

WOUND BALLISTIC WORKSHOP
FBI ACADEMY
September 15 - 17, 1987

"9MM VS .45 AUTO"

INTRODUCTION	1
SUMMARY	2
ROBERT L. ADKINS	4
Southwestern Institute of Forensic Sciences 5230 Medical Center Drive Dallas, Texas 75235	
DR. VINCENT DIMAIO	5
Chief Medical Examiner Bexar County 600 N. Leona San Antonio, Texas 78207	
DR. MARTIN L. FACKLER, COL. USA	8
U. S. Army Letterman Army Institute of Research Wound Ballistics Laboratory San Francisco, California 94129-6800	
STAN GODDARD	11
Battell Columbus Labs Research Leader, Ballistic Sciences Ordinance Systems and technology Division 505 King Avenue Columbus, Ohio 43201-2693	
DOUGLAS LINDSEY, M.D. DR.P.H.	18
Professor of Surgery University of Arizona Tucson, Arizona 85724	
SGT. EVAN MARSHALL	19
20519 Freeland Detroit, Michigan 48235	
DR. CARROLL PETERS	20
University of Tennessee Space Institute Tulahoma, Tennessee 37388	
DR. O'BRIEN C. SMITH	22
University of Tennessee Medical Center 3 North Dunlap Memphis, Tennessee 38163	
APPENDIX	26

INTRODUCTION

In September of 1987, the Weapons Advisory Committee of the FBI Academy conducted an evaluation of a number of semi-automatic pistols. These pistols represented both the 9mm (Luger) and .45 Automatic calibers and were considered for issue to FBI Field SWAT teams as well as to Special Operations Groups (SOG). During the selection process, it became apparent that the caliber question was highly controversial and very technical. In order to substantiate the final selection recommendation, a decision was made to seek outside expertise to analyze the factors involved in handgun wounding and the relative effectiveness of the two calibers. Consequently, a number of recognized experts from several disciplines accepted an invitation to participate in a three-day Wound Ballistic Workshop that was held at the FBI Academy on September 15 - 17, 1987. On the final day of this workshop, each participant presented a brief oral summary of his findings and a written position paper on same.

The key findings of the participants follows as a Summary, as well as the position papers of each.

SUMMARY

- I. WOUNDING - Except for hits to the central nervous system (CNS), reliable and reproducible instant incapacitation is not possible with any handgun bullet. Whether incapacitation occurs, depends entirely upon the physical, emotional, psychological, and mental state of the individual, including the presence or absence of narcotics, alcohol, or adrenalin. Even if the heart is destroyed, the individual still has enough oxygen in the brain for full and complete voluntary action for 10 to 15 seconds.

Temporary cavitation caused by a handgun round has no wounding effect. Kinetic energy deposit has no wounding effect. Organs will only be damaged by handgun bullets if they are hit by that bullet. Therefore, bullets must be capable of penetrating deeply enough to pass through the organs to be effective. The experts condemned the use of the well-known Relative Incapacitation Index (RII) as a viable method for the comparison of bullets inasmuch as the RII measurements are based on temporary cavitation and do not reflect actual wound results.

Given equal penetration, a bigger bullet will disrupt more tissue and hopefully cause greater bleeding. Barring a CNS hit, incapacitation can only be forced by blood loss and that takes time as well as sufficient penetration to hit major blood vessels through intervening musculature, fat, clothing, arms, etc. Any bullet that will not reliably penetrate a minimum of 10 to 12 inches of soft tissue is inadequate. Penetration is a function of bullet mass and design, not velocity. The feared hazards of over penetration are greatly exaggerated except in the possible case of full-metal-jacketed (FMJ) ammunition.

- II. 9mm vs. .45 - The single most important factor in assessing the effectiveness of any caliber is penetration. If the bullet will not penetrate at least 10 to 12 inches of soft tissue, it is dangerously inadequate. Given equal penetration, a larger bullet will disrupt more tissue and could hasten blood loss; however, the experts could not say that the damage caused by the larger .45 caliber was significantly more than that of the 9mm. Barring the FMJ ammunition in both calibers, there are no currently available 9mm hollowpoints that are adequate. If they expand, they do not penetrate enough. If they do not expand, they perform like FMJ ammunition. A new 9mm round, the 147-grain, subsonic ammunition developed for the

Department of Defense, may be the answer for 9mm pistols. Preliminary testing of this round reflects excellent penetration, expansion, and accuracy. In .45 caliber, the hollowpoint ammunition tested ranged in penetration from marginally adequate to acceptable. Three of the eight experts recommend the .45 over the current 9mm rounds with the exception of the 147-grain, subsonic round, which they recommend for further testing and evaluation. Four of the eight advised that there was no difference in the wounding effects of either caliber given adequate penetration. One of the eight recommended the 9mm based upon future military research and development that will occur in the years to come and which will improve the caliber in terms of ballistic efficiency. Such improvements are conservatively ten or more years away.

Because incapacitation cannot be predicted, the Agent should keep on shooting as long as the individual poses a threat. The shooter should not assume that one or two hits will incapacitate or stop the threat. For this reason, several of the experts opted for increased magazine capacity.

While expansion is desirable, no bullet should be selected if it must expand in order to perform properly. The perception of the Agents using the weapons can be an overwhelming factor. If the Agent believes in the reliability and effectiveness of the weapon and the ammunition, then he/she tends to shoot better with that weapon.

ROBERT L. ADKINS
Southwestern Institute of Forensic Sciences
5230 Medical Center Drive
Dallas, TX 75235

Criteria for the selection of the proper handgun and cartridge: 9mm vs. 45 ACP

The selection of the handgun must take into account the physical characteristics of the persons using the firearms. Can the persons using the firearm properly control the firearm in a rapid fire situation?

With proper training both small men and women can control both the 9mm auto and the 45 ACP. The differences in recoil are not measurable.

The single most important element in a shooting is shot placement. The bullet must strike the target to be effective.

Bullet penetration is the next most important criterion. To be effective a bullet must be able to penetrate to the vital organs. Most handgun bullets with a high KE loss deposit their energy on the surface where it is of little value. Prime examples of high KE loss bullets are the Winchester 115 gr. 9mm Silvertip hollowpoint and the Glaser which have an energy loss of 96% and 100% in a 15 cm thick gelatin block.

Bullets that show an energy loss in the 80% range in a 15 cm thick gelatin block have good wound cavities in the human body. Examples of which are the CCI 200 gr. JHP in 45 ACP, and the Remington 115 gr. JHP in 9mm, which have energy losses of 86% and 80%.

Caliber is the least important criteria in the selection process. Both the 9mm and 45 have approximately the same energy and recoil. Construction of the bullet is more important than the diameter. The new 147 gr 9mm subsonic bullet deserves a very close look.

DR. VINCENT DIMAIO
Chief Medical Examiner Bexar County
600 N. Leona
San Antonio, TX 78207

9MM VS .45ACP

The handgun is the primary individual firearm of all law enforcement personnel whether they be FBI Agents or police on patrol. Ideally, these individuals should be supplied with a weapon and ammunition that would cause immediate incapacitation of any individual they would have to shoot.

Unfortunately, there is no such weapon nor such ammunition. All that one can do is select a weapon and ammunition that increases the probability of instant incapacitation. There is no guarantee in any individual case.

Three factors determine how fast one is incapacitated after being shot. These are:

(1) The "severity" of the wound. This can be expressed as the size of the temporary cavity produced by the bullet, the amount of tissue destroyed, the kinetic energy transferred to an organ by the bullet. It is not important what you call the mechanism producing the wounding effect. We do not in fact fully understand the interaction between a bullet and a body. At present, most people quantitate the injury by the amount of kinetic energy transferred from a bullet to the body. This is not the complete picture, however.

(2) The organ injured. Wounds in some organs will produce immediate instantaneous incapacitation. A bullet through the brain stem, the basal ganglia of the brain, the spinal cord in the neck will produce instant collapse and inability to move at all. In my experience approximately 50% of all fatal wounds in homicides fall into this category. In such cases, the caliber of the gun and type of ammunition is almost irrelevant. A .25ACP kills just as quick as a .45 auto. Aside from these areas, there is generally no guarantee of instant incapacitation. Thus in one case a young man was shot at a range of 2-3 feet in the chest with a 12 gauge shotgun. His heart was literally shredded--reduced to chopped meat. The individual turned and ran 65 feet. Why? Because your brain can function for 10-15 seconds after your heart stops. Thus, the brain can cause you to lift your hand and fire a gun even if you have no heart. Of course if the

bullet shatters the wrist or the hand holding the gun you cannot shoot the gun at least with that hand.

(c) The third factor is individual physiological response.

In other words, some people are tougher than others. You can shoot a 250 lb. male in the arm with a .22 and he will keel over. Then a 130 lb. woman will take 3 hits with a .44 Mag and keep on coming. There is no way to predict physiologic response to being shot.

Let us recapitulate--There are three factors determining how fast one is incapacitated after being shot .

(A) The amount of energy delivered to the body i.e. the "severity" of the wound.

(B) The organs hit.

(C) Individual physiologic response.

Of these three determining factors we can control the first; have limited control on the second and have absolutely no control on the last.

As I said individual physiologic response cannot be controlled or predicted. What about controlling the second factor--"the organs hit". This can be controlled two ways.

(1) By frequent realistic training with weapons so the shooter hits his target.

(2) By increasing the firepower. In other words if you shoot once at the perpetrator, you have one chance of inflicting an incapacitating wound. If you shoot fifteen times you have fifteen times the chance. Of course you may get him with the first shot--or the fifteenth. If you have seven rounds in the gun, you have to reload; if fifteen, you don't have to reload.

It is of course understood that the weapon must be controllable, reliable and accurate. A .44 Magnum may be reliable and accurate but not controllable. Some weapons are unreliable; some inaccurate--some uncontrollable, unreliable and inaccurate.

The factor determining incapacitation that we have most control over is the first--the energy lost by the bullet--its stopping power--its wounding ability. We control it by selecting caliber and style of ammunition. It is of course obvious that a .45 caliber bullet weighing 230 gr. is more effective than a 40 gr. .22 LR bullet.

In this conference, however, we are comparing calibers .45ACP and 9mm Parabellum. If you compare the "stopping energy" of these two calibers with equivalent bullets, i.e. full metal jacketed to full metal jacketed; JHP to JHP, there is really no difference in their wounding ability. In other words, the amount of energy lost by each in the body in wounding is equivalent, the extent of wounding is the same and the lethality is the same.

Let me stop for a second to clear up some myths. Handgun bullets are low energy projectiles. Unlike rifle bullets, as they pass through the body, they have to strike an organ to injure it. No matter what the style of the bullet--hollowpoint or FMJ, the appearance and extent of wounding appears the same. There is no increase in lethality, i.e. killing with hollowpoint bullets compared to solid bullets. Handgun bullets kill by punching holes in an organ. Whether the bullet is hollowpoint or solid you still have a hole!

You can control the rate and degree of expansion of a hollowpoint bullet by its design. This controls loss of energy. You can design both 9mm and .45ACP bullets to lose energy anyway you want. But at the end, the most energy a .45 can lose is about 363 ft-lbs and a 9mm 350 ft-lbs--no significant difference. Thus in my opinion 9mm and .45ACP are equal in wounding ability.

If so what other criteria do you use in selection of a caliber.

(a) Controllability. Both the 9mm and .45 and about the same.

(b) Reliability and accuracy of weapons? The same.

(c) Fire power: Here the 9mm is obviously superior. You have 15 shots to 7-8 in a .45ACP. This doubles your ability to hit a vital organ or organs.

Thus, at the present time, the only major difference between these two weapons is firepower which favors the 9mm.

Whatever choice is made for a weapon, the users must have confidence in it. If the agent carrying the gun has no confidence in it, then, you have a serious problem.

DR. MARTIN L. FACKLER, COL. USA
U. S. Army
Letterman Army Institute of Research
Wound Ballistics Laboratory
San Francisco, CA 94129-6800

Aggressive action by a determined adversary can be stopped reliably and immediately using a handgun only by a shot that disrupts the brain or upper spinal cord. Even the most disruptive heart wound cannot be relied upon to prevent aggression before 10 to 15 seconds has elapsed.

Given this limitation, massive bleeding from holes in the heart or major blood vessels of the torso causing circulatory collapse is the fastest and only other reliable mechanism available to the handgun user.

The anatomic location of these vessels must be well known for appropriate shot placement and the bullet used must be capable of reaching and disrupting them regardless of body position--this includes shots that may have to pass through an arm before striking the torso.

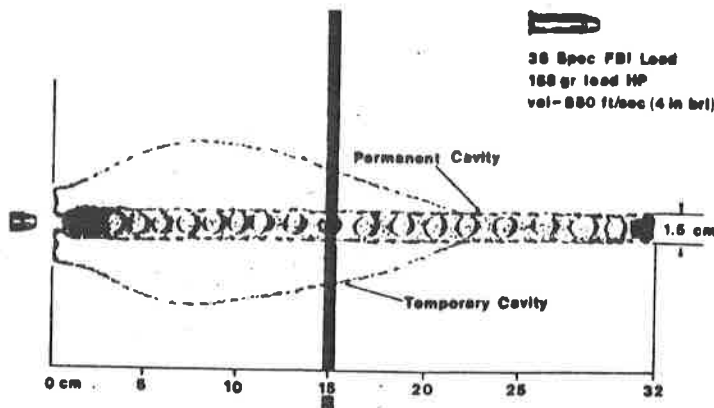
The blood vessels of the abdomen are 15 cm (6 inches) from the front abdominal skin even in a slender person. (See accompanying wound profiles with 15 cm line drawn.) In the upper chest they are at least that deep when approached from the side. Adding to this a possible 10 cm (4 inches) for the thickness of an arm or a large abdomen and it becomes obvious that 25 cm (10 inches) must be the absolute minimum penetration depth capability of any bullet that could be considered acceptable. Any angle, fat, the arm as an intermediate target, etc. will increase the depth a bullet must go to get to these vessels - and when it gets there it must have something left to go through them (they won't bleed if the bullet just nestles up beside them).

The following penetration depths and bullet expanded diameters were obtained from shots made at the Wound Ballistics Laboratory of the Letterman Army Institute of Research into ordnance gelatin calibrated to reproduce the penetration depth and bullet deformation observed in living swine muscle.

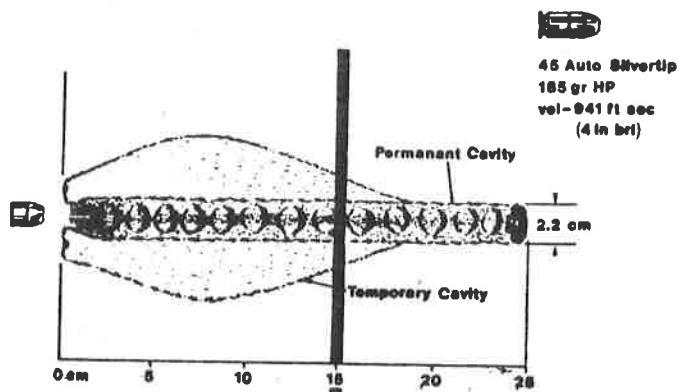
	Penetration Depth	Expanded Diameter
45ACP 185 gr. Silvertip	26.7 cm	19-20 mm
45ACP Rem 185 gr. JHP	28.1 cm	17.5-18.5 mm
9mm 115 gr. Silvertip (Recent)	21.1 cm	16-18 mm
9mm 147 gr JHP	38 cm	14-15 mm

Hardly an article on big game hunting appears that does not emphasize using a bullet which penetrates deeply enough to produce reliable disruption of heart or major vessels. Why has this most critical factor been overlooked by manufacturers of handgun ammunition? Much responsibility must lie with the National Institute of Justice for whom the seriously flawed Relative Incapacitation Index studies were done. These studies ranked bullets solely according to the temporary cavity produced in ordnance gelatin. They assumed that incapacitation of the human target by a given bullet is directly proportional to temporary cavity size. No physiologic mechanism was even postulated for this supposed effect--much less proved. Temporary cavity size for a given bullet can be increased very simply by decreasing bullet weight and increasing velocity. The 9mm 115 grain Silvertip bullet which penetrates only 21.1 cm is an example of the new generation of lighter weight--higher velocity bullets that have been produced as a result of this unfortunate but influential study.

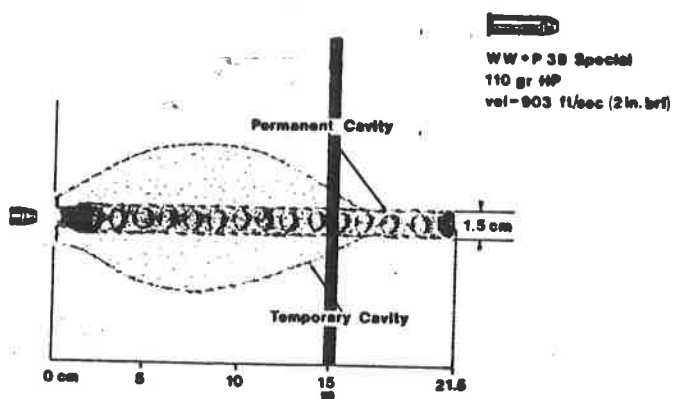
The critical consideration is that the bullet produce its permanent tissue disruption to sufficient depths to insure major vessel disruption from any angle. Of the bullets that attain this goal, common sense would dictate that the largest one would be the most effective since it would put a larger hole in heart or vessels.



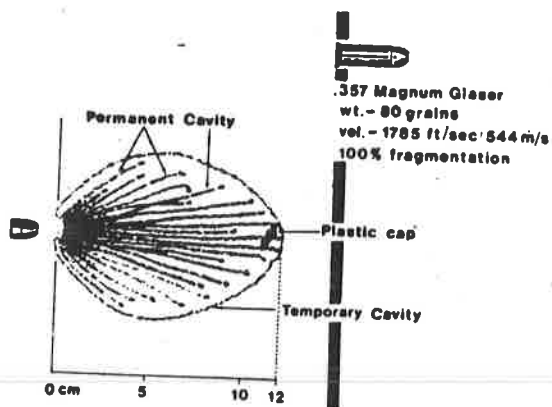
NOTE: The 9mm 1 subsonic round w profile is the s as this, except penetrates deeper 38 cm.



NOTE: Remington Hollowpoint identical but penetrates m to 28.1 cm. Current .45 Silver penetrates to 26



NOTE: The wound profile of the 9m 115 gr. Silvertip identical to this round except the 9mm penetrates ev less.



STAN GODDARD
Battell Columbus Labs
Research Leader, Ballistic Sciences
Ordinance Systems and Technology Division
505 King Avenue
Columbus, OH 43201-2693

SOME ISSUES FOR CONSIDERATION IN CHOOSING BETWEEN
 9MM AND .45ACP HAND GUNS

1. BALLISTIC ISSUES

The basic difference between the 9mm and .45ACP cartridges is the relative weight of the bullets. The powder charges for the two cartridges is essentially the same. Table 1 shows these data.

Table 1. Propellant Charge Details

PARAMETERS	PROJ. WT. (GRAINS)	PROP. CHARGE (GRAINS)	INITIAL VELOCITY (F/S)	SECTIONAL DENSITY (GRAINS/IN)
9MM	125	5.5-6	1100	1270
.45ACP	230	5.5-6	825	1437

PARAMETERS	ENERGY (FT/LB)	ENERGY/AREA (FT/LB/IN ²)	MOMENT LB-SEC X10 ²
9MM	336	3414	61
.45ACP	347	2167	84

Table 1 also shows that both of the cartridges have about the same muzzle energy when fired from a 4" barrel. This is to be expected as the propellant charges are also approximately the same, varying between 5.5 and 6 grains depending upon whether single base or double base powder is being used. The energy per unit area is quite different however, because of the large cross-sectional area of the .45 compared to the 9mm.

Typical gun propellants contain about 1.5 million foot pounds of energy per pound and a typical well designed load and gun combination is about 25-30% efficient, hence one would expect muzzle energies ranging from 321-386 foot-pounds from a 6 grain charge. The difference in the two cartridges so far as recoil or momentum is concerned is about 38%, that is the .45ACP due to its greater bullet weight will produce about 38% more recoil than the 9mm. Future developments in 9mm ammunition may close this gap to some extent.

Table 2 shows the chamber dimensions and volume for the two cases. The .45ACP chamber has 86% more volume than does the 9mm. The cross sectional area is also 57% greater.

Table 2. Chamber Dimensions, Area, and Volume

Parameter	Base Dia (in.)	Body Dia (in.)	Body Area (in ²)	Length (in.)	Volume (in. ³ × 10 ³)
9mm	0.392	0.377	0.112	0.760	84.8
.45ACP	0.493	0.473	0.175	0.898	157.8

The large volume of the .45ACP cartridge compared to the 9mm reduces the number of cartridges that can be conveniently stored in a conventional automatic pistol and the greater length of the cartridge necessitates a broader grip.

The difference in cross-sectional area is important because it also indicates the difference in the inside area of the cartridge cases upon which the gas pressure acts. For instance, if the cartridges were operating at the same internal pressure the force on the bolt would be 5% greater from the .45ACP cartridge. In two guns that are identical except for caliber, it would be necessary to reduce the operating pressure of the .45ACP cartridge if the forces transmitted to the locking surfaces were to be the same. For ballistic efficiency, that is to get the most out of the powder, it is desirable to operate at high pressure.

High pressure combustion pulls the "all-burnt" point back towards the breech, allowing more of the barrel to be used for adiabatic expansion and thus reducing muzzle flash. The direction of current interior ballistic research is toward operating at substantially higher pressures than were popular 20 or more years ago.

Table 3 shows the calculated average pressure required to reach the muzzle velocity listed in Table 1 for the bullets listed in each caliber. It can be seen that the average pressure of the .45ACP is substantially lower than the 9mm (by 57%), which is exactly the reduction needed to produce the same rearward bolt force as the 9mm.

Table 3. Average Pressure to Reach Muzzle Velocity in 4 inches of Bullet Travel.

9mm, $p = 10,227 \text{ lb/in}^2$ (11.3 calibers)
.45ACP, $p = 6,507 \text{ lb/in}^2$ (8.6 calibers)

Table 3 also shows that although the travel distance of the projectile is the same in linear measure, the difference in calibers of travel is quite remarkable. The longer the travel in calibers the more efficient the gun, because more gas expansion can occur.

It is clear from the tabulated data that the 9mm is a more efficient design both from a ballistic and from an energy packaging viewpoint. This becomes clearer when one considers the impact that cartridge size has on the number of rounds housed inside the weapon. The 9mm contains 15 rounds (or 90 grains of powder, or about 5040 foot pounds of potential energy) which the .45ACP contains only 7 rounds (or 42 grains of powder, or about 2429 foot pounds of potential energy).

The status of the two cartridges relative to their support from the U.S. and foreign governments and the resultant prospects for advances in technological development are different. The .45ACP has now been abandoned by the U. S. Department of Defense and it is not supported by any other governments except for a few third world countries that have received surplus military equipment. Undoubtedly the ammunition will still be manufactured by U. S. suppliers but it will have to share the limited research funds that those companies have with a host of other calibers that may enjoy better sales.

U. S. ammunition manufacturers have not been noted for their R&D efforts so far as bullets are concerned. They have usually been part of conglomerates that were engaged in other businesses, for whom the ammunition represented a lucrative low-tech bread and butter product. For instance Olin-Corporation was involved in the production of non-ferrous metals, propellants and rifles, thus ammunition was an ideal sideline. It is well recognized that the gun users were not well served by such conglomerates and that this in turn gave rise to various specialty bullet manufacturers such as Speer and Hornaday. These small companies also cannot be looked to for new ammunition developments

involving propellants, cartridge case, or anything other than bullets. They simply don't have the resources to afford to do otherwise, because the ammunition market is quite mature and may actually be beginning to shrink.

The situation with regard to the 9mm ammunition is quite different. It is officially supported by all of the NATO countries, many of which have an active military ammunition industry. It is well recognized in NATO that the ordinary 9mm pistol is primarily a badge of rank and that it is not an important military weapon. However, it shares its ammunition supply with a number of special purpose weapons, including sub-machine guns that do have sufficient military significance to attract R&D funding for improving their ballistic performance.

Is there room for improving the performance of the 9mm cartridge or is it approaching the end of its developmental life? The answer is that there appears to be room for significant growth in performance, namely in the both muzzle energy and momentum, without the necessity of being forced into the use of light projectiles to obtain better "paper" performance. This could be done by increasing the amount of propellant contained in the case, by simultaneously increasing its energy content, and by increasing case volume.

Recent developments by Battelle have provided the USAF with a new, fully qualified, thin wall, steel-cartridge case for the 30mm cannon that provides 15% more propellant volume than does the present aluminum cartridge case. This technology could eventually find its way into the 9mm case. In addition a significant amount of work has been done and is being continued and expanded by several nations (US, UK, FRG, and the USSR) to apply nitramines (RDX and HMX) to gun propellants. These energetic materials are denser and contain more energy than conventional propellants. They could be the means for providing more energy in a given volume.

Finally, compressed conventional and/or porous propellants are a means for increasing the propellant charge by 10-20%. The technological development of caseless ammunition has a direct bearing on this problem. Heckler and Koch together with Dynamit Nobel, in the FRG are combining this idea with nitramines for high energy density ammunition. That material could be extruded in long porous sticks and cut to length to fit a straight-cased cartridge such as the 9mm. Hence, it is reasonable to expect that the 9mm could be improved in propellant charge output by 10% in five years, 20% in ten years, and 25-30% in fifteen years. And, this could be done without requiring any radical change in bullet type, seating depth, or cartridge length.

Bullet developments that made better use of the large empty cavity found in the nose of some hollowpoints are to be encouraged. If that space were made available at the rear of the projectile instead of at the front a useful addition to the total space for the propellant charge could be made available particularly if and when porous, stick propellant becomes common.

In that regard an attempt should be made to provide a "militarily acceptable", closed-nose projectile, that will perforate various thin materials easily but that will tumble after some 10-20 calibers in penetration in gelatin. Military support for such ammunition should not be difficult to obtain as its application and value are obvious.

2. GUN ISSUES

Many of the potential ammunition developments described above would require an increase in peak pressure if the propellant is to be burnt efficiently. Higher peak pressures, perhaps as much as 50% more than is now standard would increase the loads on the bolt, locking surfaces and the barrel itself.

It is essential then if there is an intention of taking advantage of future ammunition developments that the guns chosen should be adequately strong in both design and materials used in construction.

If improved cartridge cases of the thin wall type are to be used in the gun, it is essential that none of the side wall be unsupported by the chamber walls because it is in the head of the cartridge where most of the volume increase can occur. Hence, the gun should not depend upon the use of thick-headed cartridges for containing the gases in the chamber. This should be done by the bolt face and the chamber walls.

All guns under consideration in testing should be remotely fired with several thousand rounds of high pressure proof ammunition. The cases should be saved in the order fired for later examination. The locking and other high stress areas should be examined for cracks using one of the well known non-destructive dye penetrant techniques every 500 rounds until cracks are discovered or excessive headspace occurs. Firing should be discontinued at that point. Only guns that survive a reasonable life for the intended use should be further considered for adoption.

Once a gun has been chosen its materials and heat treatments should be characterized and a set of well-defined specifications established. This is to ensure that future purchases will meet or exceed the established standards. This is particularly important for guns made from off-the-shelf light metal alloys, which tend to vary more significantly in properties from lot to lot than does steel.

3. STANDARDS ISSUES

The lack of ammunition standards in the law enforcement world leads to unexpected and unplanned variations in performance. It is naive to expect that the ammunition supplies will balance the equation between profit, performance, and quality control in favor of the purchaser. That is clearly too much to expect from human nature.

The absolute necessity for reliability of functioning and performance of both gun and ammunition requires that compatible standards be established for each. Then, when a failure of some kind occurs it will be much easier to find the cause and rectify it immediately or change the standard to prevent its future occurrence.

CONCLUSIONS

The following conclusions are based upon the discussions above:

- * Ballistically there is not much difference between the .45ACP and the 9mm. They both use powder charges of approximately the same weight.
- * The recoil of the 9mm is substantially less than the .45ACP and provides room for growth in performance of the former without exceeding reasonable limits.
- * The .45ACP presents poor packaging which limits the number of rounds in a magazine of reasonable dimensions.
- * The large internal cross sectional area of the .45ACP limits the ammunition operating pressure compared to the 9mm due to placing excessive force on the bolt and locking system.
- * R&D developments are likely to occur that will improve 9mm performance because it is an official cartridge of not just the U.S. but also most of the NATO countries.

- ★ The performance of the 9mm will gradually improve in steps for the next 20 years due to technological developments that have been or are being made in other calibers of military ammunition.
- ★ The traditional ammunition companies cannot be relied upon for developments that will require large expenditures of R&D funds.
- ★ The traditional ammunition companies cannot be relied upon to maintain the performance and characteristics of a particular round. They will change them based upon maintaining an acceptable profit margin.

RECOMMENDATIONS

- ★ Guns should be chosen whose chambers completely enclose the cartridge case and that will withstand repeated firing of high pressure overloads without developing cracks, burrs or excessive headspace. Reliability is absolutely not negotiable.
- ★ Compatible standards for both the gun and ammunition should be developed to ensure that future purchases will live up to past performance.
- ★ The FBI should adopt the 9mm cartridge with suitable guns to fire it.
- ★ The FBI should stay closely involved with the military R&D small arms community and consider cost sharing some research to stimulate Army participation.
- ★ Ammunition from foreign sources (non-commercial in particular) should be procured for testing, particularly high pressure sub-machine gun types. The test results are to guide ammunition developments/requirements.

DOUGLASH LINDSEY, M.D. DR.P.H.
Professor of Surgery
University of Arizona
Tucson, AZ 85724

Credentials:

1. My activity as a researcher in wound ballistics is dated: I left Edgewood Arsenal 25 years ago. I keep up by following closely the work of Fackler and Peters.
2. I have hunted enough big game (moose, bear, caribou, mountain goat, deer) to know that a "solid hit" to the chest usually kills, but seldom incapacitates the animal immediately.
3. I have a personal "reel" for the problem: I have been shot twice myself.
4. My main qualification for advising the FBI is that I am engaged full time in a Class I Trauma Center in Tucson--in effect, in a M*A*S*H in combat on the southwestern frontier.

From my experience with patients I have acquired no data to warrant any recommendation on caliber. I do, however, have data to support the observation that 23 cm of penetration is too little for optimum incapacitation.

You have little to gain by increasing the size of the hole, but much to gain by punching the hole deeper.

What matters to the human target is not what it is shot with, but what structures did the bullet pass through before it stopped, or exited the body. I once treated two patients shot over the heart. The patient shot with the air gun went to cardiac surgery, and spent a long time in intensive care. The patient shot with the ~~gun~~ went home with two band-aids, a tetanus shot, and an appointment slip for Southern Arizona Mental Health; the bullet bounced off the 5th rib, tunneled under the skin, and came out through the ~~axilla~~.

There is widespread and growing recognition of the fact that the importance of temporary cavitation has been overrated as a factor in immediate incapacitation. The time has come to quit worrying about delivered kinetic energy. If two handguns punch a hole of about the same size to the same depth, an excess of delivered kinetic energy of 150-250 foot pounds for one of the two weapons can be cheerfully disregarded as a trivial amount--in the same ball park as a bump on the chest by the nurse who notes ventricular fibrillation on the I.C.U. monitor, and exactly the same as the electrical ~~energy~~ we use in countershock for the same purpose.

SGT. EVAN MARSHALL
20519 Freeland
Detroit, MI 48235

Thoughts on stopping power:

1. There are no super bullets.
2. With regard to handgun bullets, bullet placement is the key.
3. The only sure stop with a handgun round regardless of caliber or design is a central nervous system hit.
4. If handgun bullets actually expand in soft tissue that is a bonus--it is extremely foolish to base one's stopping power hopes on bullet expansion.
5. The best 9mm JHPs and .45 JHPs are virtually identical performers in actual shootings.
6. We need sufficient penetration with handgun bullets to reach the major organs and vessels that when damaged will produce relatively rapid incapacitation.
7. The successful use of a handgun to produce a stop will almost certainly require multiple hits.
8. Handguns regardless of caliber or bullet type are not very good fight stoppers--if we know we are going to have to employ deadly force, we should arm ourselves with an appropriate weapon.
9. It is often very difficult to successfully produce incapacitation without producing death.
10. "Stopping power" must be tempered by factors such as: recoil control, reliability, sufficient accuracy for its intended task, etc.
11. Perceptions by the officers or agent who must ultimately carry the gun can have great impact on how the weapon is accepted. If an officer or agent feels the gun is inadequate, all the expert testimony in the world may not overcome that perception.

DR. CARROLL PETERS
University of Tennessee Space Institute
Tulahoma, TN 37388

RECOMMENDATIONS ON HANDGUN AMMUNITION

Background information on my recommendations is contained in the notes "New Evidence on Incapacitation by Handgun Bullets," which summarize the relevant results of my research on terminal ballistics. (See Appendix A). The major points made in the notes include:

1. My wound-ballistic model, which has been under development for several years, provides reliable quantitative estimates of the tissue-damage profiles caused by a variety of missiles, including both projectiles and fragments.
2. The available evidence suggests that the probability of short-term incapacitation is directly related to the spatial distribution of tissue damage and to the location of that damage distribution relative to vulnerable organs within the body. The likelihood of incapacitation by a given bullet can only be expressed in terms of a probability given a hit because of natural variations in tissue properties and because of randomness in the hit distribution. In addition, the probability is affected by other factors, such as the psychological state of the person shot.
3. For commonly used handgun loads, temporary-cavity formation plays a negligible role in tissue damage. Therefore, the widely publicized RII methodology, which relates incapacitation only to the size and shape of the temporary cavity, is incorrect and should be abandoned.
4. There is no unique relationship between projectile kinetic-energy loss and the amount of damage in soft tissue.
5. The three-zone representation of the tissue-damage profiles, given in the notes (Appendix A), shows that many of the popular JHP bullets do not penetrate deeply enough in typical soft tissue to reliably reach all of the vulnerable organs within the torso. On the other hand, traditional RN bullets, such as .45ACP hardball, penetrate much too deeply unless they tumble.
6. A handgun-load combination should not be selected solely on the basis of soft-tissue performance. Other factors which should be considered include (1) capability of penetrating "hard" materials and textile body armor, (2) the controllability of the load in the handgun selected, and (3) the occasional need for adequate terminal-ballistic performance at ranges exceeding a few meters.

RECOMMENDATIONS:

1. Well-balanced handgun performance is best achieved by relatively light (100-140 grain), very blunt bullets that are constructed of very strong material and which are loaded to relatively high muzzle energies (say 450 foot pounds). Such loads provide (1) a near-optimal damage profile in soft tissue, (2) excellent penetration characteristics in steel and other hard materials, (3) exceptional capability to perforate textile body armor, and (4) only moderate recoil for a given level of terminal-ballistic performance.
2. Before such strong-bullet loads become available, I suggest that any bullet that will not penetrate at least 30 cm into typical soft tissue should not be considered suitable for law enforcement use, and that capability to penetrate 45-50 cm is desirable.
3. With the best of the currently available bullets, the .45ACP cartridge provides a damage profile that is closer to optimum than the profile produced by the 9mm Luger cartridge. (For similar impact kinetic energies and similar stopping distances in soft tissue, a large and heavy bullet will cause more tissue damage than is caused by a smaller and lighter bullet.) Consequently, I recommend that the .45ACP be at least an optional pistol for those who do not need the large magazine capacity available in 9mm pistols. (Note that future developments in 9mm ammunition may result in better overall terminal-ballistic performance than is currently available in either 9mm or .45ACP handguns.)

DR. O'BRIEN C. SMITH
University of Tennessee Medical Center
3 North Dunlap
Memphis, TN 38163

SUBJECT: POSITION PAPER, INCAPACITATION EFFECTIVENESS
9MM VS 45 ACP

DATE: SEPTEMBER 17, 1987

1. The concept of handgun wounds to the torso (not brain) producing reproducible incapacitation, defined as the sudden physical inability to pose any further risk of death or injury to others; is a myth. There is no medical basis for this sudden incapacitation except a gunshot wound to the brain. The incompletely understood physics, the psychological state and basic human physiology involved are such that incapacitation may occur as desired, but this is in no way predictable or sufficiently within our control so as to be truly useful.
2. The psychological factors contributing to incapacitation are probably more important than any others. They are: knowledge of the injury, fears concerning the injury (death, disability, disfigurement, pain, blood, etc), intimidation by the weapon, and the desire to quit. However, mental factors are also the primary cause of incapacitation failures, evidenced on the battlefield and on the street. A person may be unaware of his wound, may be highly motivated or desire to continue fighting. Also included are the effects of chemicals, from his own adrenalin, to PCP, heroin, amphetamines, cocaine and others that are stimulants, anesthetics, pain killers, or tranquilizers.
3. Physics such as energy deposit, momentum transfer, volume of tissue damage, size of the temporary cavity, or calculations such as the RII are irrelevant or erroneous. The impact of the bullet upon the body is less than the recoil of the weapon. As such, only tissue damage has any link to incapacitation, but excluding the brain, it is not responsible for incapacitation within the time frame used here.
4. Physiological factors may play a minor role in achieving incapacitation. Only gunshot wounds to the brain or significant bodily disruption (disintegration/dismemberment) as in explosions can accomplish this. Limited to the effects of handgun bullets upon the major organs of the chest and abdomen, a motivated, aggressive individual, or one under

the effects of adrenalin or the drugs listed above, will only become incapacitated when the heart, a large vessel or a vascular organ (liver) is damaged, and bleeding causes a drop in blood pressure. Voluntary activity may persist for 10-15 seconds after the heart has been destroyed, although vision may fail before this. Some individuals will be "stunned" by their injuries, incapable of any movement. The cause of this is not known. It is an inconsistent, unreliable and not reproducible event. Pain may or may not be a factor, but the painful stimulus must first be perceived (inconstant in war and high emotional states, drug effects, etc.), and then this perception of pain must cause an emotional reaction.

5. Field results will be an individualistic reaction on the part of each person shot. Percentages may be quoted for the ability to incapacitate, based on admittedly too few cases, combining head and torso shots, and using criteria of incapacitation which may or may not be comparable with the one here. Further, no one individual responds as a percentage, but is an all or none phenomenon, which the agent cannot conceivably predict. The factors under our control fall into two areas; engineering effective combinations of weapons and cartridges, and training agents to capably place their bullets into areas of the body necessary to either destroy the brain, or where heavy, if not massive bleeding will occur. Selection of the weapon and Agent training is best left with the more capable Firearms Training Unit. This Forum discussed the 9mm parabellum and .45ACP cartridges. My specific opinions are expressed below.

- A. The effectiveness of both calibers is potentially adequate.
- B. The currently issued W-W 9mm 115 gr. Silvertip dangerously lacks penetration due to its early and full expansion.
- C. The more recently developed W-W 9mm 147 gr. subsonic JHP penetrates further and is an acceptable early replacement. Even more penetration would be desirable (enhance velocity or mass).
- D. The current W-W .45ACP 185 gr. Silvertip is marginally better.
- E. The Remington .45ACP 185 gr JHP is better yet, but even more penetration would be desirable.

- F. The wound profile (per Dr. C. Peters model or Dr. M. Fackler's gelatin/animal model) should reflect well-distributed damage extending deep into the torso rather than superficially, for any bullet adopted.
- G. With the current expanding bullet technology as evidenced by those now in use, penetration is more a function of mass than velocity. Penetration of 30 cm (12 inches) of typical soft tissues should be considered minimum. Ideally, more penetration should be available so that bullets may go through an arm and across the torso.
- H. Increasing velocity of the W-W 9mm 147 gr. subsonic JHP may increase penetration but risks over expanding it. Velocity with the present bullets is more a means to a flatter trajectory (not necessary).
- I. The risk of over-penetration (exit) is exaggerated, given the burst strength characteristics of the skin as the bullet exits.
- J. Caliber is the basic bullet dimension which produces injury at any given wound depth (a function of mass, velocity and shape). If a .45 and 9mm expand to the same diameter at the same rate and reach the same depth, they will produce identical injury. If they do not expand, the .45 produces more injury at the same depth than does the 9mm.
- K. Hollowpoint bullets are good in concept, but no bullet should be selected if this depends upon or requires expansion. Frequent failures to expand will be encountered due to abdominal shots, intermediate targets with closure of the tip, cocoons forming from lofted fiber insulation in clothing, etc.
- L. Incapacitation becomes more likely with greater tissue destruction, as heavy bleeding is more likely.
- M. The agent should maintain sustained fire until the assailant unquestionably poses no threat.
- N. Analysis of FBI shooting data should be made to determine adequacy of one magazine to meet the average conflict.
- O. Consideration of the necessity to perforate intermediate targets (especially vehicles) may require adoption of an additional bullet style (hard flat cylinder).

- P. The Bureau should not accept variations of industry specifications, but set their own, in weapons as well as ammunition.
- Q. Future developments may radically change cartridge capability or availability in 10 years time, but this probably exceeds the life span of the current handguns. Therefore, the Bureau should not reject adequate weapons and cartridges now, based upon futuristic projections.
- R. Testing of live, awake animals is required to better understand the effects of handgun wounds.
- S. Placement is the most critical feature of the shooting which is under the agents' control. Agents may also be trained to advance their psychological advantage to avoid their incapacitation should they be struck.

NEW EVIDENCE ON INCAPACITATION

BY

HANDGUN BULLETS

**Carroll E. Peters
Center for Laser Applications
The University of Tennessee Space Institute
Tullahoma, Tennessee 37388**

**Presented at
Meeting on Ammunition Selection
FBI Academy
Quantico, Virginia
September 1987**

HISTORY OF WOUND BALLISTICS

• ca. 1900 - WORLD WAR II

- 1. Identification of "explosive" wounds by rifle bullets**
- 2. Thompson - LaGarde Study**
- 3. Hatcher RSP Index**
- 4. Initiation of detailed wound-ballistic studies in U.S.**

• WORLD WAR II - PRESENT

- 1. Systematic Studies at Princeton (Harvey, et al.)**
- 2. Edgewood Arsenal Studies**
- 3. U.S. Army Incapacitation Criterion**
- 4. BRL/CSL Studies of Projectile Retardation and Temporary Cavity Formation**
- 5. Assessment of Incapacitation by Handgun Bullets (mid-70's)**
 - a. DiMaio, et al.**
 - b. Bruchey, et al.**
 - c. Peters**
- 6. LAIR Studies**
- 7. Swedish Studies**
- 8. Other Studies (Germany, China, Yugoslavia, UK)**

OBJECTIVE OF PRESENT STUDY

Development of a physically perceptive, semi-empirical model for predicting the tissue damage by an arbitrary projectile — emphasis on projectiles fired from small arms.

TOPICS ADDRESSED IN PRESENT STUDY

1. Retardation of stable projectiles
 - a. Characterization of target material strength
 - b. Drag coefficients of simple and complex shapes
 - c. Accurate calculation of projectile retardation
2. Projectile instability and yaw growth, retardation of yawing projectiles.
3. Formation of temporary cavities
4. Mechanisms of tissue damage

WHY AN ANALYTICAL MODEL?

1. In general, computations are quick and inexpensive compared to complex experiments.
2. An analytical model, even one that is not completely correct, provides guidance for systematic experimentation. (Interactive process for gaining knowledge)
3. A closed-form solution, or one that is mostly closed-form, provides a definition of the importance of the principal parameters.
4. An analytical model provides predictive capability and provides the basis for systematic optimization.
5. A well-verified and physically sound semi-empirical model is a vehicle for systematically recording experience.
6. Development of a well-verified analytical model, applicable to a wide range of parameters, requires careful assessment of the relevant physics — this is the key to understanding.

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PROJECTILE RETARDATION

The most fundamental aspect of the present wound-ballistic model is the description of projectile retardation in soft tissue. Indeed, it is pointless to consider the other aspects of the projectile-target interaction (temporary cavity formation, mechanisms of tissue damage) without a physically realistic description of how the projectile loses velocity in the target. One must derive a realistic model of the retarding force acting on the projectile, after which Newton's second law can be solved for projectile velocity vs. penetration distance.

The retarding force, F , consists of two components: (1) the force required to accelerate target material out of the projectile path (inertial force), and (2) the force required to structurally damage the material in the projectile path so that it can be displaced. In the present model,

$$F = C_D A (\rho V^2/2 + R)$$

where C_D is the drag coefficient, which depends on projectile shape;
 A is the frontal area of the projectile;
 ρ is the density of the target material;
 V is the instantaneous projectile velocity; and
 R is the rupture modulus of the target material.

A major result of the present study is the identification of the "strain-rate dependence" of the rupture modulus for tissue simulants and living tissue. That is, the material requires more energy per unit volume to rupture it as the rate of deformation increases. It has been found in this study that R is approximately proportional to the square root of the strain rate, i.e.,

$$R \propto (V/d)^{1/2}$$

where d is the projectile diameter. For convenience, the rupture modulus is written in terms of a "characteristic velocity" of the target material, U , which is related to its strength.

$$R = \rho V^{1/2} U^{3/2}$$

where

$$U = U_6 (d/d_6)^{-1/3}$$

The reference values, U_6 and d_6 , are those for a projectile diameter of 6 mm.

The relative importance of the inertial and material-strength forces is indicated by the ratio of V to U . When V/U is one, then the two components of the retarding force are equal in magnitude. When V/U is much greater than one, the inertial component is dominant. Of course, the material-strength component is dominant as the projectile comes to rest in the target. (U for soft tissue is typically 60-100 m/s.)

For handgun bullets, we are usually interested in projectile velocities less than 400 m/s, and a proper description of the material-strength component of the retarding force is essential.

The drag coefficient in tissue and tissue simulants is nearly constant in the projectile velocity range of a few hundred meters per second up to approximately 1200 m/s. Above 1200 m/s, the "transonic drag rise" becomes

significant and is reflected as an increase in the drag coefficient. At projectile velocities less than a few hundred meters per second, the material strength affects the flow pattern over the projectile nose; this is manifested as an increase in the drag coefficient with decreasing projectile velocity.

In the retardation model developed in this study, the velocity dependence of both the rupture modulus and the drag coefficient has been adequately characterized, and the model yields accurate results over the entire projectile velocity range of practical interest (0 to more than 2000 m/s). Of course, accurate prediction of projectile retardation requires adequately accurate values for U_0 and for the drag coefficient in the intermediate velocity range. In this study, U_0 values for various types of tissue and tissue simulant have been deduced from projectile retardation in these materials. In addition, reference values of the drag coefficient have been determined for a variety of projectile shapes, including various handgun bullets.

FORMATION OF TEMPORARY CAVITIES

The model developed to predict the size and shape of the maximum temporary cavity (MTC) was described in the 1986 UTSI Workshop on Wound Ballistics. In the workshop, it was shown that the model yields adequately accurate estimates of gelatin MTC's generated by a variety of projectiles. It was also shown that the model yields adequate estimates of the MTC's that are caused by the slender M2AP bullet in goat muscle and goat liver.

Two MTC's generated by 6.35 mm steel spheres in swine muscle are shown in Fig. 1. Except for the first few centimeters of penetration, the predictions are in good agreement with the experiments.

Predicted and experimental MTC's generated in gelatin by three different handgun bullets are shown in Fig. 2. Clearly, the model provides adequate estimates of handgun MTC's.

MECHANISMS OF TISSUE DAMAGE

In addition to bone, the human body consists of a variety of "soft" tissues. These soft tissues include: (1) very tough materials such as connective tissue and major blood vessels; (2) fibrous and rubbery materials such as muscle; (3) skin; (4) fragile tissues such as liver, spleen and kidney; (5) low-density tissue (lung); and (6) very fragile tissue (brain). Each of the types of soft tissue has a different susceptibility to damage by projectiles.

Primary Damage Mechanisms

1. Compression, shearing and stretching of tissue in the immediate vicinity of the projectile (prompt damage). This is the dominant damage mechanism for handgun bullets.
2. Formation of temporary cavity (mostly tensile damage).
3. Collapse of temporary cavity (mostly compressive damage). This is probably not a significant damage mechanism. Whatever damage that is caused by cavity collapse can be lumped together with mechanism #2.

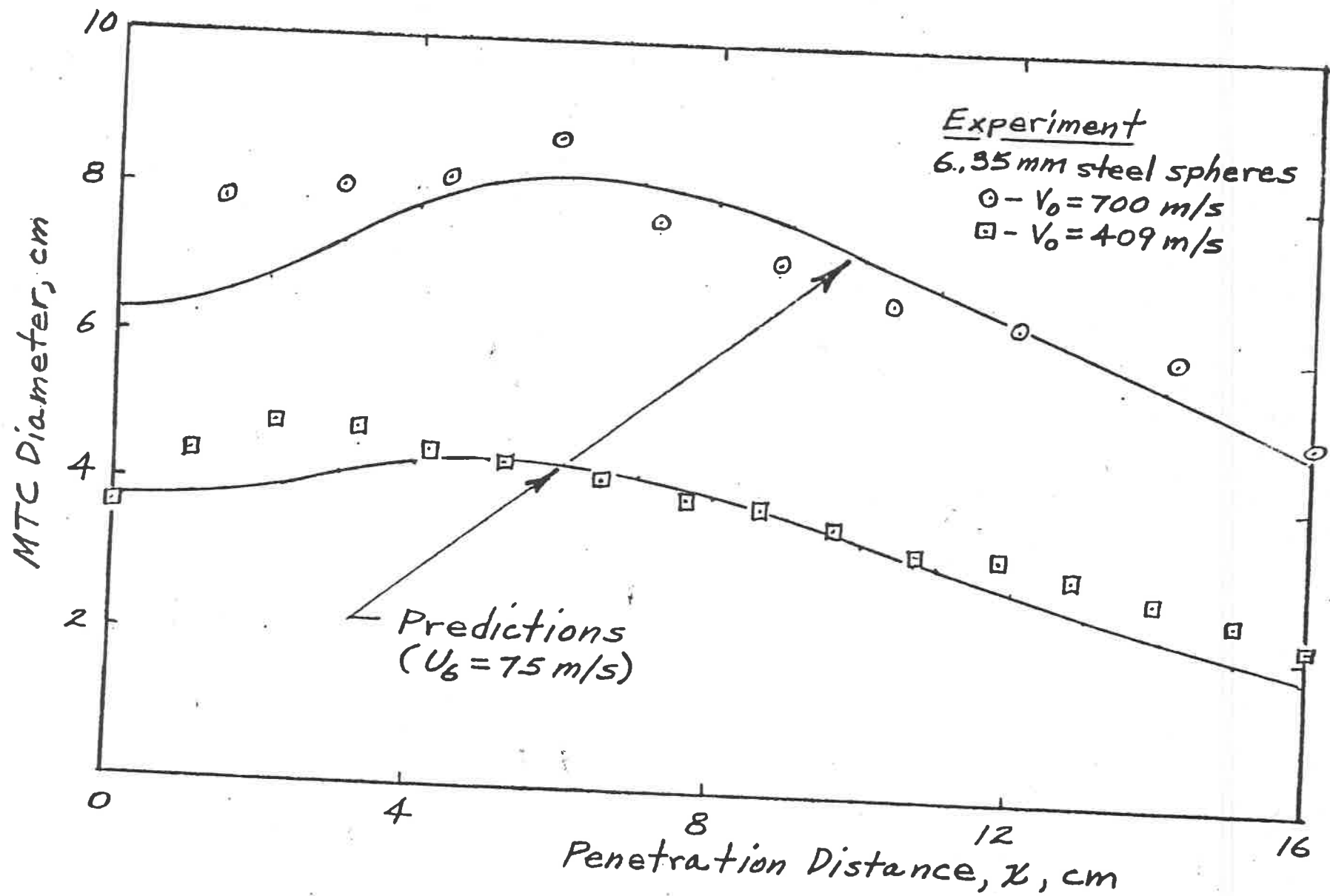


Fig.1 - Maximum-temporary-cavity envelopes in swine muscle

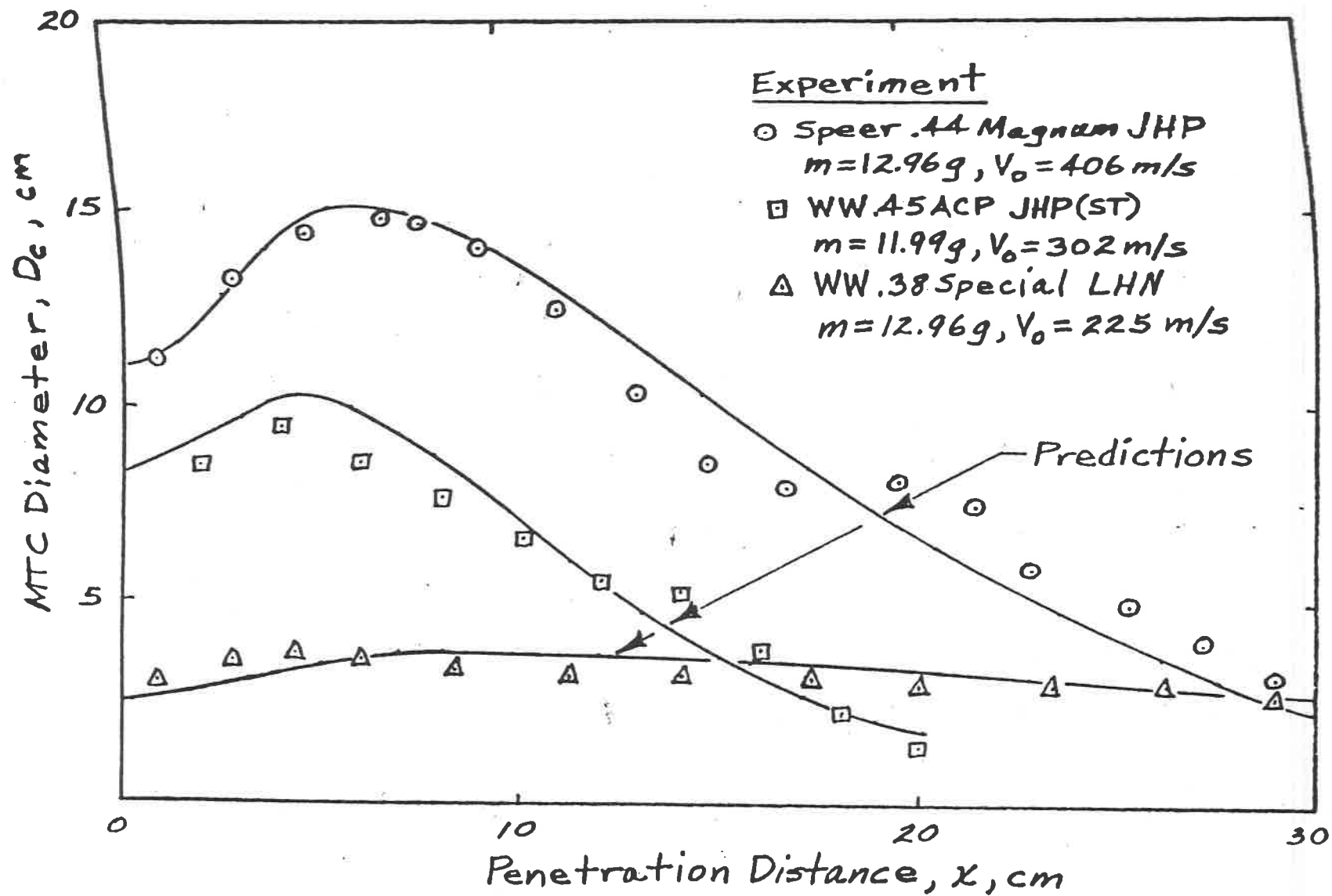


Fig 2 - MTC

Secondary Damage Mechanisms

1. Short-duration pressure pulses that are generated by projectile impact (shock waves and sonic pressure waves).
2. Longer-duration pressure pulses that are a result of temporary-cavity formation and collapse.

Incapacitation vs. Tissue Damage

The available evidence suggests that the probability of short-term incapacitation by a projectile is directly related to the amount of primary damage to vital organs. The incapacitation characteristics depend not only on the total amount of tissue damage, but also on the spatial distribution of damage relative to the position of vulnerable organs within the body.

The issue of incapacitation by a given bullet is clouded by several factors. First, because of natural variations in the properties of living tissue, there are corresponding variations in the amount of tissue damage. Second, there is inevitable randomness in the hit distribution on the target, which affects the likelihood that vulnerable organs will be significantly damaged. Third, the immediate result of a given wound is affected by the psychological state of the person shot and by whether or not he is under the influence of chemical substances. Because of the preceding factors, we can only deal with the statistical probability that a given bullet will result in incapacitation, given a solid hit. That is, we can only speak of the average incapacitation characteristics of a given bullet, observed for a large number of cases.

Composite Model of Tissue Damage

In the present wound-ballistic model, the tissue damage is described by a composite model of primary tissue damage, which includes physically realistic quantitative descriptions of both prompt damage and temporary-cavity damage. In the critical-tensile-strain model of cavity damage, the cavity damage adds to the prompt damage only if the ratio of the local cross-sectional area of the MTC to the local prompt-damage area exceeds a threshold value.

The mathematical descriptions for projectile retardation, temporary cavity formation and tissue damage have been combined in a computer program, WNCBAL. In its present state of development, WNCBAL is applicable only to nonfragmenting projectiles with negligible yaw.

QUANTITATIVE EXPERIMENTS ON LIVING TISSUE
DAMAGED BY PROJECTILES

Swedish Experiments (debrided mass in wounds to swine muscle)

1. 6 mm steel spheres at $V_0 \approx 1000$ m/s
 - a. Control experiments (1978)
 - b. Plaster-cast experiments (1983, 1985)
2. Entrance-region results for 7.62 NATO and M193 (1983, 1985)
3. 7.62 NATO at negligible yaw ($L < 10$ cm) (1975)
4. Nonfragmenting 5.56 mm bullets ($\Delta E/E_0 > 0.36$) (1976, 1977)

Yugoslavian Experiments (debrided mass in wounds to swine muscle)

1. 7.9 mm bullet at negligible yaw ($L < 11$ cm) (1979)
2. 7.62 x 39 ($\Delta E/E_0 > 0.36$) (1979)

Chinese Experiments (debrided mass in wounds to dog muscle)

1. M193 at two nominal impact velocities (1982)
2. 7.62 x 39 at three nominal impact velocities (1982)

Microscopic Assessment of Tissue Damage

1. Krauss (goat muscle) (1957, 1959)
2. Eason, et al, (swine muscle and liver) (1975)
3. Ziervogel (dog muscle) (1979)

Edgewood Arsenal Chunky Fragments (1950's)

Preliminary correlations of the present wound-ballistic model indicate that it is in satisfactory quantitative agreement with the results of the first four groups of experiments. The Edgewood Arsenal results for chunky fragments are discussed in the following section.

EDGEWOOD ARSENAL CHUNKY FRAGMENTS

Four different steel fragment simulators were fired into living goats. In this massive experimental effort, detailed physiological assessments were made, in various types of tissue at various penetration depths, of the damage caused by each of the fragments at various impact velocities. The fragments were:

<u>Fragment</u>	<u>Diameter or Edge Lath., mm</u>	<u>Mass, grams</u>	<u>Nominal Impact Velocities meters/sec (ft./sec)</u>
225-grain cube	12.36	14.69	152(500), 305(1000), 762(2500)
16-grain cube	5.14	1.029	305(1000), 914(3000), 1524(5000)
2.1-grain cube	2.65	0.135	" " "
0.85-grain sphere	2.38	0.055	" " "

The physiological assessments were used to establish probabilities of incapacitation given a hit, $P(I/H)$, for the fragments under various combat situations. The $P(I/H)$ values were found to correlate very well when plotted against $mV_0^{1.5}$, where m is the fragment mass and V_0 is the impact velocity. Note that this correlation is valid only for the class of missiles known as "chunky fragments".

Later, in order to apply the $P(I/H)$ information on chunky fragments to other types of missiles, the U.S. Army developed correlations of the $P(I/H)$ values with various energy-loss parameters, including energy loss between 1 and 15 cm (ΔE_{1-15}), energy loss up to 15 cm (ΔE_{15}) and Expected Kinetic Energy (EKE).

WNCBAL Results for EA Chunky Fragments

The $P(I/H)$ values for the chunky fragments have been found to correlate well when plotted against $mV_0^{1.5}$. Since the $P(I/H)$ values are based on assessments of tissue damage, then the damage predictions of WNCBAL, if it is a valid model, should correlate well when plotted against $mV_0^{1.5}$. WNCBAL results for typical soft-tissue damage between penetration depths of 1 and 15 cm are shown in Fig. 3, and in Fig. 4 for penetration depths between 1 and 30 cm. As shown in the figures, the WNCBAL results do indeed fall close to a single, continuously increasing function of $mV_0^{1.5}$. Therefore, one can conclude that the present wound-ballistic model is completely consistent with EA data base on chunky fragments.

In the early 1960's the U.S. Army developed correlations of the $P(I/H)$ values with ΔE_{1-15} . Predicted values of ΔE_{1-15} from WNCBAL, for the four chunky fragments are plotted against $mV_0^{1.5}$ in Fig. 5. The correlation is substantially inferior to those shown in Figs. 3 and 4. Since the WNCBAL energy-loss predictions are very reliable, one can conclude that the damage model incorporated in WNCBAL is more realistic than any model that states that the amount of damage is a unique function of projectile kinetic-energy loss. Indeed, WNCBAL indicates that the amount of damage per unit of energy loss often varies by a factor of three or more along a single wound channel.

The ratio of the damaged tissue to the fragment energy loss, both evaluated for penetration depths between 1 and 15 cm, for the four EA

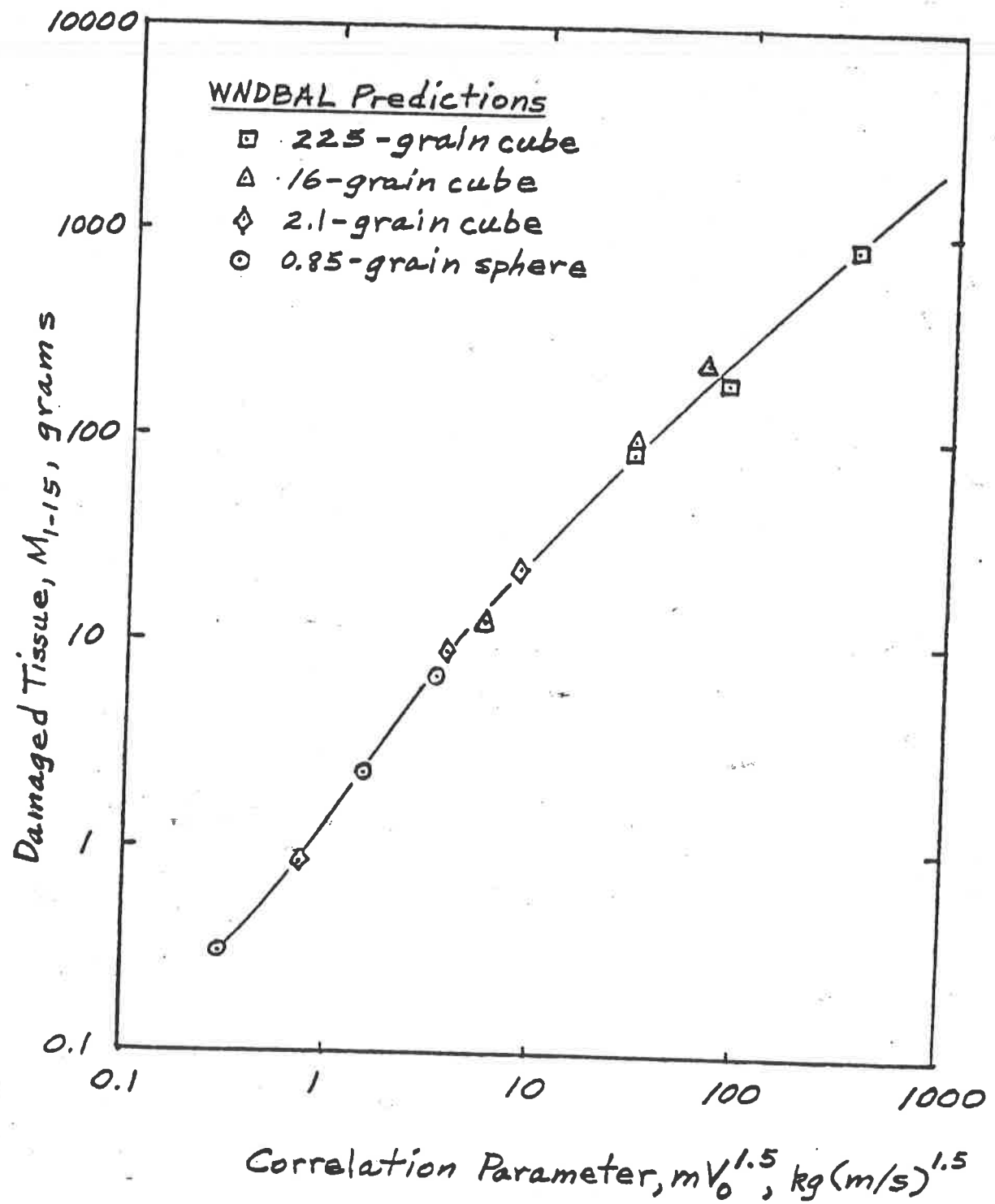


Fig. 3 - WNDBAL results for Edgewood Arsenal chunky fragments (1-15 cm)

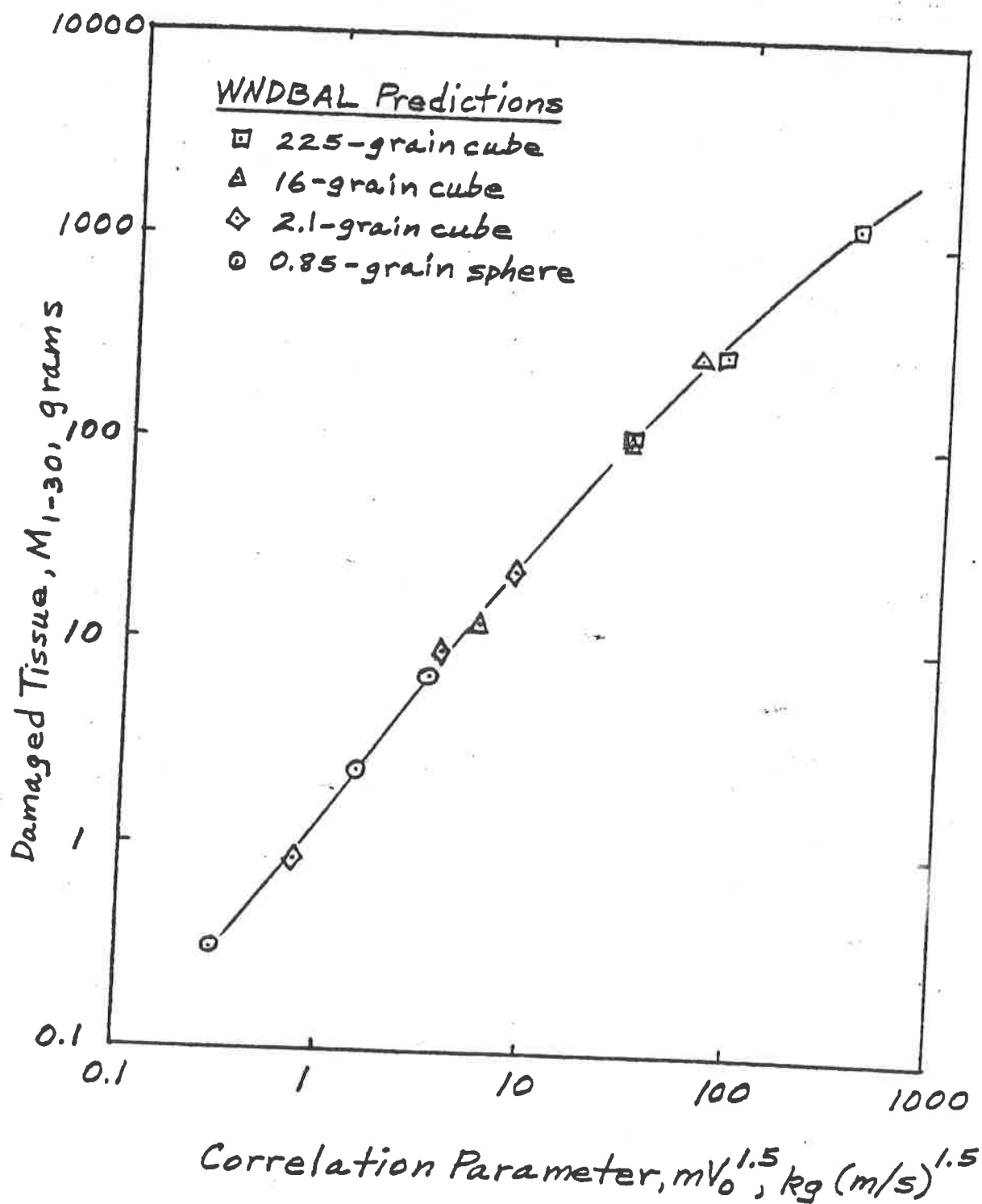


Fig. 4 - WNDBAL results for Edgewood Arsenal chunky fragments (1-30 cm)

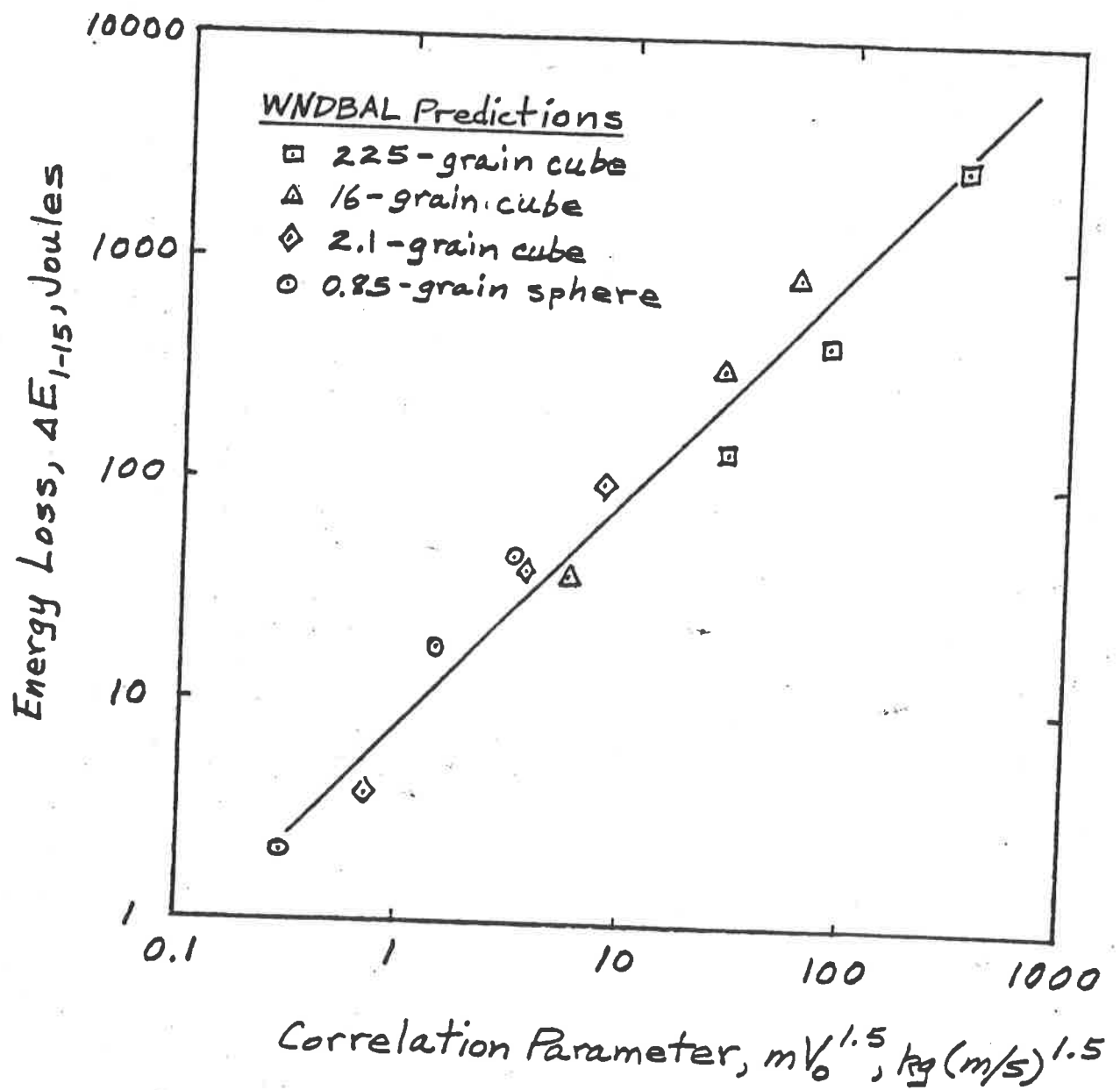


Fig. 5 - Kinetic-energy loss for Edgewood Arsenal chunky fragments

fragments is shown in Fig. 6. Clearly, there is no linear relationship between tissue damage and energy loss.

The Relative Incapacitation Index methodology, developed at BRL for the U.S. Department of Justice, is based on the premise that the incapacitation characteristics of a handgun bullet are uniquely related to the size and shape of the maximum temporary cavity (MTC) that is formed. WND BAL was used to compute the MTC geometries and the RII values for the two largest EA fragments; these two fragments penetrate deeply enough to be legitimately assessed with the RII methodology. This methodology, if correct, should result in the near-coincidence of the RII vs. $mV_0^{1.5}$ curves for the two fragments. As shown in Fig. 7, the two curves do not nearly coincide, and one must conclude that the RII methodology is incorrect. (I was motivated to make the computations shown in Fig. 7 by the fact that WND BAL calculations indicate that the temporary cavity plays little or no role in the tissue damage caused by typical handgun bullets.)

ASSESSMENT OF INCAPACITATION BY HANDGUN BULLETS

We can now predict with confidence the average damage profile in typical soft tissue that is caused by a given handgun load. However, it is not yet possible to relate accurately a given damage profile to the corresponding probability of incapacitation for randomly distributed shots into the thorax or abdominal cavity. Further research should be directed toward establishing reasonably accurate probabilities of short-term incapacitation, and I suggest the following approach:

1. Use the BRL computer man to establish the most effective shape of the damage profile.
2. Use the $P(I/H)$ values for the Edgewood Arsenal chunky fragments, along with WND BAL and the results of Step 1, to establish $P(I/H)$ values for handgun loads.
3. Systematically gather and analyze reports from actual shooting incidents in order to verify or refine the results of Step 2. A standardized methodology for gathering, screening and evaluating the case reports should be developed. (Evan Marshall's methodology should be evaluated and, if found acceptable, could be the basis for a much more extensive study.)

Steps 1 through 3 should be carried out in parallel.

In the short-term, we must select the most desirable damage profile on the basis of (1) the limited available information on the incapacitation characteristics of existing handgun loads, and (2) an intelligent assessment of the location of vulnerable organs within the human body. It is particularly important to recognize that not all shots into the torso are frontal shots into the thorax, and that the vulnerable organs in the abdominal cavity are, for the most part, located in the rear part of the cavity. Therefore, in order to be effective on frontal shots to the abdomen, the damage profile must extend quite far into the body. Lateral shots into the torso, which may pass through an arm before reaching the torso, require an even deeper damage profile.

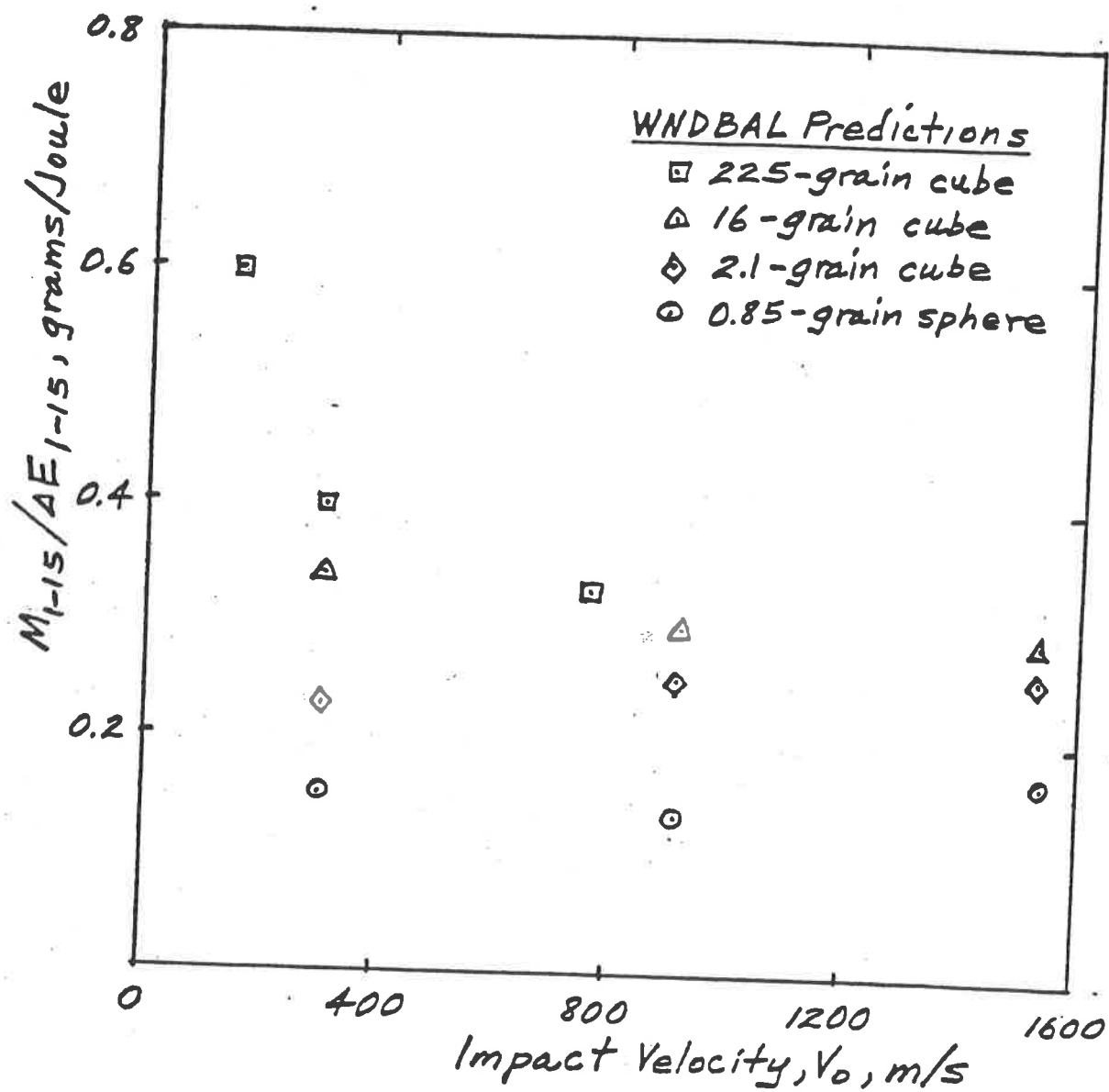


Fig. 6- Ratio of damaged tissue to energy loss for Edgewood Arsenal chunky fragments

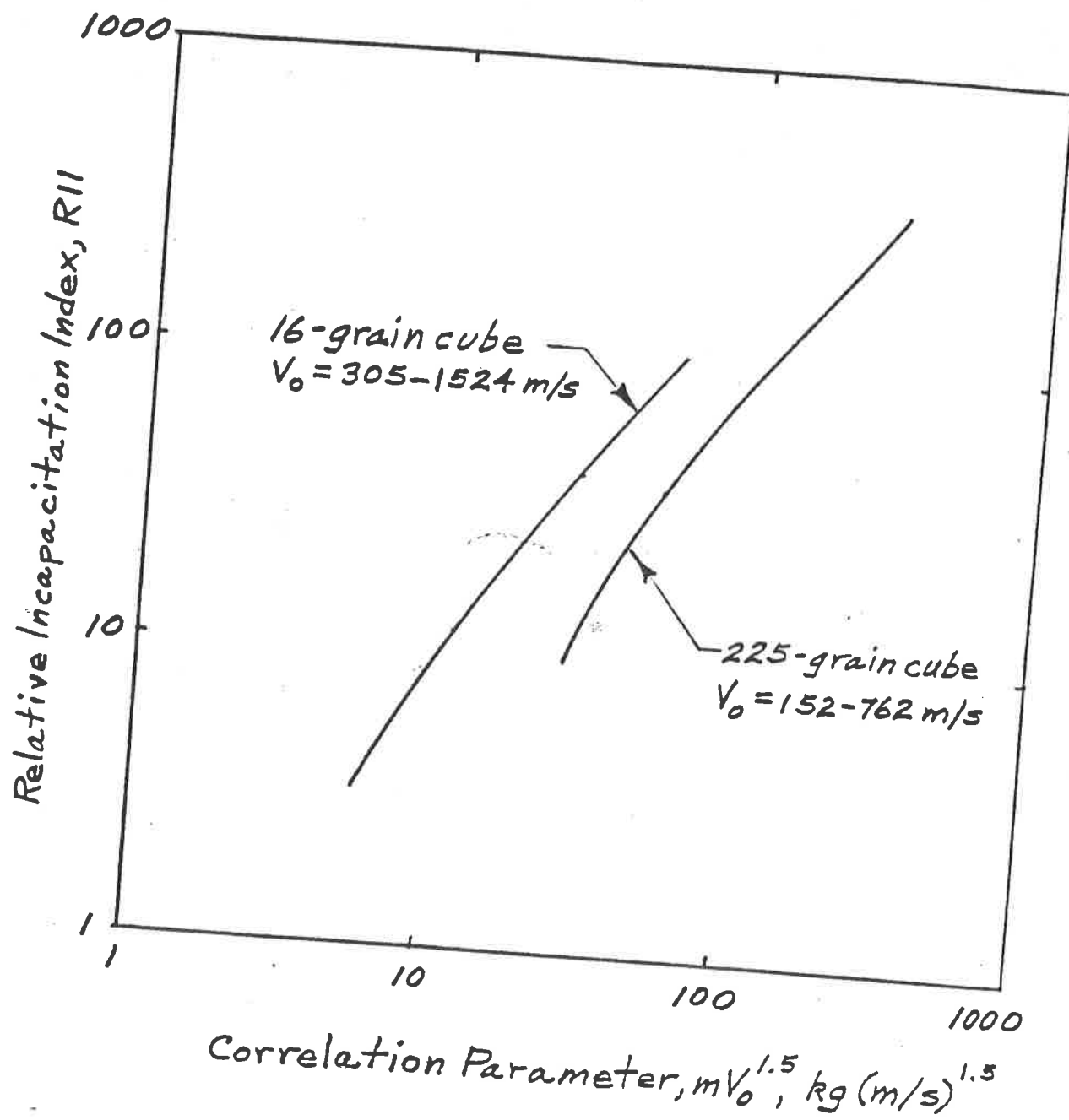


Fig. 7 - Relative Incapacitation Index for Edgewood Arsenal chunky fragments

Many JHP bullets in common use suffer from "underpenetration"; that is, they often stop after penetrating only 15 or 20 cm of typical soft tissue. This class of bullet can be expected to be effective only on frontal shots into the thorax. (In this discussion, shots into the head and neck area are not considered.) At this time, I suggest that any bullet that will not penetrate at least 30 cm into typical soft tissue should not be considered suitable for law-enforcement use, and that capability to penetrate 45-50 cm is desirable.

I also suggest that a handgun/load combination should not be selected solely on the basis of its performance in soft tissue. Other factors which should be considered include (1) capability of perforating "hard" target materials, (2) the recoil effect on the shooter, (3) the muzzle energy potential of the handgun/cartridge, and (4) the occasional need for adequate terminal-ballistic performance at ranges exceeding a few meters.

WNDBAL RESULTS FOR HANDGUN BULLETS

WNDBAL yields a detailed profile of tissue damage vs. penetration depth. Rather than present the complete profiles for handgun bullets of interest, I will show the amount of damage, in typical soft tissue, for each of three zones of penetration depth: 0-15 cm, 15-30 cm, and between 30 cm and the depth at which the projectile stops.

Results for twenty handgun loads that are or have been manufactured in the United States are shown in Table 1. The table, along with the accompanying notes, is largely self-explanatory. The traditional "round nose" bullets tend to cause only a moderate amount of tissue damage for 0-15 cm, and tend to penetrate too deeply into soft tissue unless they tumble. (For this class of bullets, yaw has an insignificant effect on retardation for $x < 15$ cm unless bone is struck obliquely.) The semiwadcutter loads provide performance significantly superior to that of RN bullets, but they also have stopping distances that are too large.

The JHP loads shown in Table 1 all cause a relatively large amount of damage for 0-15 cm, but also have stopping distances that range from marginally adequate to dangerously inadequate.

Note that not one of the twenty listed commercial loads has, without tumbling, a stopping distance close to my tentative recommendation of 45-50 cm. It is ironic that the ammunition manufacturers, in an attempt to remedy the deficiency in RN bullet performance (too much penetration in tissue), have succeeded in developing bullets that, in general, don't penetrate deeply enough.

Table 1. Predicted Short-Range Performance of Handgun Bullets
in Typical Soft Tissue

Cartridge	Bullet Type	Bullet Mass		Impact Velocity		Recoil Index	Drag Coeff. C_D	d_{exp}/d_o	Stopping Distance, cm	Tissue Damage, grams		
		grams	grains	meters/sec	ft/sec					0-15 cm	15-30 cm	>30 cm
Typical .45 ACP	FMJRN	14.91	230	255	837	1.00	0.23	1.0	88	49	41	119
Rem. 9mm Luger	FMJRN	8.04	124	330	1083	0.46	0.21	1.0	99	33	28	87
Typical .380 ACP	FMJRN	6.16	95	271	889	0.20	0.23	1.0	60	28	23	34
WW .38 Special	LRN	10.24	158	239	784	0.42	0.23	1.0	82	27	23	66
WW .38 Special + P	LRN	9.72	150	287	942	0.56	0.23	1.0	95	32	27	85
WW .38 Special	LSWC	10.24	158	281	922	0.59	0.37	1.0	68	46	36	66
Rem. .41 Mag.	LSWC	13.61	210	287	942	1.09	0.41	1.0	69	71	54	94
S&W 9mm Luger	FMJSWC	7.45	115	354	1161	0.52	0.39	1.0	60	61	41	53
Rem. .38 Special	LWC	9.59	148	225	738	0.32	0.80	1.05	31	64	38	0
WW .380 ACP	JHP(ST)	5.51	85	300	984	0.20	0.40	1.8	14	118	0	0
WW .38 Special	JHP(ST)	6.16	95	325	1066	0.29	0.40	1.8	16	146	7	0
Fed. .38 Special	JHP	7.13	110	320	1050	0.38	0.40	1.8	18	152	17	0
WW .38 Special	LHP	10.24	158	284	932	0.61	0.40	1.7	26	139	59	0
Rem. .357 Mag.	JHP	8.10	125	410	1345	0.86	0.40	1.8	25	221	57	0
Rem. & WW .357 Mag.	JHP	10.24	158	356	1168	1.00	0.40	1.7	32	184	89	5
Rem. 9mm Luger	JHP	7.45	115	365	1197	0.56	0.40	1.5	29	135	62	0
WW 9mm Luger	JHP(ST)	7.45	115	354	1161	0.52	0.40	2.0	23	203	57	0
Rem. & WW .44 Mag.	JHP	15.55	240	379	1243	2.94	0.40	1.7	38	318	151	36
Rem. .45 ACP	JHP	11.99	185	279	915	0.80	0.40	1.3	33	134	78	10
WW .45 ACP	JHP(ST)	11.99	185	294	965	0.90	0.40	1.8	19	247	37	0
General Purpose .357 Mag. load (Peters, 1977)	Rigid	8.43	130	381	1250	0.79	0.39	1.0	70	74	49	79
General Purpose .357 Mag. load (Peters, 1987)	Rigid	7.78	120	396	1299	0.73	0.65	1.0	50	120	58	39

— N TYPICAL
SOFT TISSUE

MUSCLE
LIKE
TISSUE

Best penetration (mag. & etc.)

NOTES FOR TABLE 1

1. Bullet nomenclature: FMJ - Full-metal jacket; L - Lead; RN - Round nose (actually a sphere ogive); SWC - Semiwadcutter; WC - Wadcutter; LHP - Lead, Hollowpoint; JHP - Jacketed, Hollowpoint; ST - Silvertip.
2. The impact velocities shown are for ranges of a few meters, and are nominal values for typical handguns with the following barrel lengths: revolvers (4"), .45 ACP (5"), 9 mm Luger (4"), .380 ACP (3.9").
3. The recoil index is the recoil energy relative to that of the .45 ACP hardball load, assuming that all loads are fired in handguns of the same weight. The controllability of a handgun is increased as the ratio of handgun weight to recoil index is increased.
4. The column with the heading, d_{exp}/d_o , shows the ratio of the fully expanded bullet diameter to the diameter of the undeformed bullet. The values in the table were obtained by (1) direct measurement of recovered bullets; (2) inference from observed stopping distances in gelatin or tissue; or (3) inference from observed velocity loss in gelatin. Note that failures of hollow-point bullets to expand to the diameters shown are not uncommon.
5. The computed tissue damage is for typical soft tissue that is similar in character to muscle. These results should be in reasonable agreement with the average observations of a large number of wounds with each bullet. However, because of natural variations in the strength of tissue, the damage observed in a single wound may differ considerably from the amount shown in the table.
6. The column under *Tissue Damage* with the heading >30 cm is the damage caused by the bullet between a penetration depth of 30 cm and the penetration depth at which the bullet stops. The sum of the three damage columns is the total damage that can be expected, on average, if the bullet stops in the target.
7. The results for RN bullets were obtained with the assumption of negligible yaw. For the bullets listed, the influence of yaw on retardation is usually negligible for a penetration distance of 15 cm. However, these bullets tend to be unstable in soft tissue and significant yaw growth, even tumbling, may occur at penetration depths larger than 20 cm. Consequently, the penetration depths for these bullets will often be significantly less than shown, and the tissue damage from 15 to 30 cm will often be substantially larger than shown. However, the sum of the 15 - 30 cm damage and the >30 cm damage will be unaffected.
8. Even bullets that tend to be stable in soft tissue, such as wadcutters and semiwadcutters, can become unstable if deflected and deformed by striking bone.
9. For nineteen of the twenty commercial loads listed, temporary-cavity formation contributes nothing to the calculated damage. For the single exception, the S&W 9 mm FMJ, temporary cavity damage contributes less than 2 grams to the total damage listed. It is certainly possible to design handgun ammunition that does cause significant temporary-cavity damage, but the prompt damage mechanism is the only significant one for the ammunition in common use in the United States.

RIGID AND VERY BLUNT HANDGUN BULLETS

In Defensive Handgun Effectiveness (1977), I suggested that the most suitable handgun bullet for military and police use is relatively light (120-140 grains), moderately blunt and constructed of material strong enough to resist deformation in any target material likely to be encountered. The soft-tissue performance of my recommended 1977 general-purpose load is shown in the second-last line of Table 1. By my present standards, the damage profile extends too deeply into soft tissue.

In 1977, I believed that increasing bullet bluntness to improve incapacitation also causes a decrease in hard-target performance. Consequently, my 1977 recommendation was based on a compromise between incapacitation and hard-target penetration. I have since learned that this compromise is unnecessary, because rigid, very blunt bullets (if properly designed) can provide both a near-optimal profile of tissue damage and near-optimal capability to perforate hard materials, such as steel or aluminum plates of moderate thickness. Soft-tissue performance of the type of general-purpose load that I recommend today is shown in the last line of Table 1.

To illustrate the terminal-ballistic performance of a very simple type of rigid, blunt bullet, I have made some computations for sabot-launched steel cylinders in some typical handguns. The soft-tissue performance of these steel cylinders is shown in Table 2, and their perforation characteristics in mild steel plates are shown in Table 3.

Properly designed blunt handgun bullets, constructed of a very strong material such as hardened steel, offer many advantages and only a few disadvantages when compared with conventional bullets:

Advantages

1. An unprecedented combination of a near-optimal damage profile in soft tissue and excellent penetration characteristics in steel and other "hard" target materials such as bone, wood and glass.
2. Good oblique-impact performance on hard targets.
3. Exceptional capability to perforate textile body armor.
4. No failures to expand exactly as intended in soft tissue, i.e., not at all.
5. Suitable for use by the military.
6. Limited danger zone in case the intended target is missed.
7. With careful design of sabot or driving bands, a low expenditure of propellant energy in engraving the projectile in the barrel.
8. Only moderate recoil for a given level of terminal-ballistic performance with recommended bullet mass.

Disadvantages

1. Limited downrange performance because of poor aerodynamic shape. (This disadvantage can be eliminated by use of the optional nose cap.)
2. Exceptional capability to perforate textile body armor. (This is a disadvantage only if the bad guys use such bullets.)
3. Legal status for general use?

Table 2. Predicted Short-Range Performance of Steel Cylinders in Typical Soft Tissue

Cartridge	Cylinder Dia.,		Cylinder Mass		Impact Vel.,		Recoil Index	Stopping Dis., cm	Tissue Damage, grams		
	mm	in	grams	grains	m/s	ft/sec			0-15cm	15-30cm	>30cm
.38 Special + P	8.0	0.315	7.01	108	357	1171	0.53	43.6	93	43	23
.357 Mag. (mild)	8.0	0.315	7.01	108	405	1329	0.71	47.5	117	53	28
9mm Luger	8.0	0.315	5.79	89	417	1367	0.53	40.0	113	44	19
.45 ACP	10.0	0.394	8.61	133	349	1145	0.81	35.6	127	54	17

Notes: 1. Cylinder mass does not include mass of sabot.

2. At a range of 22 meters, the mild .357 Magnum load duplicates the point-blank performance of the .38 Special load. The muzzle velocity of the mild .357 Magnum load could be increased to 465 m/s (1525 ft/s) without exceeding SAAH pressure limits. The recoil index of this heavier load would be 0.99.

Table 3. Predicted Short-Range Performance of Steel Cylinders in Steel Targets

Cartridge	Cylinder Dia., mm	Cylinder Mass, g	Impact Vel., m/s	No. of Auto Body Steel Plates Perforated	Standard NATO Plate	
					Ball. Lim., m/s	Resid. vel., m/s
.38 Special + P	8.0	7.01	357	11	219	245
.357 Mag. (mild)	8.0	7.01	405	12	219	293
9mm Luger	8.0	5.79	417	10	230	283
.45 ACP	10.0	8.61	349	8	228	216

- Notes:**
1. The number of auto body steel plates perforated refers to the number of spaced steel plates, each with a thickness of 0.9 mm (0.035"), which is perforated before the cylinder comes to rest. For reference, the typical 45 ACP hardball load perforates 6 plates, and the Remington 9 mm 124-grain hardball load perforates 7 plates.
 2. The standard NATO plate is nominal 10-gauge mild steel, with a thickness of 3.5 mm (0.138"). Most lead-core handgun bullets only dent this plate.
 3. The ballistic-limit velocity is the impact velocity at which the cylinder has a 50% probability of completely perforating the plate.
 4. The residual velocity is, for the listed impact velocity, the cylinder velocity after completely perforating the NATO plate. A cylinder-diameter plug of plate material is also ejected from the plate.
 5. The NATO plate performance shown requires that the steel cylinders be hardened to at least 45 on the Rockwell C scale.