting the water makes a larger splash as his body angle to the water surface increases. Even at the point of maximum bullet yaw the temporary cavity produced remains too small to add a detectable wounding effect.

38 SPECIAL - This lead round nose bullet (Fig. 4), like the 45 Automatic (Fig. 2) and the 22 Long Rifle (Fig. 3), produces its wounding almost solely by the crush tissue disruption mechanism. Although still too small to show an observable wounding effect, the maximum temporary cavity is of 20% greater diameter than that made by the 22 Long Rifle despite the fact that its velocity is 40% less.

9 MM PARBELLUM - This bullet is widely used in both pistols and submachine-guns. It produces a profile (with the full-metal-jacketed bullet type) that resembles that of the 38 Special (Fig. 4) but the maximum temporary cavity is about 2 cm larger in diameter and will show some stretch effects (radial splits) in the more susceptible tissues such as liver.

7.62 NATO FMC (FMC is the abbreviation for full-metal-cased which is a synonym of full-metal-jacketed. This refers to the harder metal covering of the bullet core.) This full-metal-jacketed military bullet (Fig. 5) shows the characteristic behavior in tissue observed in non-deforming pointed bullets. It yaws through 90 degrees and after reaching the base-forward position continues the rest of its path with little or no yaw. The bullet is stable traveling base first in tissue since this position puts its center of mass forward. The rotation imparted to the bullet by the rifled gun barrel is sufficient to cause point-forward travel in air, but not in tissue where such factors as bullet shape and location of center of mass outweigh rotation effects. The tissue disruption produced in the first 15 to 18 cm of bullet penetration, where the streamlined bullet is still traveling point-forward, is minimal. At 20 to 35 cm, however, where bullet yaw is marked, a large temporary cavity is produced. If the bullet path is such that this temporary cavity occurs in the liver, this amount of tissue disruption is likely to make survival improbable.

AK-47 - The Russian Assault Rifle's full-metal-cased military bullet (Fig. 6) travels point-forward for 25 to 27 cm in tissue prior to beginning significant yaw. Wounds from this rifle are familiar to those surgeons who served in Vietnam and are well documented in the WIDMET study of wounds from that conflict. Even with the long tissue path of a transverse shot across the abdomen, the disruption is likely to be no more that that produced by the 38 Special pistol bullet.

AK-74 - This new generation smaller caliber Russian Assault Rifle (Fig. 7) follows the example set by the USA with the M-16. The lighter cartridge weight makes it possible for the soldier to carry more ammunition and the considerably lighter recoil makes the weapon easier to shoot. The full-metal-cased bullet designed for this weapon has a copper plated steel jacket, as does the bullet of its predecessor the AK-47. A unique design feature of the AK-74, however, is an air-space (about 5 mm long) inside the jacket at the bullet's tip. The speculation that this air-space would cause bullet deformation and fragmentation on impact proved to be unfounded, but the air-space does serve to shift the bullet's center of mass toward the rear. This bullet yaws after only about 7 cm of tissue penetration, assuring an increased temporary cavity stretch disruption compared to the AK-47, even in many extremity hits. The typical exit wound from a soft-tissue thigh wound (12 cm thick) is stellate, with skin split measuring from 9 to 13 cm across. The underlying muscle split is about half that size. The bi-lobed yaw patterns shown in the profiles of the AK-47 and the AK-74 represent what is seen in four-fifths of shots. In the rest the bullet reaches 90 degrees of yaw and continues to 180 degrees or the base forward position in one cycle. Whether there are one or two yaw cycles, however, does not influence the point of prime clinical relevance -the distance the bullet travels point-forward before yaw.

357 MAGNUM JSP - The jacketed soft-point bullet (Fig. 8) and the jacketed-hollow-point bullet flatten their tips on impact. This "expansion" or "mushrooming"(final bullet shape resembles a mushroom) results in a doubling of effective bullet diameter in tissue, and allows the bullet to crush four times as much tissue (pi times radius squared equals cross section area of the bullet which impacts tissue). Also, the change in the bullet to a non-aerodynamic shape causes the same sort of increased temporary cavity tissue stretch as does the yawing bullet. The maximum temporary cavity produced by the expanding bullet occurs at a shallower penetration depth than that caused by the full-metal-jacketed military type bullet. This soft-point pistol bullet is typical of the type most commonly used by law enforcement agencies in the USA. Its lessened penetration depth (compare with Fig. 2) decreases the likelihood of the bullet perforating a criminal and going on to injure an innocent bystander.

7.62 NATO SP (SP is the abbreviation for soft-point)- The same cartridge case shown in Figure 5, when loaded with a soft-point bullet, produces the wound profile shown in Figure 9. Changing only the variable of bullet construction causes massively increased tissue disruption compared to that of the full-metal-cased bullet (Fig.5). Bullet expansion occurs on impact as seen with the 357 Magnum pistol bullet (Fig. 8), but, in this case the crushed tissue from the expanded bullet accounts for only a small part of the large permanent cavity. As this bullet flattens, pieces break off and make their own separate paths of crushed tissue. These bullet fragments penetrate up to 9 cm radially from the bullet path. The temporary cavity then stretches muscle that has been weakened by multiple perforations. The fragment paths act to concentrate the force of the stretch, increasing its effect and causing pieces of muscle to be detached. This synergistic effect, resulting in the large tissue defect shown in Fig. 9, is seen only with bullets that fragment. The 7.62 NATO soft-point is a popular big game hunting bullet and although shooting accidents are not infrequent with such rounds, they are rarely seen in the hospital since few victims of torso shots survive.

22 CAL FMC -This is the military M-193 bullet shot from the M-16A1 Assault Rifle (Fig. 10). The large permanent cavity shown in the profile was observed by surgeons who served in Vietnam, but the tissue disruption mechanism responsible was not clear until the importance of bullet fragmentation as a cause of tissue disruption was worked out and described (Fackler, 1984). This bullet is a full-metal-jacketed military bullet, and as with other bullets of this type, it causes little tissue disruption so long as it remains traveling point forward through tissue. Its average distance of point-forward travel is about 12 cm, after which it yaws to 90 degrees, flattens, and breaks at the cannelure (groove around bullet midsection). The bullet point remains as a flattened triangular piece, retaining about 60% of the original bullet weight. The rear portion breaks into many fragments that penetrate up to 7 cm radially from the bullet path. The temporary cavity stretch, its effect increased by perforation and weakening of the muscle by fragments, then causes a much enlarged permanent cavity by detaching muscle pieces. The degree of bullet fragmentation decreases with increasing distance (as striking velocity decreases). At a shooting distance of 80 meters the bullet breaks in half forming two large fragments, and at over 180 meters it does not break, although it flattens somewhat sqeezing out a few small fragments from its base. Thus at ranges over 180 meters the wounding capacity and mechanisms are essentially the same as the AK-74.

M-855 22 CAL FMC - The slightly heavier M-855 bullet shot from the M-16A2 Assault Rifle will eventually replace the M-193 bullet shot from the M-16A1 as the standard bullet for the US Armed Forces. The wound profile is similar to that produced by the M-193 bullet. The percentage of fragmentation is higher than the M-193, since the tip generally does not remain in one piece, and the temporary cavity size and location is about the same. Although the permanent cavity is slightly larger, a difference in wcunds caused by the two would be difficult to determine.

The smaller bullets of the new generation Assault Rifles (M-193, AK-74, M-855) are susceptible to deflection and disturbance of their point-forward flight by intermediate targets such as foliage that had insignificant effects on previous larger and slower projectiles. This can result in large yaw angles at impact and a shallower location in the body of maximum tissue disruption. For these bullets that rely on yaw in tissue for their maximum effect, the wound profiles show the average penetration depth at which this yaw occurs. It is not unusual for this distance to vary fifty percent from that pictured.

.224 SOFT-POINT - This 50 grain soft-point bullet is designed for maximum deformation and fragmentation. To produce the wound profile shown in Fig. 11, it was shot from the M-16 cartridge case (known as the 223 Remington in civilian shooting parlance). The amount and type of damage caused is about the same as that caused by the military M-193 (M-16) bullet but the location of the maximum disruption is at a shallower penetration depth. Modification of the M-193 bullet tip by filing or with a wire-cutter, a practice that is more common than realized in military conflicts, will result in a similar tissue disruption pattern to that produced by this soft-point bullet.

12 GAUGE SHOTGUN #4 BUCKSHOT - Loaded with 27 pellets of #4 Buckshot (Fig. 12), the 12 gauge shotgun at close range (3 meters in this case) causes massive crush type tissue disruption. At this short range, soft-tissue impact deforms the individual pellets, increasing their original 6 mm cross section to about 10 mm with concomitant increase in tissue crush or hole size. The 27 perforations of this size in a 7 to 8 cm diameter area result in severe disruption of anatomy by direct crush and in disruption of blood supply to tissue between the multiple wound channels.

The Wound Profiles portray an estimate of the maximum soft-tissue disruption expected at short range (under 25 meters). A gradual decrease in the amount of bullet deformation, fragmentation and maximum temporary cavity size occurs with distance as striking velocity decreases.

If bone is struck by the penetrating projectile the result is predictable (and easily seen on X-ray). Total penetration depth will be less and an increase in tissue disruption due to increased bullet deformation as well as fragments of bone acting as secondary missiles may greatly increase the damage.

FRAGMENTS FROM EXPLOSIVE DEVICES

The great majority of fragments from explosive dervices are of blunt or irregular shape - distinctly not aerodynamic- and of steel or less dense material. This causes them to lose velocity rapidly in air and decreases tissue penetration depth compared to the denser streamlined rifle bullets. The crush type of disruption predominates in the injury pattern caused by the individual fragment from these devices, with little evidence of temporary cavity stretch. The hole made by the fragment is consistent with its size and generally remains constant throughout its path. It is analogous to the wound from a shotgun pellet. Although initial fragment velocities in the 1800 m/sec range are reported for some of these devices (Beyer, 1962), the wounds observed in survivors indicate that striking velocities were less than 600 m/sec. For this reason, body armor affords much better protection against these fragments than against the rifle bullet.

In cases where a survivor was close enough to the device to be struck by many fragments in a localized area, such as stepping on a landmine, the injury pattern is similar to that produced by #4 Buckshot at close range (Fig. 11). Again, the crush mechanism predominates but this is an example of the massive tissue disruption which results when many permanent wound paths in close proximity destroy anatomic integrity.

MISCONCEPTIONS

It becomes obvious from observation of data on the Wound Profiles that projectile striking velocity and mass determine only the potential for tissue disruption. When this potential results in significant tissue disruption, the variables of projectile construction, projectile shape, and type of tissue struck determine where the disruption occurs and what kind of disruption predominates (crush or stretch). For example, a shot through soft tissue of the average human thigh by a 7.62 NATO round loaded with the soft-point bullet (Fig. 9) could result in an exit wound up to 13 cm diameter with much tissue loss. The same potential is available in the 7.62 NATO FMC military bullet (Fig. 5), but the exit wound it causes in a comparable shot would most likely not exceed 2 cm in its largest dimension.

If one walked into a large city hospital with a gunshot wound in the thigh (entrance and exit holes of less than 1 cm in diameter), and gave the history of being shot with a 22 Long Rifle bullet, surgical treatment rendered would be minimal. The same would apply if the history were of a wound from a 38 Special or a 45 Automatic. If, however, the history was given that the wound had been made by an M-16 , most likely the victim would be subjected to a massive excision of the entire bullet path and several cm of tissue on all sides of the path. Comparing the first 12 cm of penetration on the M-16 wound profile (Fig. 10) with that of the other examples mentioned (Figs. 2-4), shows that in such a wound the M-16 is unlikely to cause any more tissue disruption than the 22 Long Rifle. The widespread belief that all wounds caused by "high-velocity" projectiles must be treated by "radical debridement", is an example of a harmful fallacy resulting from failure to recognize the role of bullet mass and construction in the projectile-tissue interaction.

Serious misunderstanding has been generated by looking upon "kinetic energy transfer" from projectile to tissue as a mechanism of injury. In spite of data to the contrary (Wang,et al. 1982), many assume that the amount of "kinetic energy deposit" in the body by a projectile is a measure of the damage it does. Such thinking stops short of delving into the actual interaction of projectile and tissue that is the crux of wound ballistics. Wounds that result in a given amount of "kinetic energy deposit" may differ widely. The nondeforming rifle bullet of the AK-74 (Fig.7) causes a large temporary cavity which can cause marked disruption in some tissue (liver), but has far less effect in others (muscle, lung, bowel wall) (Fackler,1984). The temporary cavity of about the same size produced by the M-16 (Fig. 10), acting on tissue that has been perforated by bullet fragments, causes a much larger permanent cavity in tissues such as muscle and bowel wall and a similar disruption to that caused by the AK-74 in liver. A large slow projectile will crush (permanent cavity) a large amount of tissue, wheras a small fast missile with the same kinetic energy will stretch more tissue (temporary cavity) but crush little.

The "temporary cavity/energy deposit mystique" has also misled those in weapon development and evaluation. A large study (Bruchey, 1979) which attempts to rate handgun bullets makes the unfounded assumption that the temporary cavity size produced by a bullet is directly proportional to the incapacitation that bullet causes in the human target. Many body tissues (muscle, skin, bowel wall, lung) are soft and flexible - the physical characteristics of a good energy absorber. The assumption that tissue must be damaged by temporary displacement makes no sense physically or biologically. Not surprisingly, law enforcement agencies are finding increasing numbers of cases in which handgun bullets chosen on the basis of such studies fail to perform as predicted.

Anyone yet unconvinced of the fallibility of using kinetic energy alone to measure wounding capacity might wish to consider the example of a modern broadhead hunting arrow. It is used to kill all species of big game, yet its striking energy is about 68 Joules - less than that of the 22 Short bullet.

CLINICAL APPLICATIONS

Penetrating projectile wounds, like any other mechanical trauma, cause their harm by tissue disruption. The restoration of the integrity of disrupted body systems (circulatory, GI, respiratory, GU, etc.) are a top priority. The missile path, contaminated with bacteria, may later become a source of invasive infection which can threaten life or at least prolong healing. This threat is covered in detail in Chapter XVI - "Wounds and Injuries of the Soft Tissues", but it should be mentioned here that the top priorities in the treatment of penetrating projectile wounds are the establishment of an adequate blood level of a penicillin-like antibiotic as soon as possible, and the establishment of open wound drainage. The high priority of antibiotic coverage may surprise those who have forgotten that a streptococcal bacteremia was by far the most common cause of death in war wounds in the pre-antibiotic era (Ireland, 1929).

In the combat casualty with a missile caused wound, determining the course of the missile in the body is a major concern. Since the majority of penetrating projectiles follow a relatively straight course in tissue, an estimate of the missile path can be made from the location of the entrance hole and the position of the projectile in the body, or the location of the exit hole. In most cases, physical examination and biplanar x-rays establish these two points and estimation of structures that might have been damaged is clear. In some cases oblique x-ray views will be needed and it may be impossible to determine with certainty if penetration of a body cavity has occurred. "Is that fragment intraperitoneal or in the abdominal wall?" - combat surgeons are very familiar with that question. Is a laparotomy needed or not? In cases of uncertainty, do the laparotomy - missed gut perforations do not do well in the combat scenario.

Bullet fragmentation and its correlation with severe permanent tissue disruption (Figs. 9-12) is an especially useful roentgenographic sign. Rifle wounds of the chest wall in which a large disruption has occurred in the muscles of the shoulder girdle (M-16, Ak-74, or AK-47 if it hit bone) may be expected to have pulmonary contusion even without penetration of the pleural cavity. This may not be evident on x-rays taken shortly after the wound occurred. Be aware of this potentially life threatening situation, and assure adequate follow-up observation and treatment. This is probably the only common situation in which truly occult damage from temporary cavity "blunt trauma" results in a clinical problem.

Comparing tissue disruption patterns observed in the wounded with the Wound Profiles shown should allow some conclusions to be drawn about the wounding projectile. This information may well prove useful for military intelligence as it has for forensic science.

CONCLUSION

An intelligent surgeon, knowing nothing more about penetrating missile injuries than that the path they make is contaminated, would most likely treat them appropriately. Much of the data presented in this chapter is to counteract dogma that preaches unfounded, illogical, and harmful methods such as the excision of an entire missile path with several cm of healthy surrounding tissue because of a history that the wound was caused by a "high velocity" projectile.

Treatment decisions are made on hard evidence-physical and roentgenographic findings. To paraphrase Lindsey, "treat the wound, not the weapon".

MISSILE CAUSED WOUNDS

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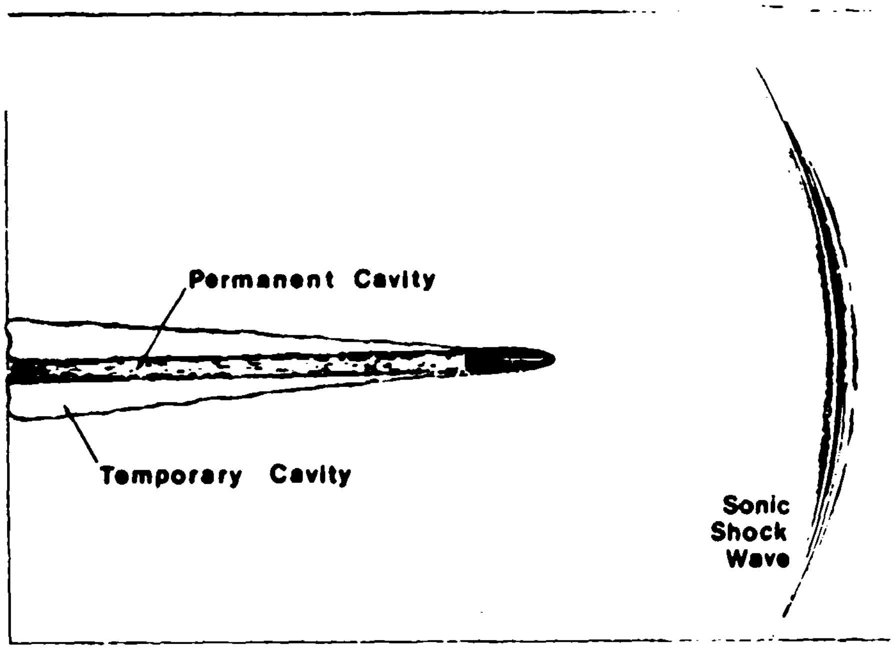

FIG. 1. - Diagram of bullet passing through tissue showing sonic shock wave and how the temporary cavity is formed by outward stretch of the permanent cavity.

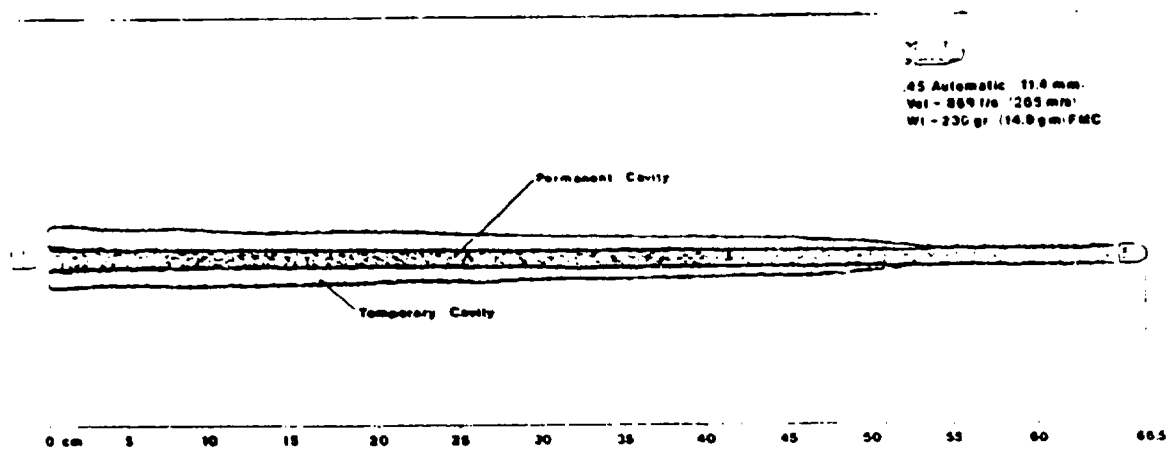

FIG. 2. - 45 Automatic - This was the standard U.S. Army pistol until recently. The short, round nosed, full-metal-cased bullet does not deform or yaw significantly in tissue but penetrates deeply.

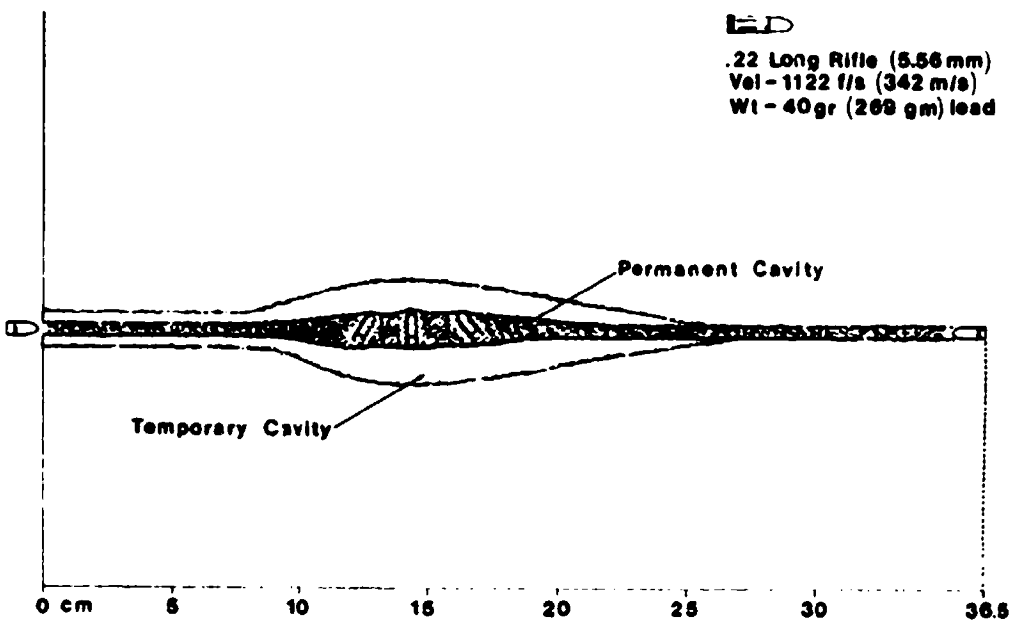

FIG. 3. - 22 Long Rifle - This solid lead round nosed bullet yaws through 90 degrees and travels base-forward for the last half of its tissue path.

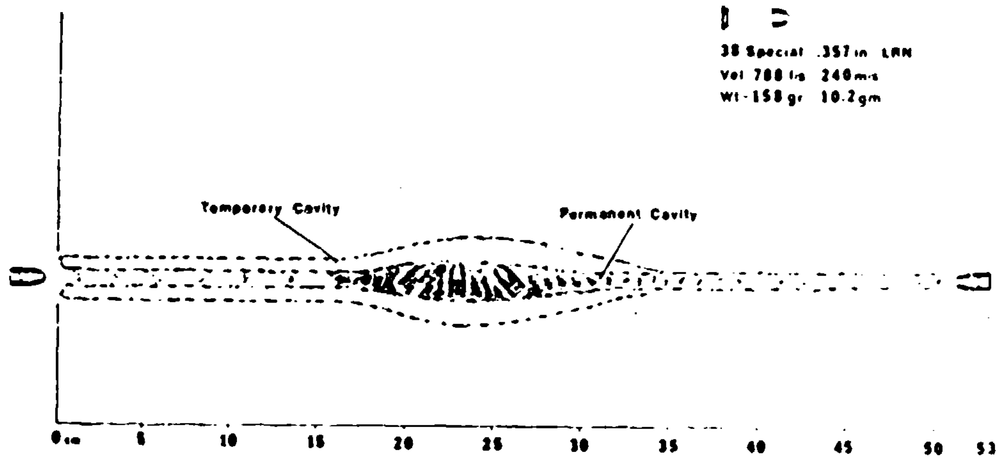

FIG. 4. - 38 Special lead round nosed bullet - Seven out of ten of these bullets yawed through 90 degrees and traveled base-forward for the latter part of their tissue path as show. Three shots yawed to about 80 degrees, then straightened out and traveled point-forward for the remainder of their path.

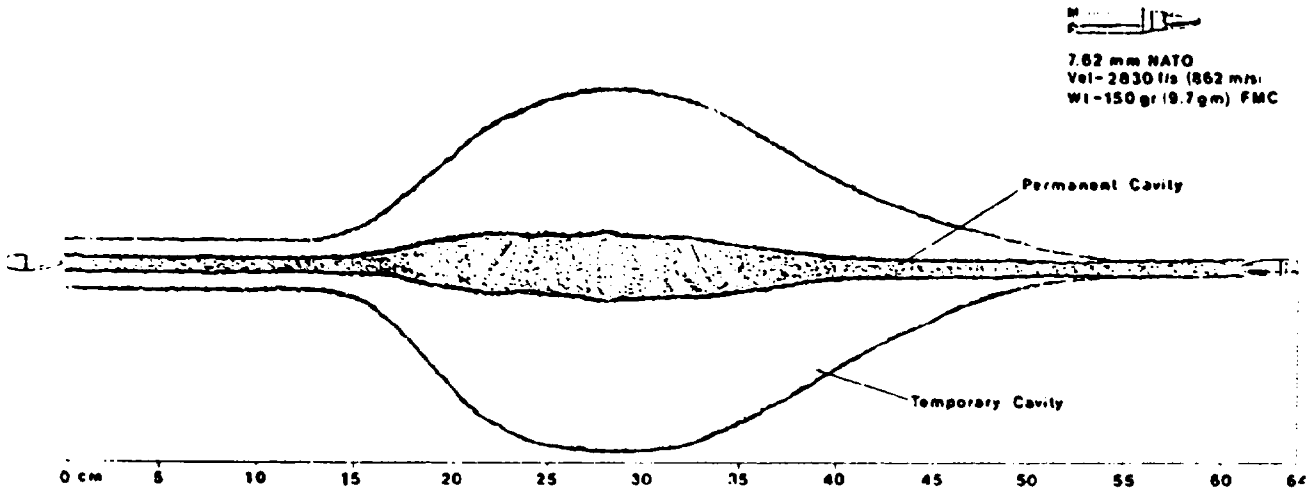

FIG. 5. - 7.62 NATO cartridge with full metal cased military bullet- This was the standard U.S. Army rifle until the adoption of the M-16 in the 1960s. It is still used in sniper's rifles and machine guns. After about 16 cm of penetration this bullet yaws through 90 degrees and travels base forward . A large temporary cavity is formed and occurs at the point of maximum yaw.

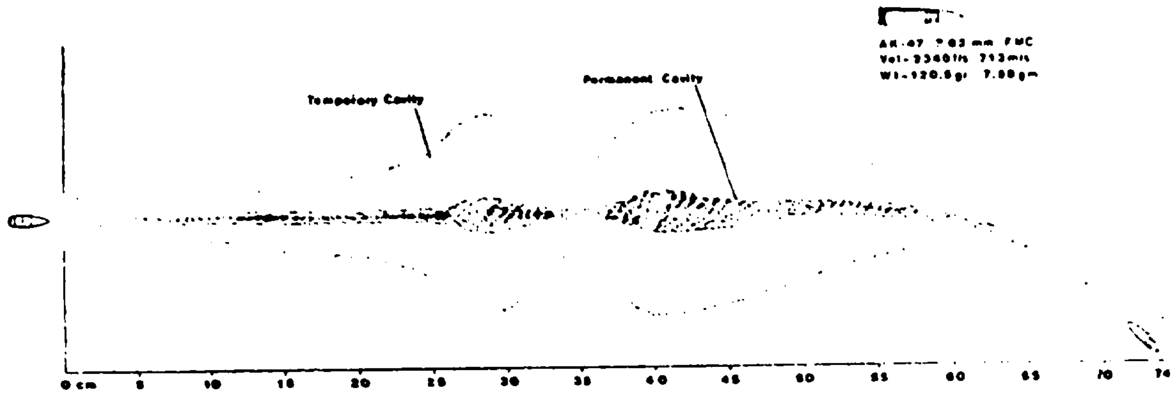

FIG. 6. - AK 47 - This was the standard rifle used by the communist forces in Viet Nam and is used today very widely throughout the world. The long path through tissue before marked yaw begins (about 25 cm) explains the clinical experience that many wounds from this weapon resemble those caused by much lower velocity handguns.

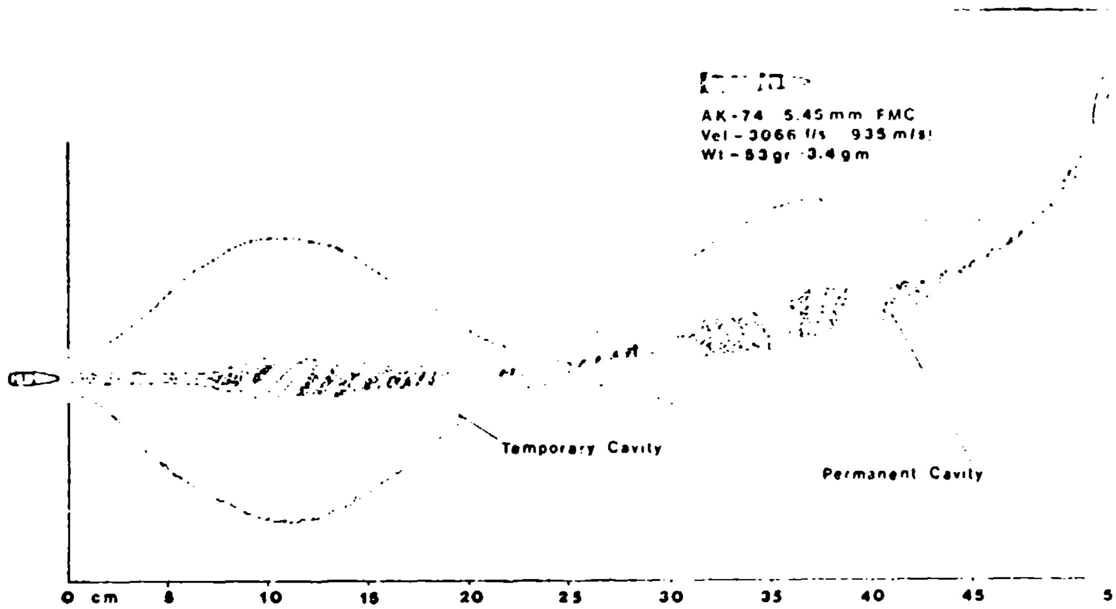

FIG. 7. - AK 74 - This is the Russian contribution to the new generation of smaller caliber assault rifles. The bullet does not deform or fragment in soft tissue but yaws early (after about 7 cm of penetration). As this bullet strikes soft tissue, lead flows forward filling the air space inside the bullet's tip. X-rays of recovered fired bullets show that this "internal deformation" produces an asymetrical bullet which may explain the unusual curve of close to 90 degrees made by the bullet path in the latter part of its penetration.

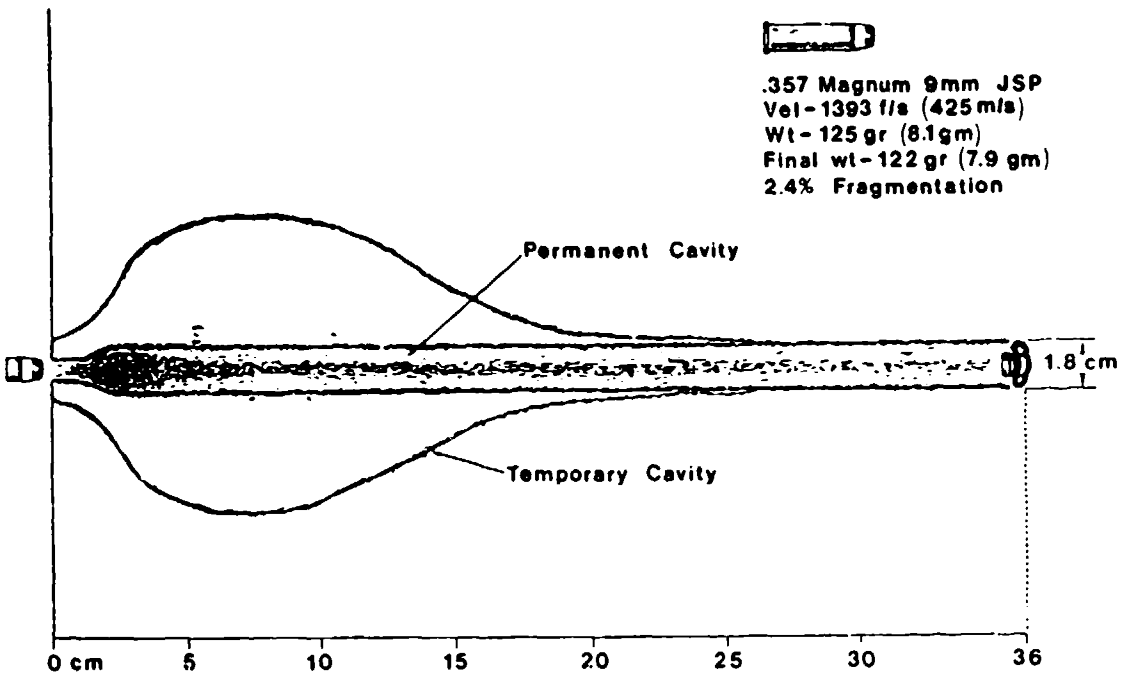

FIG. 8. - 357 Magnum jacketed soft-point pistol bullet - This expanding bullet is typical of those used by the majority of law enforcement agencies in the USA.

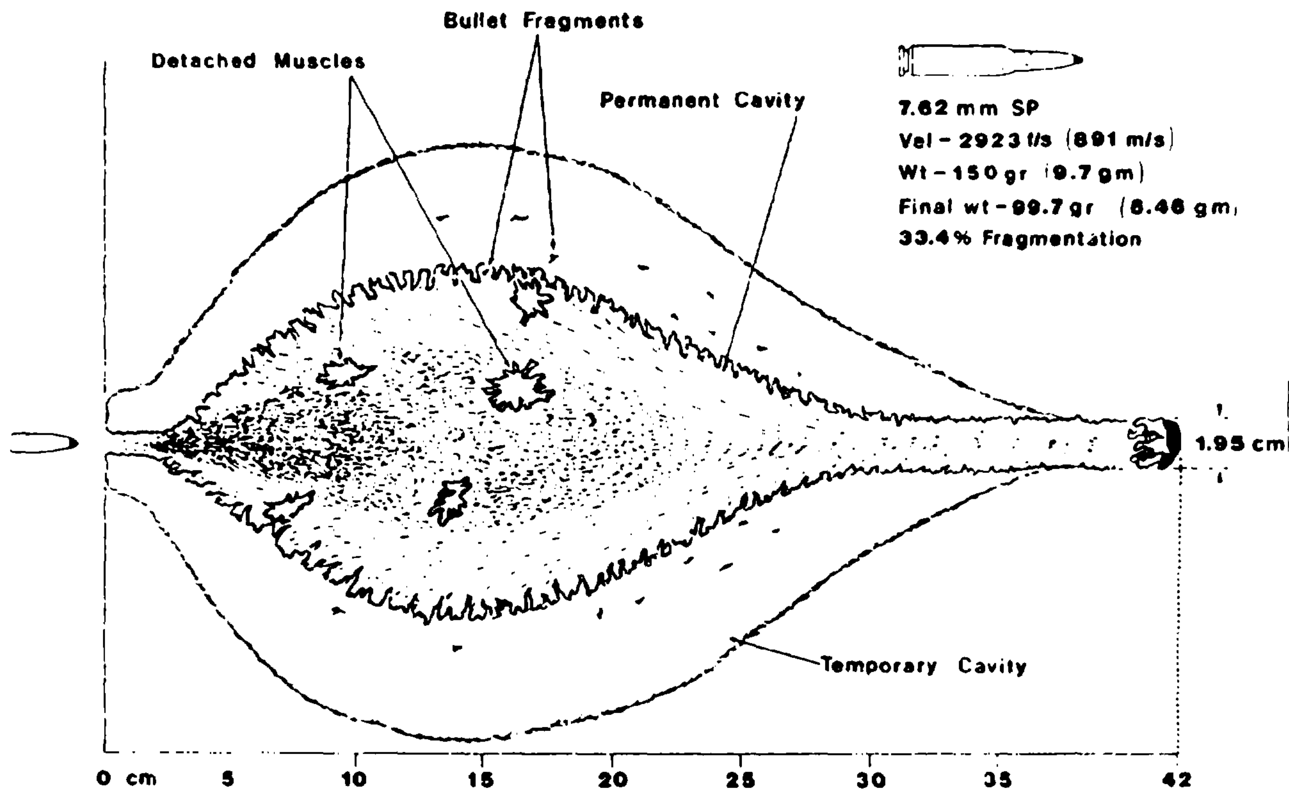

FIG. 9. - 7.62 Soft point bullet - The fragmentation of this bullet is largely responsible for the massive tissue disruption seen as compared to that produced by the nondeforming military bullet fired from the same cartridge (Fig. 5).

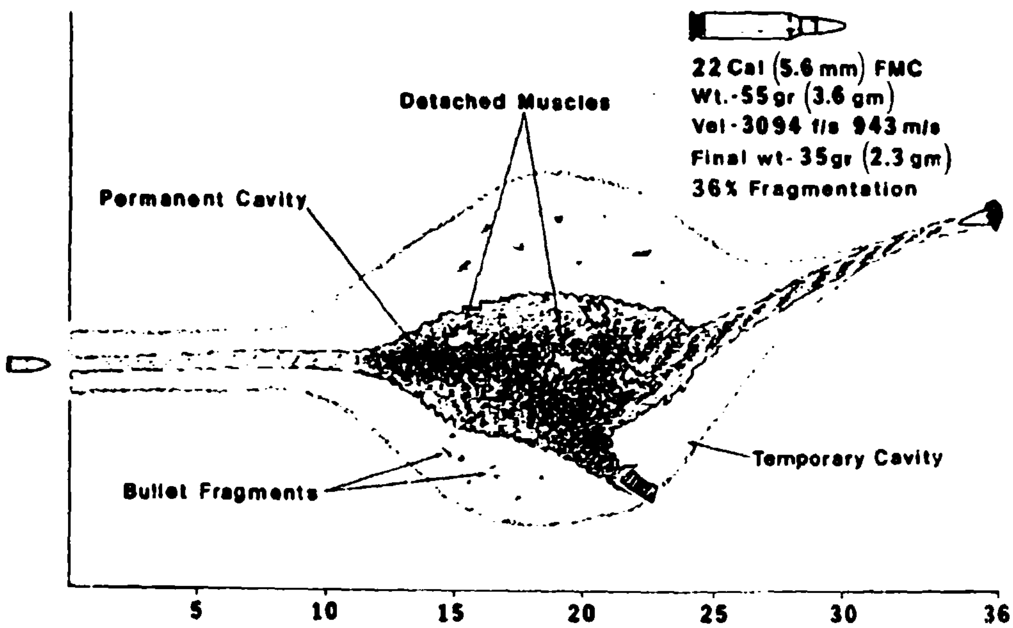

FIG. 10. - 22 Caliber full metal cased (M-16 rifle firing M-193 bullet) - This is the standard weapon of the U.S. Armed Forces, although it is soon to be replaced by a new rifle using the same caliber and cartridge but with a longer and slightly heavier (62 grain) bullet.

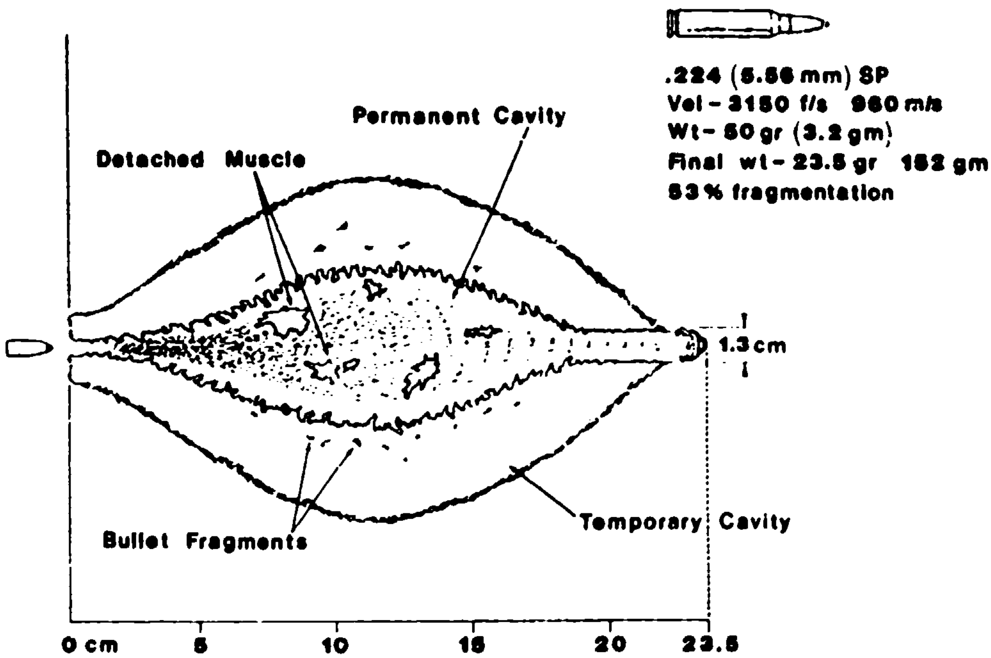

FIG - .224 soft-point bullet - This is a typical 22 cal. ... center-fire hunting bullet (.224 inches is actual bullet diameter) fired from the same cartridge as the military M-16.

12 Gauge Shotgun
no choke
#4 Buckshot
Vel.- 1351 f/s (412 m/s)
Wt.- 540 gr (35gm)
27 pellets of 24 Cal.

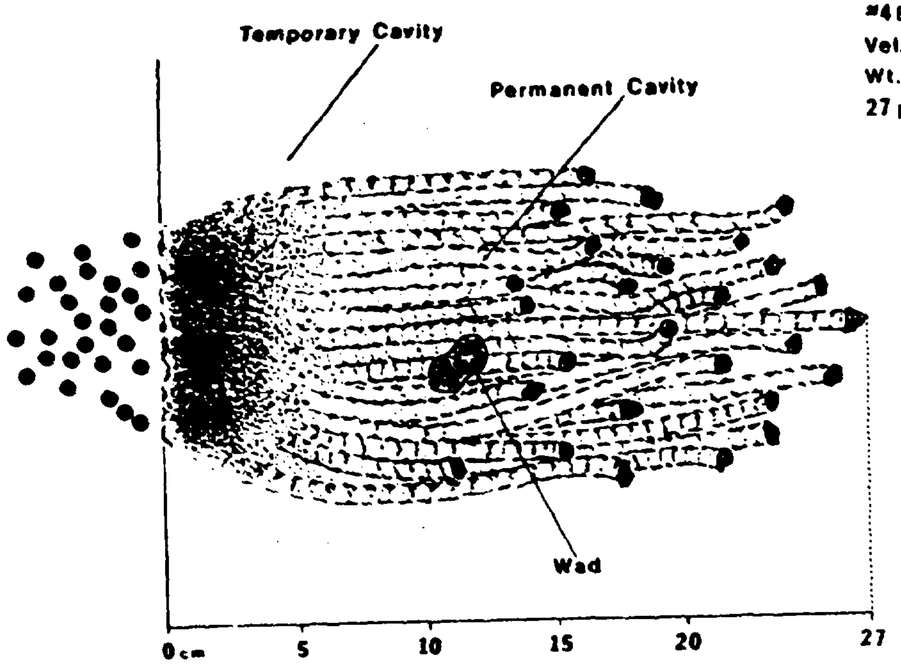

FIG. 12. - 12 Gauge Shotgun with # 4 size buckshot - This load is used by the military and by law enforcement groups for special situations.

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