
TERMINAL WOUND BALLISTICS FOR HANDGUN AMMUNITION

BASIC LEVEL BULLET TYPES AND CHARACTERISTICS

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BASIC LEVEL

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FOREWORD

This review is intended as an academic primer to be read prior to the first of three terminal wound ballistics courses.

1. Basic Level – Instruction encompassing the tactical realities of what stops a human target, basic human anatomy and the interaction of a projectile, the differences between handgun and rifle projectiles, the different types of handgun bullets and the four characteristics of bullet wounding. This course concentrates on the big picture and understanding general concepts, wound ballistic terms and definitions.

2. Intermediate Level Wound Ballistics - Discusses terminal wound ballistic testing to include testing protocols, media, phases, grading criteria, ballistic ratio, volume of wound index, bullet type summaries, round summaries and ballistic data sheets. This course focuses on specifics of different ammunition and includes results from over seven national level government ballistics tests. Comparison of eight different calibers shot into various media and barriers. The Basic Level course is a prerequisite.

3. Professional Level Wound Ballistics - The most advanced level introduces academics dealing with barrier performance, ammunition testing vs armor products and engineering concepts of fluid dynamics, leading edge pressure waves and pressures on hollow points and fluid transfer, Bernoulli's principal, the venturi effect, hydraulic jump and velocities required for temporary cavity, cavitation and the effects of twist rate. The Basic and Intermediate Level courses are a prerequisite. This course is available to Military, Government and Law Enforcement only.

There are five main types of handgun bullets, each with a distinct design and purpose. There are also four main characteristics or qualities a bullet has in regards to wounding. This review will define and discuss the four individual characteristics of all five bullet types. This document brings together the most credible information regarding terminal wound ballistics. It combines the knowledge and results of many federal wound ballistics tests. Research into wound ballistics includes both industry accepted ballistic gelatin and medically recommended animal tissue media to create relevant realistic data. Representative data of a real target is needed for instruction and selection.

No specific ammunition will be discussed rather this is an overview of bullet characteristics and types. No conclusions or choices will be included in this report. Any agency wishing to use this report to make conclusions must first understand their needs and be able to quantify their requirements using the four characteristics described herein. Any agency wishing to discuss either in person or remotely the contents of this report or more detailed information need only contact us. For a list of all of our published reports or to receive a copy please see:

<https://viperweapons.us/ballistics-testing-1>

TACTICAL REALITIES

There are four main determinants involved in stopping a human target. Wound placement, number of hits, bullet capability and the target being shot.

1. Wound placement is the most important determinant in stopping or incapacitating a human target. However, shot placement is NOT wound placement and where a projectile impacts the target does not always determine the path of the bullet through the target due to bullet performance, failures and barriers (clothes, bones and outside items). Many common defensive rounds are easy to defeat or vector away from the original path of the bullet. Barrier performance is extremely important in judging whether a round will continue on its original path or be deflected / defeated. “Shot placement is an important and often cited consideration regarding the suitability of weapons and ammunition. However, considerations of the projectile are equally important and cannot be ignored. For example, a bullet passing through the central nervous system with any caliber of ammunition is likely to be immediately incapacitating. Even a .22 rimfire penetrating the brain will cause immediate incapacitation in most cases. But no one is stating that a .22 is preferred for defensive purposes.”¹ This determinant is a factor of the shooter’s accuracy and the projectile capability.

2. Amount of hits on target is critical. Simply doubling the amount of hits on a target generally doubles the amount of damage depending on the wound placement. “A review of law enforcement shootings clearly suggests that regardless of the number of rounds fired in a shooting, most of the time only one or two solid torso hits on the adversary can be expected. The probability of multiple hits with a handgun is not high.” “The handgun is the primary weapon for defense against unexpected attack. Given the idea that one or two torso hits can be reasonably expected in a handgun shooting incident, the ammunition used must maximize the likelihood of immediate incapacitation.”² This determinant is simply the shooter taking multiple shots and achieving multiple hits.

3. Bullet capability is the wound ballistic profile of that exact ammunition. This is what is measured and documented in terminal wound ballistic testing. Test data must provide measurable results that answers questions in regards to how the projectile performs in relation to desired characteristics witnessed in real world shootings. Bullet capability is a quantifiable measurement of the performance of a single round in regards to the four terminal wound ballistics criteria.

¹ Wound Ballistic Workshop: “9mm vs. .45 Auto”, FBI Academy, Quantico, VA, September, 1987. Conclusion of the Workshop.

² US Department of Justice, “Handgun Wounding Factors and Effectiveness”, FBI Firearms Training Unit, Quantico, VA, September, 1989

1. Penetration Depth
2. Reliability and Consistency
3. Barrier Performance
4. Permanent Wound Cavity (PWC) size.

This is the most complex determinant and must occur in four steps. It starts with understanding wound ballistics, then determining what your requirements are for a bullet in regards to the above characteristics, finding the data that is quantifiable and relevant to your expected target and finally, matching your requirements to the test data to find the best fit. “The critical wounding components for handgun ammunition are penetration and permanent cavity.”³ “The incidence of failure to incapacitate will vary with the severity of the wound inflicted. Severity is a function of location, depth and the amount of tissue destroyed.”⁴

4. The health and physical condition of the target is extremely important in determining the results of a shooting. Age, sex, size, health and outside influences such as drugs and alcohol greatly affect the targets capability to stay active or be incapacitated. This last determinant is completely out of the control of the shooter.

³ Wound Ballistic Workshop: “9mm vs. .45 Auto”, FBI Academy, Quantico, VA, September, 1987. Conclusion of the Workshop.

⁴ US Department of Justice, “Handgun Wounding Factors and Effectiveness”, FBI Firearms Training Unit, Quantico, VA, September, 1989

THE HUMAN TARGET

There are four main kinds of human tissue.

1. Epithelial: Covers the body surface (skin) and forms the lining of most internal cavities and organs. “The skin is tough and flexible. Experiments have shown that it has the same resistance to bullet passage as approximately four inches of muscle tissue.”⁵
2. Nervous: Thin nerve tissue which constitutes the smallest percentage of human tissue. The neural network of the Central Nervous System (CNS). The brain, spine and neurons.
3. Connective: Tissue providing a variety of functions to include support and protection. Bone, cartilage and blood vessels are the most common types of connective tissue. Bone is an excellent protective barrier and is similar but stronger than the plywood that is used in 2 phases of testing as a consistent barrier IAW IWBA and FBI/DoD standards.
4. Muscular: Muscles and internal organs are the most common type of human tissue in the thoracic cavity which is the target area or center of mass. Testing media during phase 4 and phase 5 is animal tissue to as closely as possible, consistently replicate human muscular and organ tissue.

“The mechanism of formation of the injury includes the compression of tissue by the projectile and their disruption when these compressive forces exceed the elasticity of the tissue.”⁶ Objects pushed away from the wound track, to include projectile fragments, bone fragments and the compressed destroyed tissue from impact, contact and can destroy adjacent tissue not directly impacted by the bullet.

There are three physical causes of incapacitation from Gun Shot Wounds (GSW).

1. Severing / destroying parts of the Central Nervous System (CNS). Sufficient damage to the brain and or spine will incapacitate a human.
2. Extreme damage to a vital organ required for immediate activity (heart, lungs and liver). Sufficient damage to these organs may cause immediate incapacitation. The larger the hole and the more the damage the greater the chance of elimination of body activity. “Structures that are less dense and have elasticity may sustain less damage than structures with greater density and more rigidity. For example, lung tissue has low density with high elasticity and tends to be less damaged than muscle with higher density and some elasticity. The liver, spleen, brain and adipose tissue have little elasticity and are easily injured. Organs that are fluid-filled, such as the bladder,

⁵ Fackler, M.L., M.D., Director, Wound Ballistics Laboratory, letter: “Bullet Performance Misconceptions”, International Defense Review 3, 1987

⁶ National Library of Medicine, National Center for Biotechnology Information. “Gunshot Wounds Forensic Pathology.” Shrestha R, Kanchan T, Krishan K. Updated 2023 Apr 17

heart, great vessels and bowel, may rupture due to the pressure waves from extremely high velocity projectiles (>2000 feet per second)⁷ even without direct contact by the missile.”⁸ “Temporary cavitation can also cause the tearing of tissues if a very large amount of force is involved. The tensile strength of muscle ranges roughly from 1 to 4 MPa (145 to 580 lb.f/in²), and minimal damage will result if the pressure exerted by the temporary cavitation is below this. Gelatin and other less elastic media have much lower tensile strengths; thus, they exhibit more damage after being struck with the same amount of force. At typical handgun velocities, bullets will create temporary cavities with much less than 1 MPa of pressure, and thus are incapable of causing damage to elastic tissues that they do not directly contact.”⁹

3. Large amount of blood loss or a large enough drop in blood pressure which is required for muscular and systems function. The human body has a positive internal pressure and external holes depressurize the system and allow for more blood loss than only internal holes. Large loss of blood or excessively low blood pressure will shut down voluntary control.¹⁰ Gun Shot Wounds (GSW) require immediate sterile compression to attempt to stop the bleeding and cause blood clotting. “Open wounds greatly increase the chance of death from blood loss. Multiple openings must all be treated as each will have a significant impact on the survival of the patient.” No matter where the wound is, applying steady and firm compression directly over it is the only effective way to slow the blood flow.”¹¹ “Circulatory collapse results from massive bleeding caused by bullet wounds primarily to the heart, other major organs or major blood vessels of the torso. Circulatory collapse will result in significant deprivation of oxygen to the brain. This can take several seconds to several minutes or even longer. There is sufficient oxygen in the brain to support voluntary, life-threatening actions against an officer for 10 to 15 seconds after the heart has been destroyed.”¹²

⁷ Emergency Medicine Practice article. “Ballistic Injuries In The Emergency Department (Trauma CME)”, 2022

⁸ EMSworld, article “Shootings-What Emergency Medical Service Providers Need To Know”. hmpgloballearningnetwork.com, 2010

⁹ National Library of Medicine, National Center for Biotechnology Information. “Experimental evaluation of fiber orientation based material properties of skeletal muscle in tension.” Kuthe CD, Uddanwadiker RV, Ramteke A. *Mol Cell Biomech*. 2014 Jun;11.

¹⁰ Rhee, PM; Moore, EE; Joseph, B; Tang, A; Pandit, "Gunshot wounds: A review of ballistics, bullets, weapons, and myths". *The Journal of Trauma and Acute Care Surgery*, 2016

¹¹ “How to Treat a Gunshot Wound”. Jeffrey Luk, MD, director of prehospital and disaster medicine at University Hospitals Cleveland Medical Center and professor of emergency medicine at Case Western University School of Medicine in Ohio. Medically Reviewed by Jennifer Payne, MD. Reviewed: July 7, 2022

¹² Police-1. “Why bullet size matters in officer-involved shootings”. Mike Calahan, 2017

“Incapacitation results from central nervous system (brain or spinal cord) disruption, massive organ destruction and hemorrhage (critical loss of blood and blood pressure)”¹³

“The tissue disruption caused by a handgun bullet is limited to two mechanisms. The first, or crush mechanism is the permanent hole the bullet makes after passing through the tissue to include fragments or other material. The second, or stretch mechanism is the temporary cavity formed by the tissues being driven outward by a pressure wave. The crush mechanism, the result of penetration and permanent cavity, is the only handgun wounding mechanism which damages tissue. Temporary cavity from a handgun has no reliable wounding effects in elastic body tissue and is nothing more than a stretch of the tissues.”¹⁴ The temporary stretch cavity is caused by a pressure wave interacting with muscle and organ tissue. It is not caused by material propelled away from the permanent cavity such as bullet fragments, bone or liquid tissue cast-off. Those materials create a permanent cavity of their own by physically contacting adjacent material which adds to the overall PWC caused by the path of the bullet.

“A systematic review of 1400 rifle wounds sustained in the Vietnamese War and analyzed in the Wound Data and Munitions Effectiveness Team (WDMET) study of: M16 5.56x45mm, muzzle velocity 2,800 fps and AK-47 7.62x39mm, muzzle velocity 2,350 fps: Military rifle bullets have clearly disproved the assertion that all tissue exposed to temporary cavitation is destroyed.”¹⁵ Further studies also show that the 14-cm-diameter temporary cavity produced by the AK-74 (5.45x39mm, muzzle velocity 2,900 fps) assault rifle does not destroy a great amount of muscle.”¹⁶

Stretching distance: The average human male is 10" thick. Most human tissue can be stretched as much as 6 times its normal size before overexpansion and tearing occurs. The distance created by the temporary cavity does not exceed the capability of muscular tissue to stretch without tearing.

Stretching velocity: Medical and military studies have shown that human tissue can expand extremely rapidly. A projectile velocity greater than roughly 2,000-2200 fps may cause the pressure wave to have an outward force velocity exceeding the maximum rate of expansion for most human tissue which in turn causes a tearing wound in muscular or organ tissue. “Most tissue in the human target is elastic in nature. Muscle, blood vessels, lung, bowels, all are capable of substantial stretching with minimal damage. Studies have shown that the outward velocity of the tissue in which the temporary cavity forms is no more than one tenth of the velocity of the

¹³ National Library of Medicine: “Ballistics reviews: mechanisms of bullet wound trauma”, 2009

¹⁴ Wound Ballistic Workshop: “9mm vs. .45 Auto”, FBI Academy, Quantico, VA, September, 1987. Conclusion of the Workshop.

¹⁵ US Army. “Gunshot Wounds: 1.Bullets, Ballistics and Mechanism of Injury”
Jeremy J Hollerman, Douglas Coldwell

¹⁶ Ibid: US Army. “Gunshot Wounds: 1.Bullets, Ballistics and Mechanism of Injury”

projectile. This is well within the elastic limits of tissue.”¹⁷ To quote the FBI Firearms Training Unit: “Unlike rifle rounds, there is no temporary wound created by pistol bullets.” “Temporary cavity is frequently and grossly overrated as a wounding factor when analyzing pistol wounds.”¹⁸

Energy transfer is often quoted and is completely immaterial. First, the transfer of energy is represented by the temporary stretch cavity and as stated is insufficient in low-speed pistol rounds to cause wounding. The human body can absorb a great amount of energy without being damaged (a baseball hit in a game, or a hockey puck has approximately half the energy of a 9mm bullet being shot). Lastly, the human body is not one solid mass where energy is easily transferred throughout the body. Changes in tissue density and space between organs nullifies a vast amount of transfer of energy. The human body is compressible which absorbs energy and the pressure wave unlike ballistics gelatin, which is an uncompressible liquid. We must also discuss Energy vs Momentum. Comparing hollow points during our tests and the six other major federal handgun ballistics tests it was conclusively found that the heaviest hollow point bullets in each caliber average larger Permanent Wound Cavities (PWC) than lighter bullets in the same caliber. “Increased bullet mass will increase penetration.”¹⁹ “Increasing velocity does not increase expansion as almost all hollow points regardless of velocity wrap back on themselves. In fact, increased velocity typically increases failure rate.” In 6 of 7 tests the heaviest hollow point 9mm (147 grain) bullets averaged the largest PWC over any other weight 9mm. In 5 of 6 tests the heaviest 40 S&W bullets averaged the largest PWC over any other weight 40. In 7 of 7 tests the heaviest 45 ACP (230 grain) hollow point bullets averaged the largest PWC over any other weight 45 hollow point. In all cases the heavier bullets in any caliber have less energy than the lightweight bullets in that caliber that have the highest energy. Energy is simply a mathematical formula that has no bearing on projectile capability. So, does that mean that momentum is more important? Well, the heaviest rounds do have more momentum, but in actuality what it proves is that **energy calculations have no bearing or indicators to bullet performance.** Otherwise, the fastest bullets in any particular weight / caliber would be the best and that simply isn’t the case. “Kinetic energy does not wound. Temporary cavity does not wound. ‘Knock down’ power is a myth.” No emergency room surgeon ever said “I need to repair the energy dump that my patient experienced.” Dr’s only repair actual wounds. Furthermore, with a hollow point, the energy the projectile contains at impact is mostly used to deform the bullet and bend / tear the metal to form the mushroom shape. Only a small portion is transferred to the tissue and that energy is what tears the impacted tissue forming the permanent cavity.

¹⁷ Fackler, M.L.M.D., Director, Wound Ballistics Laboratory, “Ballistic Injury”, Annals of Emergency Medicine 15: 12 December 1986

¹⁸ Lindsay, Douglas, MD: “The Idolatry of Velocity, or Lies, Damn Lies, and Ballistics”, Journal of Trauma 20, 1980.

¹⁹ US Department of Justice, “Handgun Wounding Factors and Effectiveness”, FBI Firearms Training Unit, Quantico, VA, September, 1989

Hydrostatic shock is the controversial theory that a projectile can produce a pressure wave that causes "remote neural tissue damage" and "rapid incapacitating effects" in living targets.^{20 21 22} Whereas the temporary stretch cavity is a pressure wave interacting with muscle or organ tissue, hydrostatic shock is that pressure wave interacting with neural tissue which has completely different density and elasticity.²³ The concept was first proposed in 1942 and quickly gained popularity with circumstantial evidence. Later it was debunked by many scientific and medical professionals.^{24 25} Recently it has resurfaced with the increased amount of Traumatic Brain Injuries (TBI) from wartime explosions caused by pressure waves and physical evidence of remote neuron damage caused by high velocity projectiles.²⁶ The medical research supporting hydrostatic shock has shown that very high velocity projectiles do create a pressure wave fast enough to interact and damage the neural network, but that the amount of damage is unpredictable and difficult to quantify. Their medical results show that with a penetrating projectiles velocity above 2600 -2800 fps (different from different sources) the damage to neurons has been witnessed. One assertion was stated that with a velocity as low as 2200 fps the effect may still be possible. It is still a highly debatable topic. What we do know is this:

1. Penetrating projectiles do create a shock (pressure) wave.
2. The shock wave does travel throughout the body far in excess to the distance of both the permanent wound cavity and the temporary stretch cavity.
3. The shock wave does interact with nerve tissue. It is unknown whether or not this causes wounding or incapacitation, but circumstantial evidence supports the claim that it does.
4. The amount of possible wounding is unpredictable and unreliable to calculate, so judging one projectile or another using hydrostatic shock as the determinant is invalid.
5. All sources agree that high velocity is required. Most quote a minimum velocity of between 2600-2800 fps although one source says it might be possible to have minimal effects as low as 2200 fps. The only Handgun rounds at this velocity are 5.7mm (see section three).

²⁰ "Scientific Evidence for Hydrostatic Shock". Michael Courtney; Amy Courtney, 2008

²¹ Deadly fighting skills of the world, Steve Crawford (1999) pp. 68–69

²² AK-47: the weapon that changed the face of the war, Larry Kahaner, John Wiley and Sons (2007) p. 32

²³ Firearms Legal Protection. article, "Hydrostatic Shock: Real Or Myth?" Tom Gulley, 2022

²⁴ Maneater. article, "IS HYDROSTATIC SHOCK REAL?" Jordan Sillars, 2021

²⁵ Neurosurgery, article, Dr Marvin Fackler and numerous authors. 2007

²⁶ Terminal Ballistics Research, article, "Effective Game Killing", 2011

6. Discussion of hydrostatic shock in low velocity pistol rounds is unjustified and has no basis in science even among those medical professionals who believe in the controversial theory

The critical element is penetration. Given desirable and reliable penetration, the only way to increase bullet effectiveness is to increase the severity of the wound by increasing the size of the hole made by the bullet.”²⁷ Different bullet types yield different wound results as the actual mechanism to destroy tissue is different for each bullet type. The above discussion of weight and velocity vs wound cavity size is for hollow points only as their destructive mechanism is crushing or tearing of tissue through physical contact with the bullet. Other bullet types will yield different weight vs velocity results. See chapter “Five Types of Handgun Projectiles.”

“Except for penetration into the brain cavity or spinal cord, reliable and consistent immediate incapacitation of the human target by projectile wounding to the torso is extremely unreliable.”²⁸ “Even shots to the heart are not immediate as stored oxygen may allow for voluntary action for 10-15 seconds after functional heart destruction.”²⁹ “Failure of the Central Nervous System (CNS) and / or massive blood loss sufficient to drop blood pressure, cause organ failure or deprive the brain of oxygen is the only way to cause reliable incapacitation.”³⁰ Important tissue destruction equals stopping power. Common “One Shot Stop” and “Knock Down Power” are both myths perpetuated by the uninformed. “The impact of the bullet upon the body is no more than the recoil of the weapon.”³¹ “A ten-pound weight equals the impact of a 9mm bullet when dropped from a height of .72 inches (velocity attained is 1.96 fps).”³² Mathematical calculations without shooting are not tests and have no bearing on reality. True bullet performance must be tested and measured in a consistent media. Realistic animal tissue media yields better analysis to real world shootings. “The incidence of failure to incapacitate will vary with the severity of the wound inflicted. Severity is a function of location, depth and the amount of tissue destroyed.”³³

²⁷ Smith, O’Brien C., M.D., presentation to the Wound Ballistics Workshop, Quantico, VA.

²⁸ Wound Ballistics Laboratory, Letterman Army Institute of Research, letter: “Bullet Performance Misconceptions”, International Defense Review 3. Fackler, M.L., M.D., Director

²⁹ Wound Ballistic Workshop: “9mm vs. .45 Auto”, FBI Academy, Quantico, VA, September, 1987. Conclusion of the Workshop.

³⁰ US Department of Justice, “Handgun Wounding Factors and Effectiveness”, FBI Firearms Training Unit, Quantico, VA, September, 1989

³¹ Ibid US Department of Justice, “Handgun Wounding Factors and Effectiveness”

³² Ibid US Department of Justice, “Handgun Wounding Factors and Effectiveness”

³³ Josselson, A., MD, Armed Forces Institute of Pathology, Walter Reed Medical Center, Washington, D.C., lecture series to FBI

VOLUME OF WOUND INDEX (VWI)

Volume of Wound Index is a calculated volume of Permanent Wound Cavity (PWC). It is not a direct measurement from any single test, but rather a calculation from a combination of four tests or phases. Its scale is in cubic inches of volume and can be used as a direct comparison from round to round. Using multiple medias to more truly understand the actual effects of projectile destruction of target material is required. Volume of Wound Index uses two different medias to ascertain a better understanding of real-world shootings and provide quantitative results for comparing bullets.

International Wound Ballistics Association (IWBA) Calibrated FBI 10% ordnance gelatin has several good and some bad properties. Ballistics gelatin started being accepted in terminal wound ballistics in the 1970's. There was no standardized recipe used in the different tests leading to very different results and interpretations. "In National Institute of Justice testing, bullets were evaluated and scored on their ability to penetrate between 1.6 and 8.7 inches in the test media (20% gelatin), while US Secret Service testing focused on the 1–5.9 inch range (20% gelatin), US Navy testing focused on the 7–12 inch range (20% gelatin), and US Immigration and Naturalization Service testing favored performance in the 9–12 inch range (10% gelatin). Based on this factor alone, it's easy to see how a bullet that scored highly in one test could fail the test conducted by another agency."³⁴ The Wound Ballistics Laboratory for the Letterman Army Institute of Research Center standardized the recipe for the gel used by the FBI. The FBI introduced its own standardized testing protocols in December 1988 which quickly became commonly used among US law enforcement agencies. The IWBA used the FBI recipe and calibration techniques as their standard, and now that is the accepted industry standard. The density was designed to replicate soft body tissue, not dense tissue (four times the density and resistance when compared to soft body tissue) and not skin. "Our FBI tests were *absolutely not simulating a human*. We only use gel as a comparative test media and it works great, but ballistic gel doesn't simulate a human body."³⁵ "To make a good test you have to have: A. a huge sample size to create a real understanding of the round's ability. Other tests throw out failed shots...that doesn't work. You have to include everything so you can determine the failure rate. B. everything must be measurable... a number that can be put on a spreadsheet, otherwise you either have to see it (observational data) or you have an opinion in discussing it...numbers don't have opinions. C. you have to find a media to be used in addition to gel that can more closely replicate human tissue, since gel doesn't do that...good luck in that"³¹ Clear ballistics gel is not used during our testing. First, a sample-based calibration guarantee from the manufacturer is given, but FBI protocols require every gel block to pass calibration prior to testing. Second, deviations using IWBA gel hover around 5% and are always less than 10%. Tests have shown that even with calibrated

³⁴ Police1. "Ballistic gelatin comparisons: Part I" November 2019

³⁵ FBI Firearms Training Unit. Telephone interviews and conference calls with DoD ballistics testers. 2015

synthetic clear gel, penetration depth increases >30% are common.³⁶ Given that penetration is judged as the most important wound characteristic and that handgun ammunition is a notorious under-penetrator this is disastrous. During demonstrations, our clients may use the clear gel because the synthetic product is more easily seen and photographed from outside the block. No data from any demos using the synthetic clear gel is ever added to our database or into our spreadsheets. Using penetration data from tests incorporating synthetic clear gel is unprofessional and absolutely leads to poor analysis and ammunition decisions.

IWBA gel benefits: “The FBI protocol has been widely accepted by both the law enforcement and manufacturing communities and has given them a standard to work from. The FBI protocol has established a common language, a standardized testing process and standardized benchmarks for performance that have allowed a variety of different agencies, companies and individuals to conduct their own testing and contribute data that is directly comparable to the data derived from other tests and sources.”³⁷ It is consistent, yielding similar results from shot to shot with the same projectile. When inconsistencies exist, it is an indicator of poor bullet design or unreliability. Gel shows what happens as the projectile goes through the media by being clear enough to witness the effects, and are retained post-shot for measuring. Its density and drag does mimic some low-density tissue types so the penetration depth results may be similar to reality. Using gel to compare permanent wound cavities works as long as you are comparing only rounds of the same bullet type. It is one of the only media that has all of these great factors.

IWBA gel problems: IWBA gel is a non-compressible liquid unlike human or animal tissue which is compressible. Compressibility causes absorption and dissipation that limits the distance the force can travel, and thus the overall size of the wound and the damage inflicted. This makes gel a poor tissue simulant as hydraulic effects are completely different than in human or animal tissue. The permanent cavity in gel does not replicate or represent human tissue so using it alone does not simulate a real target. Each bullet type utilizes a different mechanism for destroying tissue and how that mechanism works in different media or tissue is substantially dissimilar. For some projectile designs, like the hollow point that only uses direct contact as its destructive mechanism, the wound diameter is similar in gel as it is in tissue, but rounds that cause compression create a huge permanent cavity in gel that is not witnessed in actual tissue as seen in testing and forensic reports. “The tensile strength of muscle is from 1 to 4 MPa (145 to 580 lb.f/in²), and minimal damage will result if the pressure exerted by the temporary cavitation is below this. IWBA gelatin and other less elastic media have much lower tensile strengths exhibiting more damage after being struck with the same amount of force. Handgun bullets create temporary cavities with much less than 1 MPa of pressure, and are incapable of causing damage to elastic tissues that they do not directly contact.”³⁸

³⁶ Police1. “Ballistic gelatin comparisons: Part II/III” November 2019

³⁷ Police1. “Ballistic gelatin comparisons: Part I” November 2019

³⁸ National Center for Biotechnology Information. “Experimental evaluation of fiber orientation based material properties of skeletal muscle in tension. “Kuthe CD, Uddanwadiker 2014

Therefore, it is incorrect to believe that if one round does better in gel then it will do better in tissue. When only testing rounds like hollow points, that cause minimal compression, gel works ok, but when mixing bullet types, the results in gel are impossible to compare. In some tests, measurements of recovered bullet diameter are used which doesn't equal gel wound diameter because of rounds turning or fragmenting (which happens frequently) and some rounds cut through material while others push allowing the gel to recover. Lastly, with rounds that tumble or cause compression, gel results are artificial and are very different from actual tissue tests or post shooting medical reports. Consequently, results in gel, while being outstanding for comparative reasons, are very poor at expressing what damage happens to a human target and predicting reality. This requires a more realistic media to be used in conjunction with gel.

Realistic target media is required exactly the same as realistic barriers to make the results relevant. Adding testing in a realistic media (animal tissue) produces results that match real life shootings. Our Phase 4 and 5 use actual animal tissue to make up for the deficiencies in using only gel and getting artificial results. By combining two different medias the test data is closer to real world results. Comparison of the tissue tests to medical and forensic reports we obtain have shown that the results are very comparable and much closer than the results from IWBA calibrated gelatin.

To calculate VWI we use the two gel tests (phase 2 and 3) to determine the penetration part of the formula. Phase 2 is IWBA FBI gel with 4 layers of denim (exact same test the FBI and DoD use). Phase 3 is the same as phase 2 with the addition of a light domestic barrier layer consisting of a single sheet of 3/4 inch AA fur plywood (exact same barrier test the FBI and DoD use). This is a combination of non-barrier and barrier data and the average is where the penetration depth for VWI comes from.

Next, we shoot into tissue in each phase 4 and phase 5. Phase 4 is 7-9 inches total thickness of hanging tissue (2 pieces back-to-back) with a denim barrier. Phase 5 is phase 4 with an added 3/4-inch AA fur plywood barrier. The 2 phases are averaged and the diameter is converted to area, which includes both the non-barrier and barrier tests.

That wound area (from phases 4 and 5) is multiplied by the penetration depth (from phases 2 and 3) discussed above to create a 3-dimensional volume. That's VWI. It combines consistent penetration measurements from IWBA gel along with consistent realistic measurements of hole size in real tissue and uses barriers and non-barriers.

Volume of Wound Index is currently the most comprehensive single value of comparative bullet effectiveness in determining Permanent Wound Cavity size. This value does not represent and is not intended to describe the actual volume created in a human target. It is only used for comparison purposes.

FIVE TYPES OF HANDGUN BULLETS

Five types of handgun bullets exist.

1. Hollow Points. The most common defensive ammunition used. These rounds are intended to expand upon impact to increase the frontal area of the projectile. This will create a larger diameter wound (if the bullet doesn't turn) and also increase drag which limits penetration depth as compared to an FMJ. The destructive mechanism of the hollow point is crushing or tearing of tissue through physical contact with the bullet. Most hollow point rounds are copper jacketed lead, but some monolithic hollow points have no lead. Some of the lead-free hollow points are only copper but will be considered hollow points because their design is identical to other hollow points and the only difference is the material. Hollow points are generally not designed to fragment, but rather have weight retention. This will keep the mass high to allow for deeper penetration. Some common hollow point failures include but are not limited to: fragmentation, jacket separation, failure to expand and turning. All these failures are detrimental limiting the round's ability to wound and are not supposed to occur.

2. Full Metal Jacket (FMJ). The second most common defensive ammunition used and also the most widely used training or practice ammunition. This is typically a copper jacketed round that is solid and is not designed to expand, tumble or fragment. They create deeper wounds of less diameter. The destructive mechanism of the FMJ is the crushing of tissue through physical contact with the bullet. About the only failure is deformation due to barriers. Since the copper jacket is thin this is possible with strong barriers and this can cause revectoring after contact with the barrier.

3. Solid Metal Fluid Transfer (Fluted) Rounds (copper, brass or steel). These projectiles have varied designs, most are fluted. Some perform extremely well, while others are simply gimmicks. For the purpose of this discussion the solid metal type is comprised of non-expanding bullets. Their designed destructive mechanism is tearing and fluid transfer through the Venturi Effect. Recent testing has proven that fluted solid metal bullets transfer fluid (castoff speed) as high as 37% projectile velocity. This is compared to less than 10% from hollow points or FMJ (see chapter "The Human Target"). Fluted bullets lower the Terminal Ballistic Coefficient, increasing drag, which increases cast off fluid velocity through constriction. This high-volume high-speed liquid tissue cast off destroys adjacent tissue through direct impact. This is not energy transfer temporary stretch cavity which doesn't destroy tissue. This fluid transfer is direct contact high-speed fluid on live tissue. Since they are solid and don't expand about the only failure is tumbling which stops the designed fluid transfer. A tumbling round of this type will create a substantially smaller wound diameter and also less deep penetration than normal.

4. Frangible. These rounds are designed to break apart and fragment upon striking a target either immediately at the surface or after minimal penetration. They are designed to create large diameter wounds that do not penetrate deep. In all cases these rounds did not penetrate the required 12 inches of ballistics gel, except for some cores. The only common failure of frangible rounds is failure to fragment. If minimal penetration or absolute barrier failure is desired, then these rounds are designed for that task.

5. Tumbling. These rounds are designed to have the center of gravity as far back towards the base as possible. This creates an unstable round. The rounds are perfectly stable in flight as the rifling of the barrel imparts a stabilizing spin. At impact of the target the round immediately starts to slow and the imbalanced center of gravity causes the round to tumble. Since the round is longer than it is wide, the wound channel is substantially larger than an FMJ. The longer and thinner the round is, the easier it is to get the center of gravity so far aft that the tumbling occurs reliably. Also, the higher the speed at impact the more the tumbling reliably occurs as the round cannot simply weather vane and self-correct. At high speed the momentum of the base tumbling forward is too great to be offset by drag. This tumbling is one of the primary kill mechanisms of high-speed rifle rounds, the 5.7x28mm rounds and the 4.6x30mm rounds and is extremely effective. Unfortunately, in normal handgun calibers like the 9mm, .40 S&W, 10mm, .45 ACP and the like the round is not long and thin enough to create a large center of gravity imbalance and the velocities at impact are extremely lower than required to cause tumbling. During testing with a sample size or over 60 shots none of the calibers produced tumbling even half the time and some calibers never tumbled at all essentially becoming FMJ. This was true in both gel and tissue with and without barriers. For that reason, tumbling traditional pistol caliber rounds are simply a gimmick and are completely unreliable.

FOUR CHARACTERISTICS OF BULLET WOUNDING

There are four main criteria in quantitatively grading handgun projectile wounding. Before picking a bullet type or specific ammunition you must understand these criteria and decide what value is needed for each. From there determine the best bullet type and specific round that matches your requirements for each criterion for your application. If your agency believes in putting these characteristics in a particular order and believes that their importance is not equal, please use the following test data favoring your requirements. We have tested, measured and reported these characteristics separately so each agency can use the criteria best suited for their purposes.

1. Penetration Depth: The overall distance traveled by the bullet through the target or media. It is measured during the two IWBA gel phases (2 and 3). Phase 2 yields penetration depth numbers used to describe a rounds overall penetration capability. The FBI's Firearms Training Unit states that "Effective pistol rounds must be able to penetrate a minimum of 12 inches into a human target to offer the best chance of striking a major artery or organ." "A penetration of 18 inches is preferable." Currently the FBI and DoD desire 15-21 inches in gel (Federal Standard). *Originally the FBI used 18-inch gel blocks which created the 18-inch maximum. That depth had nothing to do with over-penetration.* The FBI, US Law Shield and USCCA all report that not a single case in US history has occurred from an over penetrating pistol round. Phase 3 adds a plywood barrier to determine the penetration after passing through a light domestic barrier and uncover failure issues. Penetration was judged to be the single most important component of projectile wounding.

Penetration can be divided into four distinct depths:

- A. Shallow (<10 inches). Rounds providing this penetration depth: Frangible
- B. Low (10-15 inches). Rounds providing this penetration depth: Hollow Points, Tumbling
- C. Duty (15-21 inches, aka: the federal standard). Rounds providing this penetration depth: Solid Metal Fluid Transfer (Fluted), Tumbling
- D. Deep (roughly 24+) since there are no tested rounds between 21 and 24 inches there is a gap. Rounds producing this penetration depth: FMJ, Solid Metal Fluid Transfer (Fluted)

2. Reliability and Consistency: Reliability is a measurement of failure rate. Each of the 5 handgun bullet types is constructed specifically with separate and different design features. If the round doesn't do what it is designed to do then that is a failure. It is a failure when bullets accidentally fragment (frangible rounds are designed to fragment), accidentally turn sideways (tumbling rounds are designed to turn sideways, yaw and tumble) or in the case of the hollow points Fail To Expand (FTE) and jacket separation. On every single shot we note if there are any failures and what the failures are. When we divide the number of failures by the total quantity of shots, we derive a failure rate and therefore the reliability rate. "Handgun bullets (hollow points) expand in the human target only 60-70% of the time at best. Damage to the hollow point by hitting bone, glass, or other intervening obstacles can prevent expansion. Clothing fibers can wrap the

nose of the bullet in a cocoon like manner and prevent expansion.”³⁹ Consistency is the ability of the round to perform the same way every time and how much deviation occurs between shots during the same phase. Once a specific round is graded it is important to know how often it can perform to that standard. Reliability and consistency are typically thought to be the second most important criteria in ammunition selection but are unfortunately under appreciated. Since failures cause dangerous under-performance the reliability and consistency of duty rounds is critical.

3. Barrier Performance: Barriers are items that may cause degradation to the bullet before bullet stoppage or exit, and can exist between the weapon and target or be part of the target.

Barrier Performance can be divided into four categories:

1. Penetration through no barriers. Frangible rounds are designed for this.
2. Light domestic barrier (plywood, drywall, thick clothing and bone) penetration. We use light domestic barriers in our phase 3 and 5 and the results in comparison to the non-barrier phases (2 and 4) give barrier results.
3. Heavy barrier (hardwood 2x4’s, auto glass and metal car doors) penetration. Testing on heavy barriers yields information where we grade deflection, bullet properties after contact with the barriers and terminal performance for the rounds that pass through the heavy barrier.
4. Armor penetration. We do extensive testing with armor using products from multiple manufacturers and levels of protection using the NIJ levels.

Barriers can destroy, degrade and deflect a bullet. Penetration and Permanent Wound Cavity (PWC) size lost from non-barrier shots to barrier shots are analyzed and calculated. Real-world shots including barriers are extremely common and are generally out of the control of the shooter. Multiple shots on a barriered target does not increase the chance of penetration or incapacitation. Barriers that stop one bullet generally will stop multiple shots. Human bone is a light domestic barrier and the target area of a human (torso and head) is covered by bone for 70% of that area.

4. Permanent Wound Cavity (PWC): The volume measured in cubic inches of the destroyed part of the target created by the bullet after it goes through the target or media. A composite PWC is calculated as Volume of Wound Index (VWI). Unlike penetration depth, reliability of a round and barrier performance this characteristic can be increased with multiple shots and hits. With a given penetration depth, a projectile creating a larger diameter wound will destroy an equally larger amount of tissue. Small increases in diameter cause large amounts of area change ($A = \pi r^2$). Unfortunately, many reports simply measure the area of the recovered bullet after it stops or passes through the media. **The hole created by the bullet in actual tissue in most cases is not equal to the size of the projectile.** This is greatly misunderstood and is caused by several factors. In hollow points, the round does not expand fully immediately at impact. Also, if a hollow point tumbles or turns sideways then the large frontal area of the bullet is not what’s producing the

³⁹ US Department of Justice, “Handgun Wounding Factors and Effectiveness”, FBI Firearms Training Unit, Quantico, VA, September, 1989

wound resulting in a much smaller wound than the recovered bullet size would suggest. In frangible rounds the individual channels often times cross or pieces follow other paths already destroyed in the target. With solid metal rounds the fluid transfer destroys adjacent tissue which can only be measured on the actual target. Measuring the recovered bullet will render no information on the wound channel size. The wound area is extremely difficult to measure in the case of accidental turning rounds, fragmenting rounds, solid metal rounds which create holes larger than their caliber and tumbling bullets that have holes that vary greatly at different depths. Fluid transfer from the solid metal rounds sends a jet of high-velocity liquified tissue into adjacent tissue. It is not energy transfer! This will destroy tissue not actually contacted by the bullet. It increases the actual hole in the tissue target (PWC). Outside of that wound channel there is still more material that is the temporary stretch cavity which just like the other bullet types is non-destroyed material and is insignificant in wounding in handgun rounds.

“The critical wounding components for handgun ammunition are penetration and permanent cavity.”⁴⁰

Temporary Cavity: The temporary cavity is caused by tissue being stretched away from the permanent cavity by a pressure wave.⁴¹ If the temporary cavity is produced rapidly enough in elastic tissue, the tensile strength of the tissue can be exceeded resulting in tearing of the tissue. This effect is seen with very high velocity projectiles such as in rifle caliber, but is not seen with handgun caliber. For the temporary cavity of most handgun projectiles to have an effect on wounding, the velocity of the projectile needs to exceed roughly 2,000 fps.⁴² “At the lower velocities of handgun rounds, the temporary cavity is not produced with sufficient velocity to have any wounding effect; therefore any difference in temporary cavity noted between handgun caliber is irrelevant.”⁴³ High speed (>2,600 fps) rifle rounds were tested at some of our events and the animal tissue media was dissected and showed tearing outside of the permanent wound cavity hole which was never present in any of the handgun rounds, further confirming that temporary stretch cavity has no effect on wounding a target with <2,000 fps projectiles. Also, recent testing has showed that the actual projectile velocity required for the temporary cavity to have a wounding

⁴⁰ US Department of Justice, “Handgun Wounding Factors and Effectiveness”, FBI Firearms Training Unit, Quantico, VA, September, 1989

⁴¹ Emergency Medicine Practice article. “Ballistic Injuries In The Emergency Department (Trauma CME)”, 2022

⁴² Emergency Medicine Practice article. “Ballistic Injuries In The Emergency Department (Trauma CME)”, 2022

⁴³ FBI Firearms Training Unit, Quantico, VA,

effect from tearing human tissue is nearer to 2200 fps.⁴⁴ The real velocity (2000 or 2200) doesn't matter and is probably not exact. What is important is that pistol rounds all travelling significantly slower than these figures do not produce a temporary cavity that creates any wounding effects. Unfortunately, it is still used by non-experts during handgun ammunition assessment. When evaluating high speed rifle rounds the temporary cavity may have significant impact on a target and may increase the amount of damaged and destroyed tissue. (See chapter "The Human Target" for forensic results and combat evaluation of rifle temporary cavities.)

⁴⁴ Johann Boden: Federal Ammunition, Technical Lead, Law Enforcement Division

HOLLOW POINT SUMMARY

All hollow points are designed to expand after contact with the target/media. Some are designed to open slowly or a lesser amount to aid in barrier performance and to provide deeper penetration, while others are designed to open more rapidly to cause the largest area wound. Multiple tests have showed the four main characteristics to hollow point performance in order are:

1. Caliber. The larger the caliber hollow point the deeper the average penetration depth, the more reliable the rounds were with a lower failure to function percentage, better barrier performance and the largest average PWC. In all four grading criteria the largest caliber hollow point rounds did the best when compared to other hollow points.

2. Weight. In each of the 5 major calibers that hollow points were tested the heaviest weight in each caliber did the best in all four graded characteristics.

3. Bullet Design. Certain bullet designs outperformed other designs. This was the third most important characteristic after caliber and weight.

4. Velocity. In all calibers of hollow points velocities less than 800 fps resulted in larger failure to expand percentages in all 7 major tests. Between 800-900 fps the percentage decreased and ceased to be a major problem above 900 fps until barriers were applied. Velocities over 1,200 fps resulted in extremely high failures due to jacket separation and fragmentation. This happened with bonded hollow points as well. The reliability rate was slightly better between 1,100-1,200 fps and accidental fragmentation happened far more rarely below 1,100 fps. The sweet spot for hollow point reliability is between 900-1,100 fps. Hollow points are designed to expand and function properly with specific impact velocities. Changing barrel lengths or using +P rounds may alter the desired effects in a negative manner. A faster hollow point is not always a better hollow point. For the other types of ammunition tested increased velocity always produced better results, not true for hollow points.

1. Penetration. Most hollow points penetrated at least 12 inches in IWBA gel, but fail to reach 15 inches, unless experiencing a failure. Some exceeded 24 inches during failure to expand occurrences. In all cases increasing bullet weight increased penetration, while increasing velocity did many things and none of them reliably.

2. Reliability and Consistency. Unfortunately, of all 5 types of bullets tested hollow points recorded the second worst reliability and consistency. Hollow point bullets failed to function properly about 30% of the time. Reliability and consistency continue to degrade as barriers are added. Factors in this include the caliber, velocity, target media, barriers and bullet design. This means that at least 1 out of every 4 shots resulted in a failure! In realistic tissue with barriers such as clothes and bone 1 out of every 3 hollow point shots resulted in failure to function. This is extremely poor reliability and consistency. Failure to expand can cause the hollow point to behave as an FMJ with extreme penetration depths. Fragmentation occurs unintentionally by the accidental breaking apart of the projectile. Hollow points have the highest occurrence of accidental fragmentation. Two distinct characteristics increase accidental fragmentation with hollow points.

- a. Velocity. Rounds traveling at over 1,200 fps have an alarmingly higher rate of accidental fragmentation. Rounds below 1,100 fps had a relatively low fragmentation rate. Between 1,100-1,200 fps the rate was abnormally high but not as catastrophic as over 1,200 fps.
- b. Thickness of the metal of the sidewall of the hollow point projectile. Smaller caliber rounds have less thick walls. This makes them less strong and increased the rate of fragmentation. At the same velocity the smaller the caliber the higher the accidental fragmentation rate across the board with no exceptions.

These two characteristics which cause accidental fragmentation greatly reduced the penetration, consistency, reliability, barrier performance and overall Permanent Wound Cavity size. “When fragmentation does occur, fragments are usually found within one centimeter (.39 inch) of the permanent cavity.”⁴⁵ For these reasons, wounding effects secondary to any handgun caliber bullet fragmentation are considered inconsequential.”⁴⁶

3. Barrier Performance. Barriers greatly affect hollow points. Hollow points are neither barrier blind nor barrier fail. Results varied significantly from shot to shot. With light domestic barriers such as drywall and plywood:

- a. 9mm hollow point rounds recorded an average of a 30% degradation in penetration and PWC due to light domestic barriers.
- b. 357 SIG hollow points recorded an average of a 35% degradation due to light domestic barriers. The higher velocity caused more cases of accidental fragmentation.
- c. The 40 S&W recorded an average of 15% degradation due to light domestic barriers.
- d. The 10mm hollow points recorded an average of 20-25% degradation in penetration and PWC due to light domestic barriers because of accidental fragmentation caused by excessive velocity similar to the 357 SIG.
- e. The 45 ACP recorded an average of 10% degradation due to light domestic barriers.

4. Permanent Wound Cavities were almost always slightly larger than the FMJs, tumbling rounds and frangible rounds due to the expansion resulting in larger diameter wounds. Within a certain caliber and bullet weight the differences in PWC were minimal signifying that penetration, reliability and barrier performance are of greater concern.

Overall, hollow points generally don’t penetrate as deeply as desired and are less reliable than the other bullet types. They don’t go through barriers or get stopped by barriers consistently. Their overall wound cavity is smaller than the solid metal fluid transfer (fluted) rounds.

⁴⁵ DiMaio, V.J.M.: “Gunshot Wounds”, Elsevier Science Publishing Company, NY, NY

⁴⁶ US Department of Justice, “Handgun Wounding Factors and Effectiveness”, FBI Firearms Training Unit, Quantico, VA, September, 1989

FULL METAL JACKET (FMJ) SUMMARY

FMJs are the second most used defensive rounds and are also the most used training ammunition.

1. Penetration. FMJs penetrate the deepest of all five projectile types. FMJs routinely penetrate 24-32-inches through the IWBA calibrated gelatin blocks and all light domestic barriers that are used during testing.
2. Reliability and Consistency. Every round does almost exactly what it is supposed to do and does it every time. There are rarely problems with function on any FMJs. About the only failures that can occur would be tumbling which was witnessed almost never.
3. Barrier Performance. FMJs are almost completely barrier blind in regards to light domestic barriers. They did extremely well and are a great choice if you consider barrier performance to be one of the top criteria in ammunition selection. They easily exceeded the barrier capability of all the hollow points and frangible rounds. Given that hollow points fail 25%-35% of the time and are unreliable versus barriers consider Full Metal Jacket rounds.
4. Permanent Wound Cavity. In each caliber tested the FMJ rounds produced permanent wound cavities comparable, but slightly smaller than hollow points. The difference is the shape, where the FMJ has a long narrow wound channel.

Overall, if extremely deep penetration, reliability/consistency and barrier performance are important while small diameter wounding is acceptable then FMJs are a logical choice.

SOLID METAL FLUID TRANSFER (FLUTED) SUMMARY

Solid metal fluid transfer (fluted) bullets are non-expanding. Their designed destructive mechanism is contact tearing and fluid transfer. Since they are solid and don't expand about the only failure is tumbling which stops the designed fluid transfer. A tumbling round of this type will create a substantially smaller wound diameter and also less deep penetration than a functional projectile. As stated earlier some hollow points are made exclusively of copper but their design (expansion) remains the same and those rounds are discussed in the hollow point section.

These non-deforming rounds are designed to use a specific technology to create a larger wound cavity than FMJ or hollow point bullets. Tearing and hydraulic constriction, tissue redirection (fluid transfer) are the two mechanisms used to create larger wounds. Because gel is non-compressible and human tissue is compressible wound channels from these rounds are larger in gel tests than in tissue tests. This makes the use of animal tissue in testing required because gel is used not as a tissue simulant but rather a consistent media. With solid metal rounds, due to their design use of constriction, testing in a non-compressible liquid (gel) creates unrealistically large wound channels. If only gel was used then solid metal rounds would appear to be an order of magnitude better than all hollow points.

Tissue is liquified by the bullet shock wave and by impact. The radial flutes increase liquified tissue velocity because liquid is non-compressible. The flutes constrict the fluid described by the Venturi Effect using Bernoulli's Principle to increase velocity and direct the tissue outward to impact and destroy adjacent tissue not being contacted by the projectile itself, increasing wound diameter. With the increased velocity of the transfer fluid (castoff speed) almost four times higher than static, the fluid impacting the adjacent tissue is fast enough to tear that tissue. This is fluid transfer, not energy transfer. *Many testers wondered if vectoring high speed liquified tissue sideways into tissue would actually destroy that adjacent tissue that is not directly being impacted by the projectile. Remember that a hollow point opens the same way. Hollow points do not open because of friction, they open because tissue fills the hollow point cavity, gets crushed into a liquid (instantaneous) and then pushes outward, tearing and bending the metal petals. Once the petals are pushed outward the pressure is released and then friction takes over causing the continued opening to complete the expansion. If liquified tissue can create a pressure to the point of tearing and bending metal (hollow point) then higher speed liquified tissue can certainly destroy tissue. For those who think this will only work in a non-compressible fluid like gel, it was confirmed that this technology works extremely well in actual animal tissue with or without barriers.* In every tissue test and forensic report with these rounds the wound diameters far exceed the actual diameter of the projectile. Animal tissue tests confirmed that in over 200 shots the measured wound channel was not only larger than that of an FMJ but in most cases was the largest wound channel produced in that caliber compared to all other rounds to include fully functioning hollow points. Human forensic exams conclusively show larger than caliber wound holes.

There are several main characteristics to the solid metal fluid transfer rounds performance.... Amount of liquified tissue (caliber), focus of that tissue into a jet, and pointed away from the bullet

(flute design) and velocity. The faster any solid metal round goes the larger the wound diameter. We tested the same 9mm projectile in .380, standard pressure 9, 9+P, 9+P+ and the 357 Sig in multiple tests in gel and tissue. That's 5 of the exact same projectiles with the only difference being velocity (pressure). The wound channel size always increased with velocity. Unlike hollow points which are designed for a certain impact velocity to best perform as designed, solid metal (fluted) rounds always work better when faster.

1. Penetration. All solid metal (fluted) rounds in all calibers tested penetrated 15 – 20 inches with and without barriers.
2. Reliability and Consistency. Every single shot did roughly the same thing. There were few recorded instances of tumbling, a 0% chance of failure to expand, and no chance to fragment. These were the most reliable and consistent rounds tested at over 95% reliability.
3. Barrier Performance. The solid copper rounds and FMJs were the most barrier blind rounds tested. Not only did barriers not deflect the round it didn't change the wound diameter much and only slightly reduced penetration depth. Solid metal barrier degradation was approximately 5% vs light domestic barriers.
4. Permanent Wound Cavity. In the realistic animal tissue tests these rounds produced the largest wound areas and with the incredible penetration depth exhibited in the gel tests they recorded the largest overall PWC in all calibers. Data from the IWBA gelatin tests show results with enormous wound diameters. The radial flutes work perfectly in fluid/gel. As noted, the PWC numbers are inflated in the gel tests due to non-compressible gel, but the penetration depths are more realistic to compare. Calculated PWCs in all medias and forensic reports are the largest ever recorded in all calibers.

Overall, the solid metal fluid transfer (fluted) rounds are very impressive if deep consistent penetration is desired. They exhibit great reliability and have the largest permanent wound cavity of any of the five bullet types.

FRANGIBLE SUMMARY

Frangible bullets are designed to break apart, fragment or disintegrate into small pieces upon striking any solid object either immediately on contact or after minimal penetration. Frangible rounds were created to minimize penetration and to be less likely to cause injury or damage to unintended objects. They are designed to create large diameter wounds and not penetrate deeply. During testing in all cases, the frangible rounds did not penetrate 12 inches of ballistics gel, except for the core of one type of round (accidental). Each fragment path must be included in the calculation of the PWC. Frangible rounds tend to create large wound cavity areas but shallow wound penetration. The overall Permanent Wound Cavity (PWC) is generally less than a non-fragmenting round due to the smaller mass of each fragment, larger surface area after fragmentation resulting in greatly increased drag. Since most critical body parts reside deep inside of the thoracic cavity a superficial wound that does not encounter and destroy critical organs/blood vessels and CNS tissue does little in the way of incapacitation. Given that the FBI and DoD protocols call for a minimum gel penetration of 12 inches with a goal of around 18 inches (15-21 inches desired), low penetrating frangible rounds do not qualify well for duty use, but could be considered by those looking for the no-barrier penetration characteristics.

1. Penetration. Frangible rounds are not designed to penetrate deeply and they don't. None averaged anywhere close to 12 inches in IWBA calibrated ballistic gel.
2. Reliability and Consistency. All had extremely consistent numbers and reliably opened on every test. One gimmick round displayed erratic results.
3. Barrier Performance. Frangible rounds are supposed to be barrier fail rounds. All properly opened in contact with barriers.
4. Permanent Wound Cavity. Frangible rounds PWC size calculations are extremely difficult to measure because in gel the multiple fragments/projectiles produce many tiny hard to measure wound paths and in tissue most of the rounds Did Not Exit (DNE) the media, so measuring wound exit diameters was problematic. The measurements calculated were generally smaller than the hollow point rounds and much smaller than the solid metal fluid transfer (fluted) rounds.

Overall, if minimal penetration or absolute barrier failure is desired than frangible rounds are designed for that task.

TUMBLING ROUND SUMMARY

Tumbling bullets are designed to impact and immediately start to tumble. This will increase the wound size since the round is longer than its diameter and increase drag which will limit the penetration depth. Unfortunately, tumbling only reliably occurs in high-speed rifle rounds, the 5.7 and the 4.6mm where the designed instability is very high. In traditional pistol calibers this is not the case and they don't tumble hardly ever. Information below is only for traditional pistol calibers and not the 5.7mm or 4.6mm,

1. Penetration. When the rounds did tumble the penetration results were very inconsistent. More than half the time the rounds failed to perform as designed and didn't tumble causing penetration similar to the FMJs.
2. Reliability and Consistency. These rounds were the most unreliable and least consistent of any of the five bullet types.
3. Barrier Performance. Tumbling rounds are nearly barrier blind vs light domestic barriers equal to the FMJs and the Solid Metal Fluid Transfer (Fluted) rounds.
4. Permanent Wound Cavity. The tumbling rounds could generally be considered equal to FMJs in regards to PWC. On the rare occurrences where they functioned as designed and actually tumbled their PWCs were larger.

Overall, these rounds fail more times than function as designed. They are extremely unreliable and normally act as FMJs.

PENETRATION DEPTH GRADING CRITERIA SUMMARY

Penetration is the overall distance traveled by the bullet through the selected media or target and is considered the most important characteristic of projectile wounding.

Choice of penetration depth is critical. Hollow point penetration was unreliable and inconsistent. FMJs very reliably and consistently penetrated 24-32 inches. The solid metal fluid transfer (fluted) rounds in all calibers consistently penetrated between 15 – 20 inches with and without barriers. Frangible rounds all under penetrated (<12 inches) as designed. Tumbling rounds very unreliably penetrated deep.

RELIABILITY AND CONSISTENCY GRADING CRITERIA SUMMARY

All involved agencies in recent tests stressed how important reliability and consistency are and demanded that they be addressed and reported. Many tests do not reference this critical benchmark.

Reliability was defined and graded as to whether the round performed as designed or failed to function properly. Function depended on the type of round. Failure to perform as designed (Failure to open/tumble, accidental fragmentation and jacket separation).

1. Hollow Points. They are designed to expand, stay linear (not tumble) and retain weight. Failure to do so, regardless of the cause, caused penetration depth and permanent wound cavity (PWC) size to be greatly affected. Of all five types of rounds tested hollow points recorded the second worst reliability. Hollow point bullets fail approximately 25-30% of the time. Reliability continued to be degraded as barriers were added. Failure factors include the caliber, velocity, target media, barriers and bullet design.

- a. Failure to expand was particularly noted for low-speed rounds less than 900 fps. Barriers also caused failures to expand especially in the 9mm and less so as the caliber or velocity were increased.
- b. Fragmentation was noted in high-speed hollow points like the 357 Sig and 10mm resulting in much smaller PWC. Also, the smaller the caliber the more cases of fragmentation that occurred.

2. Full Metal Jacket. These rounds are not designed to do anything except retain weight and not tumble (stay linear). Failures are rarely noted since FMJs seldom fragment or deform enough to alter the results.

3. Solid Metal Fluid Transfer (Fluted) Rounds. Failure from these rounds comes from tumbling and not creating the designed tissue tearing. This was extremely rare in all of the tests. These rounds reliably and consistently perform as designed.
4. Frangible Rounds. These rounds open and fragment as designed with very little rate of failure.
5. Tumbling Rounds. These rounds in traditional pistol calibers (not 5.7mm or 4.6mm) had the highest failure rate and rarely tumbled.

Consistency was defined and graded as to whether the round's performance was persistent. A standard deviation for each shot tested was used. Large changes in the values showed rounds to perform differently from shot to shot which was deemed as low consistency. Obviously, failure rates were the largest cause of inconsistency, but some rounds were inconsistent even while functioning. Generally speaking, hollow points, exhibited the lowest consistency. The FMJs and the solid metal fluid transfer (fluted) rounds were the most consistent.

Overall, reliability to function on target as designed cannot be overstated. Choosing a round with excellent characteristics really doesn't matter if it fails to function. Round reliability rates under 80-90% is a serious problem. Consistency is also important but less so than reliability. There were some rounds that were extremely reliable (nearly 100%) and very consistent in the solid metal fluid transfer (fluted) and FMJ categories.

BARRIER PERFORMANCE GRADING CRITERIA SUMMARY

The main target area to stop/incapacitate a human target is the upper thoracic cavity and head. Bone protects over 70% of that area and in most conditions, clothes cover about the same percentage. Barriers are encountered on about 2 of 3 shots taken. Bone tissue is an excellent protective barrier and is similar but stronger than the plywood that was used as a consistent barrier IAW IWBA standards. Shot placement is NOT wound placement and where a shot hits the target does not always determine the path of the bullet through the target due to barriers (clothes, bones and outside items) and bullet performance/failures. Many common defensive rounds are easy to defeat/vector away from the original path of the bullet. Barrier performance is extremely important in judging whether a round will continue on its original path or be deflected/defeated and how much a round is degraded by going through barriers.

Barrier performance was graded by comparing the results in both media (IWBA calibrated gelatin and animal tissue). Each media had tests accomplished with a light domestic barrier and without. Comparing those yielded a barrier performance metric, where the only differences were the addition of a single ¾ inch thick AA fir plywood panel IAW FBI / DoD protocols. Additional

phase 6 testing to include heavy barriers (auto glass, auto doors, thick solid wood) and armor is also accomplished but is not noted in this report.

Penetration and PWC degradation: Percent of penetration and PWC size lost from non-barrier shots to barrier shots.

1. Hollow Points.
 - a. 9mm- 30% degradation due to light domestic barriers.
 - b. 357 SIG- 35% degradation due to light domestic barriers.
 - c. 40 S&W- 15% degradation due to light domestic barriers.
 - d. 10mm- 20-25% degradation due to light domestic barriers.
 - e. 45ACP- 10% degradation due to light domestic barriers.
2. Full Metal Jacket. No measurable degradation in penetration or PWC. Barrier Blind vs light domestic barriers.
3. Solid metal. Very minimal degradation on the order of 5% degradation in penetration and PWC regardless of caliber.
4. Frangible. Frangible rounds are supposed to be barrier fail rounds. All bullets performed as designed by functioning and opening due to contact with light domestic barriers.
5. Tumbling. Tumbling rounds were equal to the FMJs due to their inability to tumble reliably.

Overall, the ultimate goal is for a round to be either barrier blind or barrier fail, that way the shooter will know the capability of the rounds and not have unexpected results. The solid metal fluid transfer rounds and all FMJs were barrier blind, while the frangible were barrier fail as designed. The hollow point results were erratic and it would be impossible to classify any hollow points as either barrier blind or barrier fail.

PERMANENT WOUND CAVITY GRADING CRITERIA SUMMARY

Penetration was judged the most important characteristic of a defensive handgun bullet. Permanent Wound Cavity (PWC) is a mathematical calculation comprised of penetration depth and wound diameter converted to area and is expressed in cubic inches of destroyed material (Volume of Wound Index). Literally it's how big a hole was made by the bullet. Whereas this seems to be extremely important, there are four issues with concentrating solely on this number.

1. A large PWC that doesn't destroy any important body tissue because the wound is too shallow is virtually meaningless. Since the important organs are deep within the body this drives up the importance of penetration. Destroying a lot of skin and subcutaneous material does little to stop/incapacitate a human target.

2. Many rounds that create large PWC exhibit low reliability and consistency. Many of the hollow points that open extremely wide tend to do it inconsistently or accidentally fragment often.
3. Most of the PWC calculations are done using IWBA gel. Human tissue is compressible and gel is non-compressible which creates results that don't represent reality. Using a media closer to human tissue is required to get actual realistic data.
4. About 70% of the target area of a human is covered by clothes and bones. So, 2/3rds of the shots are going to encounter barriers which are not considered for most PWC calculations. Barriers greatly lowered some PWC figures. That is why VWI is considered more valid because half of the calculation comes from light domestic barrier tests.

1. Hollow Points. The PWC of hollow points were some of the biggest seen along with the solid metal fluid transfer rounds. Caliber and weight had the largest bearing on hollow point PWCs with design being less important.

2. FMJ. The PWCs measured were slightly smaller than the hollow points.

3. Solid Metal Fluid Transfer (Fluted). The solid metal rounds produced the largest wound hole areas in tissue and with the deep penetration had the largest volumes. This was true in gel tests and animal tissue tests, with and without barriers.

4. Frangible. Results varied depending on ammo. Some large wound channels were observed but difficult to measure due to fragmentation creating multiple wound paths. Also, since penetration depth was so low the overall PWC was smaller than the hollow points and solid metal rounds.

5. Tumbling. The PWC of the tumbling rounds were very similar to the FMJs.

Overall, PWC is important but should not be overestimated and the data used should be from a realistic media, should include barriers and must take into account the reliability and consistency of the wounding by looking at a great many shots. Lastly, the PWC has to be deep enough to actually account for the destruction of important organs/material and not just superficial tissue.

ACKNOWLEDGEMENTS

This review is a composite from testing accomplished from 2016 to present using the exact same protocols, phases and materials. Please contact us for any of our published reports listed on our website.

There are so many people to credit with the amount of data that was measured and calculated during all of this testing. People involved in this test came from multiple agencies to include the FBI, DHS, CBP, DoD, Marshalls, NASA, and multiple state DPS's and local police, sheriff and constables' offices, a local gun store and 2 training schools. One local grocery store chain gave a great discount on the brisket used in Phases 4 and 5. No ammunition or armor manufacturers were allowed to attend any test. They were only allowed to provide supplies and nothing else.

A very special thanks to all the volunteers who helped set up, tear down, measure, re-measure, document, calculate and check all the data. Only through their diligent thorough work could this much accurate data be generated. We would also like to thank our sponsors from 3rd Coast Ordnance that provides all of our gunsmithing and Slick Shot Gun Lubricants that provides us with all our training gun grease, oil and cleaning solvents and also Triple T Holsters.

There are no conclusions in this test. Testing was accomplished only to provide quantifiable raw data on a large scale with an enormous sample size on multiple realistic media.

Any questions regarding this review, other tests or to inquire on a future test, or our three terminal wound ballistics academic courses, should be made to: viperweaponstraining@gmail.com

Other information and reports are available at: www.viperweapons.us

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