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Terminal Ballistics

I've been interested in terminal ballistics for a long time. There are lots of opinions out there but finding hard scientific fact is not easy, though there is a lot of stuff that pretends to be.

Luckily I've been able to talk to a few people doing weapons R&D for the military, and have been able to combine some of the things they've told me with known mechanisms of physiology and anatomy to produce the model explained below.

Small Arms Round Effectiveness *(the Pigboard page)*

Some of what you see will fly in the face of current fashions in Gun Magazines, but my reasons for these should hopeful be clear.

This is a pretty long article I'm afraid. The first part deals general principles of incapacitation, with some emphasis on combat pistols since this is the usual field of interest. Later there is a section on high penetration pistol rounds for hunting, animal defence and other purposes, and a discussion of rifle rounds, including some notes on the 5.56

Most of this article deals with incapacitation. Wounds that incapacitate are not necessarily fatal, while fatal wounds do not necessarily incapacitate. With the exception of hits to the brain few wounds are instantaneously fatal, so an incapacitating hit is important in preventing a target being a further threat. From a hunting perspective an incapacitating round cuts down on the tracking.

There have been many theories of Incapacitation a.k.a. Stopping power. "Stopping power" is a somewhat more catchy term than "Incapacitation", other commonly used terms including "knockdown energy", "knockdown potential" etc. Certain writers will pedantically argue that a bullet doesn't have the power to knock someone over or recite stories about people shot in the front falling forward etc. This is rather a waste of time. These are convenient terms for the property under discussion if it is borne in mind that they should not be taken literally.

Discussion of Incapacitation has been known to get quite heated. In fact it often degenerates into personal attacks and name calling.

There are two bodies of data you are most likely to encounter these days, the Marshall and Sanow study and the IWBA.

The M&S study was a bold effort but poorly designed, so little credibility can be given to many of the results. Less forgivable is that some of its proponents refuse to admit that there are errors.

I've included several links to the International Wound and Ballistics Association since it is a good source of basic data. If reading their articles on the site be aware that it is a matter of dogma with many of them that temporary cavity has no contribution to stopping power unless it causes physical damage. This seems to be an over-reaction against those that say all you need to stop someone is to dump lots of energy.

When it comes to close range shooting the main consideration is incapacitation. –i.e. quickly stopping the target doing whatever it was than made you shoot him in the first place. Whether or not such a wound proves fatal is a secondary consideration. Incapacitation is dependent on several factors. These are what I call the "Five **P**s":-

Placement. Firstly you have to hit your target, and you have to hit him in the correct place. One of the main faults of the Marshall and Sanow studies was that it failed to consider hits to different regions of the torso. No differentiation was made between a shot that pierced the heart and shattered the spinal column and one that simply hit a lung. This procedure had some interesting effects.

For one thing it biased results in favour of rounds already in widespread use with police departments. This is most noticable for the 125gr .357 magnum. Trained personnel such as police and military can be expected to shoot better under stress than civilians. Most officers carry .357, 9mm or .40S&W pistols since they are lighter than larger bore weapons. There is therefore lots of data for “one shot stops” for these weapons and for the bullet weights in most common use. By the same mechanism, data from rounds that are not so popular such as .45 Long Colt, 44 Spl and 44 magnum would have come from less practiced personnel and show a lower effectiveness. This also explains why the most popular load in .32ACP shows such a high level of one shot stops (better than .45ACP hardball!). Most of the data for this round was probably from backup guns and was fired at very close range.

Marshall and Sanow classed different rounds by a percentage “one shot stop” value. The Fuller Index is a formulae that estimates this figure from bullet performance. Because of the flaws in experimental design these figures have little real relevance.

The primary target for incapacitation against humans is the Central Nervous System (CNS) –the brain and spinal cord. Any hit to this area will have a decisive effect as long as the bullet has sufficient penetration. In combat we cannot guarantee perfect placement, which is why we use ammo that increases the effects of other mechanisms too.

The location of the CNS as a target can be visualized as a “Lethal **T**”, the cross bar being between the two temples and the vertical down the centreline. This is a good enough image if the target is facing you, but if not you must be aware that the vertical runs down the middle of the back and the cross bar is really a ring around the head. Certain organizations train there personnel to shoot “Centre of Mass”, but if the target is not facing you such targeting may miss the CNS.

Penetration. To reach the CNS a bullet must have enough penetration to pass through the skull or the flesh in front of the spine. This is the reason that low energy bullets such as .25 and .22LR are best selected in a non-expanding configuration for self defence.[(1)] Mushrooming may limit penetration to such an extent that the CNS is not reached, removing the primary incapacitation mechanism.

After damage to the CNS, the main mechanism of incapacitation is a sudden drop in blood pressure caused by physical damage. The effects of this pressure drop are not permanent, but often the related blood loss can prove fatal before the target recovers. Penetration contributes to this mechanism too, since the deeper the bullet goes the more likely it is to pass through a vital organ or major blood vessel.

How much penetration is a topic of some debate. You want the bullet to reach the vitals, but in a police situation it is undesirable to have the bullet exit the body and endanger innocents. Also it can be argued that a bullet has only a finite amount of energy and that a bullet that stays in the targets body places all of it into a target.

The average depth of the human torso is 9.4". In combat a subject's arms may obscure a shot to the torso so for combat rounds a penetration of 12-15” is probably sensible. The far side skin of a torso can absorb the equivalent of 4” of flesh penetration, so there is some leeway. For a close range defensive weapon penetration as low as 10" may be acceptable. Some authorities have claimed that 18” is preferable, but rounds that have been designed to meet these criteria have poor stopping records and often over-penetrate.

Rounds such as the 44 magnum will usually penetrate to greater depths and will exit the body. Such bullets have sufficient size, weight and energy to still do decisive damage even though only a fraction of the potential energy is used. Exit wounds tend to increase the rate of blood loss anyway.

Physical Damage/Wound channel. As well as penetrating deep enough, an effective bullet will also make as wide a wound channel as is possible. This facilitates rapid blood loss. Wound channel size is increased by bullet size, tumbling, mushrooming and bullet shape –a round nosed bullet tends to push flesh aside while a flat faced one crushes what is ahead of it, creating a more open channel. This channel caused by the bullet's path is called the permanent cavity.

Power/Energy. The final bullet characteristic that contributes to incapacitation is energy, and more importantly how a particular bullet uses it.

A bullet may use its energy to cause the bullet to mushroom. This increases the diameter of the wound channel, and also increases the rate of energy transfer to the surrounding tissue. This energy is used as a wave of movement that causes the a temporary "stretch" cavity. The stretch cavity can contribute to the permanent cavity if it passes through a tissue that has an elasticity exceeded by the speed of expansion. This is usually seen in hits to the bones, spleen, pancreas, kidneys or liver. Most pistol rounds have insufficient energy to cause permanent damage resulting from temporary cavitation.

The other effect of the temporary cavity occurs if it passes through a nerve plexus. Stretching of the nerve membranes disrupts their membrane potentials and causes a temporary stunning effect rather like a punch from a boxer.

This is a more variable and therefore less reliable mechanism than the effects of the permanent cavity. Some authorities dispute that such an effect exists, but such a model that they propose does not account for the effects of stun bags, baton rounds or simply being punched. Martial artists know that even a light blow can stun a nerve, so it seems unlikely that a stretch wave passing through a nerve plexus will have no effect. Interestingly, several of these the major plexi of the thorax have nerves associated with factors that will effect blood pressure such as heart rate and vasodilation.

Certain bullet designs have tried to maximize energy dump at the expense of penetration –not surprisingly they've had variable success.

Psychology.

The mental state of the target definitely has an effect on the reaction of a bullet hit. The same strike may make some people give up while make others berserk. This is a factor in incapacitation, but one nearly impossible to predict and unrelated to bullet characteristics.

Pistol Bullets:- Size does matter!

Playing with numbers- Energy, Velocity, Weight and Momentum.

The lighter something is, the easier it is to accelerate it to a high speed. By shaving a few grains off a bullet's weight, muzzle velocity can be increased, and this gives a big increase in muzzle energy, since

$$\textbf{E}\text{nergy} = \tfrac{1}{2} \times \textbf{M}\text{ass} \times \textbf{V}\text{elocity}^2$$

or

$$\textbf{E}\text{nergy (ftlbs)} = [(\textbf{V}\text{elocity (fps)})^2 \times \textbf{W}\text{eight (grains)}] \div 450{,}240$$

This looks good on paper but it is not how much kinetic energy a bullet has but how it puts it to use that is important.

Also, it is not how much energy the bullet has at the muzzle but how much it has at the target that is important. The same property that lets a light bullet be accelerated more readily (low inertia) also means that it can be more easily slowed by the air it is passing through. Most handgun fights take place at less than 6 metres, and light high velocity rounds are intended to give the best performance within this range. However, shots at longer ranges are by no means exceptional, and at these ranges lightweights often lack sufficient target effect.

A heavy bullet may have less energy at the muzzle, but will have a greater proportion of this energy retained by the time that it reaches the target.

This can be visualized by imagining a graph of energy plotted against distance. The lighter bullet will have a zero point much higher on the axis than the heavier one. However, the line plotted for the lighter bullet will have a steeper downward gradient than for the heavier one.

Muzzle energy can be deceptive, and is not really a good indicator of incapacitation capability. For example, a .38 Spl +P 115gr bullet at 1,250fps has 399 ftlbs of energy, while a 158gr at 890fps has only 278 ftlbs. Penetration of gelatin for both rounds is effectively the same (14.8-15.4"), and in actual shootings the 158gr has proven a more consistent manstopper. An interesting thing about these two rounds is they also have very similar momentum. Momentum is calculated by Velocity x Mass, which in bullet terms translates as

Momentum (ftlbs/sec) = Weight (grains) ÷ 7000 x Velocity (fps)

You seldom see momentum mentioned in the Gun press, and when it is it is often misunderstood. As this page on bullet physics nicely explains

"One can think of energy absorption *(of a target)* as Force x Distance, and momentum absorption as Force x Time. Hence, the heavier but slower bullet with the same energy will travel the same distance in the absorbing material, but because of larger momentum, will take a longer time doing it. It will therefore also impart a greater "kick" to the absorber object."

When talking about firearms, Kinetic energy is expressed in terms of "Foot-pounds". 200 ftlbs is theoretically the energy needed to move a one pound weight 200ft vertically off the ground, or a 200lb weight one foot, or a 100lb weight two feet, etc. However, the KE is a scalar quantity, with magnitude but no direction.

To illustrate this, lets consider a 150gr bullet impacting at 2700fps, giving a terminal energy of 2,428 ftlbs. If fired against a 400lb object it should move it 6ft off the ground, or a similar distance if hit from the side. A 200lb object should be thrown nearly 12ft. Obviously we don't see anything like this in the real world. Even if we allow for the friction of the ground and elasticity of tissue, a man or deer hit by such a bullet doesn't move anything like this distance. This is because the movement of an object hit by a projectile is determined by the momentum, not the kinetic energy.

http://www.batesville.k12.in.us/physics/PhyNet/Mechanics/Energy/KENOTMomentum.html
http://www.glenbrook.k12.il.us/gbssci/phys/Class/energy/u5l1c.html

The 150gr bullet has a terminal momentum of 57.8ftlb/sec, which will move our 400lb target back at a speed of no more than 1.7" per sec. This correlates with what we see in the real world. A deer hit by a bullet flinches rather than being thrown several yards.

http://regentsprep.org/Regents/physics/phys01/miscons/default.htm
http://www.physics.unlv.edu/~radoslav/Bad_physics/badphysics_5.htm

Now let us compare that bullet to another projectile, a 1lb cannon ball with the same 2,428 ftlbs of terminal energy. This ball would be moving at 395fps, which does not sound much in firearms terms, but is about 269mph. Since the ball weighs a pound, momentum will be 395ftlbs/sec. That should move our 400lb target back at a speed of 11.85" per sec, which sounds credible for a projectile of this weight and speed.

The difference between a 1lb cannon ball and 150gr bullet is obviously extreme. Is what we have seen significant with smaller differences in projectile weights? If we calculate the momentum for two more bullets with the same energy, we get a 200gr at 2338fps giving 66.8ftlbs/sec and a 250gr at 2091fps giving 74.68ftlbs/sec.

What we have just illustrated is that:-

- **More momentum means better application of kinetic energy to the target.**
- **If two projectiles have the same energy, then the heavier will have the greater momentum.**

Momentum is, of course, a product of both velocity and weight. At a very high velocity a lighter round may have more momentum than a heavier one, and therefore be more effective. However, velocity decays in flight while mass remains constant. For most handgun bullets this does not seem to be a significant factor out to beyond 50yds, even though the rounds of lower sectional density lose a greater percentage of their initial velocity.

Both .38 rounds described earlier have a muzzle momentum of 20.1-20.5 ftlbs/sec. When both rounds have a terminal energy of 250 ftlb the 115gr at 989fps has 16.25ftlb/sec of momentum while the 158gr at 844fps has 19.05ftlb/sec. From these figures it should become apparent why throughout history slow heavy pistol bullets have proven so effective.

Some simple calculations show that the most effective loads in a given calibre have high terminal momentums, all other factors such as bullet construction and efficiency of hollow-point being equal.

Most 9mm/.38 combat rounds have a muzzle value of about 20ftlb/sec, while one of the reputed best performers in the calibre, the 125gr 357 at 1450fps has a value of 25.9ftlb/sec. The .380ACP has between 11 and 13.5 ftlbs/sec. Most .40S&W loads average 25ftlb/sec while .45 ACP start at 27ftlb/sec. Momentum seems a good way to compare loads of the same calibre. If there is a choice of two rounds of similar momentum, the larger calibre is preferable due to the larger diameter wound channel.

An important point worth repeating is that it is Terminal Momentum, not initial momentum that is important. Lightweight rounds with a high muzzle energy and momentum may not have this when they reach the target. The website below has velocity figures for handgun rounds at 25 and 50yds. This includes rounds fired from carbines so some of the tables are at much higher velocities than are possible from pistols.

http://www.exteriorballistics.com/ebexplained/index.cfm

To get some idea of the effective range of round, calculate the terminal momentum at several ranges and plot these on a graph. This is probably one of these jobs were it is quicker to use paper than a computer. Also include a "standard" round of the same calibre, such as 124gr 9mm at 1200fps or 230gr .45ACP at 850fps. It should be obvious if and at which ranges the round has more momentum.

You'll also notice from these tables that the percentage of retained velocity at 50yds seems to correlate with the round's sectional density, formula for SD being.

Sectional Density = Weight(gr)/7000 ÷ calibre (in)^2

A 135gr .40 with SD of 0.12 has only 86% of its original velocity at 50yds, a 9mm 115gr (0.126) has 91%, .357 125gr (0.14) has 94% and a 230gr .45 (0.162) has 98%

Another advantage of using a heavy bullet is that it is far less likely to be deflected. There is no point in having good shot placement if the bullet takes a random path as soon as it encounters a rib or pocket of change.

As a rule of thumb, chose the heaviest expanding round available for that particular calibre. Most pistol bullets are loaded with rounds way below their optimum weight for the charge and calibre, so unless you start using very exotic handloads you are unlikely to get a bullet weight "too heavy" for the charge.

Once you have the heaviest bullet, find the highest velocity loading in that weight that you can handle. A slow-heavy bullet is better than a fast-light one, but a fast-heavy one even better.

There are a couple of possible exceptions to the above. One is for 9mm Luger ammo. Some of the 147gr subsonic Hollow point rounds have been designed with too much emphasis on penetration, so have a very pointed nose that often fails to mushroom. Some large bore magnum rounds such as the 44 magnum can be found with very heavy hollow points intended for hunting that may not be as effective as lighter rounds in the human torso. On the other hand, these still make a big deep hole and it is not the percentage of energy the bullet deposits that is as important as the quantity and rate of transfer.

With very low energy bullets such as 22s and .25s, hollowpoints should not be used for defensive fire since they may limit penetration to such an extent the bullet does not reach the vital structures.

Taylor Knockdown Formula

Great White Hunter John “Pondoro” Taylor suggested the Taylor Knockdown formula (TKO), sometimes called “Taylor Index”, which integrates calibre and momentum to generate a relative value that is a guide to the potential of a round to incapacite a target.

TKO value = [Weight (gr) x Terminal Velocity (fps) x calibre (in)] ÷ 7000

This obviously does not take into account any factors such a bullet shape, construction, design or tendency to tumble, mushroom or fragment. In this respect the basic TKO offers a indication of the minimal performance one could expect from a round. It is, however, still a useful tool for comparing loads and gaining some idea how a round may perform if it fails to mushroom. I don't think the TKO is exact enough to let you say that, for example, a round with a TKO of 15 has twice the likelihood of stopping someone as a round with a TKO of 7, but a load with a higher TKO will usually be a better choice for defensive applications.

Jane's Infantry Weapons and Jane's Ammunition Handbook give all data in metric. TKO can be worked out directly with the following formulae:-

TKO value = [Weight (gm) x Terminal Velocity (m/s) x calibre (mm) x **1.996**] ÷ 7000

Taylor Index and suggested levels for hunting

Most pistol hollowpoint rounds are designed to expand to 150% of their original diameter, so one can multiply the calibre by 1.5 to get an idea of how the round will perform if it mushrooms. Since we don't know the likelihood of mushrooming we must express the bullet's TKO value as a range rather than an average. Therefore a 230gr Hollowpoint .45 at 850fps has a TKO of 12.57-18.85 and a 124gr 9mm Hollowpoint at 1200fps has a TKO of 7.55-11.32.

Some argue that TKO is only useful for comparing pistol bullets to pistol bullets or rifle to rifle. Some hunters that have used both handguns and rifles assert that TKO is relevant for comparison. A 44 magnum 240gr at 1400fps with a TKO=20.6 is more likely to drop a deer more often than a .270 Win 130gr at 3100fps with a TKO=15.9.

John Linebaugh on TKO

If there is a discrepancy, it is in comparing bullets with a high tendency to tumble with those that do not. One factor I don't think TKO figures in is the tumbling of modern spitzer bullets. I suspect that many of the hunting weapons Taylor used used round nose ammo –this would certainly be true of the large calibre big game weapons.

If a bullet tumbles then at some time during its rotation it will present its lateral areas, which will be larger than its frontal area. Suppose we multiply a bullet's length by its calibre, and use a correction factor of, say, 0.75 to allow for the shape not being a rectangle. This gives us an approximate area for the side of bullet. If we divide that area by π , take the square root and multiply by 2 then we have the equivalent bullet diameter that would have the same area. For a 62gr 5.56mm round of 0.224 x 0.906 area is equivalent to a 0.44 bullet, and for a 150gr 7.62mm bullet of 0.30 x 1.28 area is equivalent to 0.60 calibre. As a "Quick and Dirty" calculation we can simply double the calibre.

TKO of a 5.56mm 62gr at 3100fps will therefore range from 6.15-12.08 and for a 7.62mm NATO 150gr at 2750fps as 17.68-35.36.

This would seem to agree with the observation that the 5.56mm often displays very variable stopping power. For the 5.56mm I think the true TKO is in fact much higher, since the round causes extra damage if it fragments. I've not idea how to quantify this, however.

As I've stated earlier, comparison of a bullet's momentum is only really relevant when calibers are similar, and the

TKO illustrates this. If two rounds have the same TKO, then by definition they will have the similar performance when it comes to incapacitating a target. The smaller calibre round would have a higher momentum to give it the same final TKO. A .45 with a TKO of 12.57 has a momentum of 28ftlb/sec. A 180gr .357 at 1369fps has the same TKO and a momentum of 35.2ftlb/sec. The smaller, higher momentum round should move an object it hits at a higher speed than the larger, but the TKO is the same, illustrating the effect the larger calibre has. A higher momentum is therefore only an indication of a better round if the round is of the same or larger calibre.

Pistol rounds for Military applications.

The 1899 Hague convention prohibits the use of expanding ammunition for conventional conflict between military forces. In fact the Hague convention is only binding to the signatory nations. [(2)] Not only does the Hague Convention not apply to non-signatories, but it no longer applies to the signatories should a non-signatory be involved in the conflict.

"The Contracting Parties agree to abstain from the use of bullets which expand or flatten easily in the human body, such as bullets with a hard envelope which does not entirely cover the core, or is pierced with incisions.

The present Declaration is only binding for the Contracting Powers in the case of a war between two or more of them.

It shall cease to be binding from the time when, in a war between the Contracting Parties, one of the belligerents is joined by a non-Contracting Power. "

Laws of War: The Hague Convention of 1899, Declaration III

Many non-signatories such as the US and UK voluntarily observe certain parts of the Hague convention so use FMJ pistol ammo. This may seem a little odd given that the St Petersburg Declaration on Explosive ammo is freely ignored for HMG and Cannon rounds.

"The Contracting Parties engage mutually to renounce, in case of war among themselves, the employment by their military or naval troops of any projectile of a weight below 400 grammes, which is either explosive or charged with fulminating or inflammable substances"

Laws of War: St Petersburg Declaration of 1868

For most western military forces the choice is between the .45ACP round and the 9mm Luger/ Parabellum round. From the principles described above, it should come as no surprise that the .45ACP is the more effective incapacitation round in FMJ configuration. Quite simply, the .45ACP makes a bigger hole to let the blood out quicker.

Tests of the 9mm FMJ and the .45 FMJ prove to be interesting. Both have a similar level of muzzle energy and both have adequate levels of penetration. The .45 creates a large diameter wound channel and a good sized temporary cavity. The faster 9mm round creates a narrower channel and a larger temporary cavity. A large permanent cavity is a more reliable incapacitation mechanism than temporary cavitation, and this is borne out by combat reports of 9mm and .45 FMJ performance.

Suppose for purposes of illustration we assume that both rounds penetrate 12" and the only tissue they destroy is that directly in their path. A 9mm round would therefore create a cavity with a 13.4 square inch surface area from which blood would be lost and the .45 would create a cavity with a 17 square inch surface area which is 27% more surface for blood loss. Due to the elasticity of the tissue the wound cavity will in fact contract after the bullet has passed through. For a non-exanding, non-tumbling bullet wound channel diameter will reduce to 66% of the bullets calibre but the bullet will have damaged a surface area of tissue equal to its full circumference multiplied by depth.

In fact the superior stopping power of large bore rounds over smaller faster ones has been well known since the days of the Indian Mutiny,[(3)] if not earlier. We can make modern medium calibre rounds travel at much higher velocities, but this only seems to increase the temporary cavity, not the permanent one, at least for non-expanding ammunition.

For military operations where non-expanding ammunition must be used a large calibre automatic pistol is to be preferred. If possible, a bullet with a flat area of nose should be used. This provides better energy transfer and also cuts a more efficient wound channel. Round nose and ogival bullets tend to push tissue to one side, while a flat nosed bullets destroy tissue in front of it. Suitable rounds include TMJ and semi-wadcutters -although some automatics will need tuning to feed these reliably.

Expanding ammunition.

If in a situation where you can use expanding ammunition, the question presents itself:-

"Will expanding ammunition give you adequate incapacitation without needing to use a large bore weapon?"

Medium calibre guns can be more compact or have a higher magazine capacity, although many modern .45 autos are available in both compact and high capacity models.[4] If you look at a table of data from tests against calibrated gelatin you'll see that many medium rounds will penetrate to a desirable depth and expand to the same diameter.

Some Sample penetration figures.

185gr .45ACP JHP	10"	158gr .38spl ("FBI load")	12.6"
125gr .357 JHP	14"	147gr 9mm Luger JHP	13.2"
230gr .45ACP JHP	14.2"		

other data can be found at

http://www.firearmstactical.com/ammo_data/ammodata.htm

Doesn't this make the medium rounds the equal of the large bores?

The quick answer to the question is -"**No**".

The first reason for this is that hollowpoint and softpoint ammo is not 100% reliable.

Jacketed soft point and hollowpoint was developed in the 1960s. The rounds had to be robust enough to feed though automatic pistols, and to ensure that there was sufficient energy to mushroom the round the bullet weight was decreased to increase velocity. This worked, but energy decreased rapidly with range, and beyond a certain range the bullet was less effective than a FMJ round of the same calibre. Improvements in bullet design mean that we can now have heavier hollow point ammo, but beyond a certain range the bullets will still not mushroom.

For any hollow point round of a given calibre, weight and design there is obviously a threshold level of energy or momentum under which it will not mushroom. I've seen references about there also being a upper threshold for hunting rifle bullets, but this is unlikely to be a factor at handgun velocities. I've not seen any published data on thresholds for pistol hollow-points. These would be of great use to shooters, but for commercial reasons we are unlikely to see them.

Reliability is another factor. Even at shorter ranges, expanding ammo does not work every time. I've seen a test where four brands of HP ammo each had four rounds fired into water tank. Only one brand expanded 4/4, another 2/4 and the other two all the rounds deformed but did not mushroom. The sample group is not big enough to say "brand A works every time and brand D never does", but it does illustrate that there is considerable variation in performance. These rounds were fired under ideal conditions -in combat hollowpoint cavities can often be plugged by clothing and building materials.

Against humans hollow-points must deal with clothing of differing thicknesses and construction plus belts, zippers, buttons, cigarette packs, and varying layers of fat. Ribs are a solid barrier but brittle, capable of partially fragmenting some bullets and itself becoming secondary fragments. There is nothing consistant in what the bullet is hitting so results are unlikely to be consistant too. In some animals such as pigs hollowpoints have filled with plugs of hide and acted as solids.

Bullet design also has an effect on the reliability to mushroom. Soft lead rounds that can be used in revolvers or derringers will expand more easily that the semi-jacketed bullet needed by automatics and high velocity revolver loads. Automatics may have problems feeding rounds with a proportionally large diameter hollowpoint.

I suspect that the larger cross section of a large bore bullet and the larger capacity of the hollowpoint cavity also improve the tendency to expand.

Any combat round must have sufficient weight and diameter to deliver and effective wound even if it fails to expand.

Many medium calibre rounds have a good penetration depth. If they mushroom they create a good diameter wound channel, but when this doesn't happen the channel created is much smaller. It is also worth observing that some of these rounds mushroomed have a diameter not much more than an unexpanded .45. The statement should not be taken to mean that I am suggesting that a .45 FMJ is more effective than an expanded 9mm JHP but that the difference between an expanded 9mm and an unexpanded .45 may be less significant than one might think.To prevent underpenetration many hollowpoints are designed to expand to 150% of their original calibre which for a 9mm gives a diameter of 0.53". Therefore many 9mm loads that expand do not create a wound channel that much bigger than a .45 JHP that fails to expand. Potentially the 9mm JHP that can expand to 150% can create an initial wound channel of between 0.355" and 0.53" while a .45 JHP with the same expansion characteristics creates a channel of between 0.45" and 0.675" diameter. After the bullet has passed through the wound channel will close to 66% of the projectile's diameter if it was a non-expanded pistol round and to 82% if the projectile was mushroomed. I believe this tendency has more relevence to those that have to treat bullet wounds than to incapacitation. The surface area of the cavity from which blood will be lost will be a product of the full diameter of the projectile.

http://www.firearmstactical.com/wound.htm

Most medium calibre expanding rounds are too light. Tests indicate that bullets lighter than 200gr are far more likely to be deflected by an impact and veer off path, missing the internal structures that they were aimed at. The only medium calibre round that did not show this tendency in tests was the 200gr 38 Spl LRN round. Soft lead versions of this round had even more marked wounding. 200gr bullets are available for the 10mm Auto, but these are of FMJ configuration. [(5)]

Most large bore rounds use bullets of at least 200gr. Rounds such as .45ACP 230gr., .44 Special 246gr., .45 LC 255gr are widely available and noted for their effectiveness.

The most effective hollowpoint ammunition is that which has sufficient weight to perform as normal FMJ should it fail to expand. Large calibre rounds are more effective in such an instance than medium ones. Quite simply –bigger hole, faster blood loss.

Testing Bullets.

Some gun magazines have taken to publishing Gelatin performance when discussing new loads. Unfortunately some writers discard the data from rounds that fail to expand, when how often this happens would be one of the most useful things to know! Ballistic Gelatin needs to be quite carefully prepared if it is to be a realistic tissue analogue and you have no guarantee that this has been done correctly. Many writers fail to mention the range that the shots were made at too.

The Gelatin usually used is 10% Gelatin chilled to 4 °C. As a calibration a .177 caliber steel BB fired at the block at 590fps (± 30) should penetrate 8.5cm ± 0.8 (for a 10% calibration tolerance) or ± 1.7cm for a 20% calibration tolerance. This formula was developed by Dr. Martin L. Fackler at the U.S. Army's Wound Ballistics Laboratory to give the most reproducible simulation of muscle tissue or soft tissue. Incidentally the NATO standard for gelatin testing is 20% Gelatin, a concentration that appears to have been arrived at arbitrarily and seems to have little physiological basis.

Making Ballistic Gelatin
Alternate site on making gelatin
Calibrating Ballistic Gelatin
More on Calibrating Ballistic Gelatin

Can you test ammo yourself? A bullet fired into a body of water takes twice the distance to mushroom and lose its energy than it would in flesh. Some clever souls have built troughs filled with water filled plastic bags or rows of paper cartons. From these they have been able to study mushrooming, penetration depth and even if the bullet stays on course. The paper or plastic may change the conversion factor slightly, but this can be catered for by firing a round with a known performance in gelatin.

http://www.firearmstactical.com/briefs3.htm

JD Jones: One quick test I've used for years is plastic anti-freeze bottles filled with water. A hit in about a 3-4" circle in the center of the bottle is necessary—off center hits results in blowout on that side too quickly. A steel plate with appropriate hole cut in it saves a lot of time. Back it up about a foot behind it with cardboard. The hole left by the bullet—and its fragments are easily seen and size measured—also if they are going sideways. Any bullet that expands in the 4" (approx) thick water column will do well on a deer double lung shot. Just back up to change the distance—impact velocity. Quick, crude, and works for pistol bullets. HV rifles need a much stronger backing. Bottles are about $0.15 each from the manufacturers of plastic bottles.

Summary for Combat Pistol rounds.

- Large calibre bullets are more effective than Medium calibre bullets, including high velocity rounds such as the .40 S&W, 10mm Auto and .357magnum.

- A heavier pistol bullet will perform better than a lighter one. Ideally select rounds of at least 200gr.
- Choose the highest velocity cartridge loading in that bullet weight that you can handle.
- Use expanding ammo of a proven performance. Revolvers and Derringers can often be loaded with more efficient soft or wide mouthed rounds that would not feed through an automatic.
- Don't be misled by muzzle energies or % efficiencies.
- Learn some anatomy and where to place your bullets.
- Remember – it's your life.

Pure penetration.

There are two cases where you might want to use a high penetration round. The first is for hunting or defensive use against large animals. The second is if shooting through body armour or car bodies.

Handgun bullets for large animals.

Bullets for use against animals often need far greater penetration than is required against humans. Animals are often bigger, with thicker skins and tougher muscle and bone. Their vital structures are often deeper. Hits against the CNS are often difficult because of the animal posture and temporary cavitation is often reduced because a greater bulk of flesh around the bullet's track provides greater inertia against displacement. Permanent wounding and exsanguination become more likely killing/incapacitation mechanisms.

What contributes to high penetration in pistol bullets? Is it better to use a light high velocity round or a slower heavy one?

The website at

http://www.mindspring.com/~ulfhere/ballistics/mechanics.html

provides a useful formulae from **Veral Smith** for predicting the penetration of non-expanding flat nosed pistol bullets.

Penetration (in) = (Bullet weight in pounds x Impact velocity/ diameter of Meplat in inches)/5

Where bullet weight in pounds is given by dividing weight in grains by 7000 and the Meplat is the flat area of the bullet's nose.

Note that the values that this formulae generates will only tally with real life performance if the bullet was a non-expanding flat point. We can use this formulae to investigate how factors such a velocity and weight will effect penetration if we are aware that the results are just for comparison. We'll assume that the bullets are all of the same shape.

The results of various bullet weights and their velocities suggest that an increase in bullet weight is more beneficial that one of velocity. This makes sense. To push a bullet through several feet of meat needs a sustained pressure, and a heavy round has more inertia. A heavier bullet will also have more of its original energy by the time it reaches the target.

Hard non-expanding pistol bullets are better to use against large animals since expanding rounds may not have sufficient penetration to reach vital organs.

The other question that occurs about shooting high penetration rounds against animals is will the high velocity medium calibre rounds penetrate more than large bore ones?

To answer this I resorted to the formulae again. Comparative results indicate that .45ACP, 9mm Luger and .40 S&W would all produce similar depth penetrations, although the wound channel of the .45 would be wider. [(6)]

Most 38spl rounds would be similar in performance, although one "hot and heavy" loading (158gr at 1115fps) had a significantly better penetration, on par with 125gr .357 magnums and high velocity loadings of 38 Super.

158gr .357 and 10mm Auto rounds had about 50% better penetration than the .45, .40 and 9mm.

44 magnum rounds exceeded the penetration of any other rounds and created a broad wound channel.

The muzzle energy of a round seems to be a useful rule of thumb here.

The 44 magnum is the best beast killer, although the weight and controllability during rapid fire may make the pistol less suitable as a defensive weapon.

An 8-shot .357 revolver or 10 shot 10mm Automatic may be a more convenient weapon for constant carry. Medium calibre magnum rounds penetrate better than large or medium bore non-magnums. [(7)]

For standard power bullets, suitably loaded large bore weapons are preferable for defensive use since they create a wider wound. A .45ACP loaded with standard military FMJ rounds will penetrate 29" of gelatin.[(8)] The .45ACP is ballistically very similar to the .45 long colt, which was designed as a cavalry round capable of killing the enemy's horses.

It is also worth mentioning that higher velocity bullets are often better suited to hunting since their speed reduces the effects of wind and holdover errors at longer ranges or against small targets.

Shooting against body armour and car bodies.

Heavy, pointed non-expanding ammo will also prove effective in this role. However, since the medium being penetrated is usually quite thin, other bullet options are possible.

The first is to use a very light high velocity bullet with a high muzzle energy. This will only be useful within ranges where the bullet's energy exceeds that of a conventional round of the same calibre. An example of such a round was the THV round. This was designed as a fast energy dump bullet but its shape concentrated all of its initial energy on a very small point, so it showed good penetration against plate metal etc. As an anti-personnel round the THV would only penetrate 6” of flesh.

A similar concept is seen with Russian bullets that have a small calibre steel core surrounded by a aluminum jacket. These are effectively small versions of the APCR rounds once used in anti-tank guns. It is possible that the jacket is broken off on impact, allowing the core to penetrate deeper.

Another technolgy that may be worth looking at is Abraham Flatau's Ring Airfoil bullets, marketed as "Ultramag" or "Cyclone"

Another option, although not common in pistol rounds is the Armour piercing discarding sabot bullet. This also uses a lighter bullet to increase velocity, but the use of a discarding sabot produces a better sectional density and therefore the bullet retains its energy longer.

Finnish Tricks

So called because I first encountered these ideas in the writings of Peter Kekkonen.

The first dodge is to fill the cavity of a hollow point bullet with **vaseline.**This will increase the bullets weight slightly but I suspect that the main action is to provide a more relieable expansion of the hollowpoint. Hollowpoints work by a hydralic mechanism, and pre-filing the cavity with a liquid provides a better transfer of energy. Filling the cavity this way may also prevent it becoming plugged with clothing material.

Second dodge is to load standard bullets into a case backwards. I'm not sure these will feed through some weapons. Often the reversed round was loaded directly into the chamber and the magazine filled with more conventional ammo. Reversed rounds provide a round with a broad meplat and what is effectivly boat-tailing, useful for the sub-sonic portions of a round's flight, which for short barreled guns or weapons like the .45ACP is from the muzzle onward.

Rifle bullets.

The fact that rounds like the 5.56x45mm tumble on impact with a target is fairly well known. What is not appreciated by many is that all pointed (Spitzer) bullets have a tendency to tumble, although this tendency is dependent on rifling rate, range, velocity, bullet shape and ratio of length to calibre.

A pointed bullet has its centre of gravity towards the base, and it is a property of projectiles that they are more stable travelling heavy end first. A good example is a shuttlecock, which is launched with the heavier nose to the rear but will turn to arrive nose first. The pointed bullet is made to travel point first because it is spin stabilized. When the bullet hits something denser than air, this will destabilize it and this may occur to such an extent that the bullet flips over to a more stable base first configuration.

How readily this occurs is an important consideration in terminal ballistics. When a bullet is turning sideways it is creating a bigger wound channel and dumping a lot of energy to form a large stretch cavity. Some bullets will not begin to flip until they have traveled through the equivalent of several feet of tissue. In practice they do not start tumbling until they have exited the body so tumbling does not contribute to wounding. Other rounds tumble more readily, although at what depth is important. Some rounds will punch a neat little hole through an arm or leg but cause great disruption if the torso is hit. Some bullets will tumble just once, while others make multiple somersaults.

Range has an effect too. When a rifle round leaves the muzzle it is yawing or wobbling for some distance before it fully stabilizes. This distance can be in the order of dozens of yards. If the bullet hits within this range it is far more prone to tumbling. On the negative side it means that a bullet will not be as effective at penetration of hard cover at such ranges. At long ranges where the bullet's trajectory becomes very curved the spin stabilization on the bullet keeps it pointing in the direction it was aimed, rather than that which it is travelling. This means the bullet will hit the target slightly side on, and will tumble more readily. Because they have a more central centre of gravity, round nosed rifle bullets are not so prone to tumbling, so may produce their most effective wounds at close or long range.

Terminal ballistics of Common Military Rifle Rounds.

http://www.fen-net.de/norbert.arnoldi/army/wound.html
http://home.snafu.de/l.moeller/military_bullet_wound_patterns.html
http://matrix.dumpshock.com/raygun/basics/pmrb.html

- Russian 7.62x39mm rounds begin to tumble 25cm after impact and adopt a base forward configuration at 50cm. Total penetration depth will be 74cm. A Yugoslavian 7.62x39mm round began tumbling at 9cm and finished tumbling at 33cm.
- 5.56x45mm M855 and M196 rounds both have the same terminal performance when the impact velocity is the same. The rounds began to tumble after 12cm and showed considerable fragmentation. Total penetration was 36cm.
- 5.45x39mm Russian tumbled after 7cm and continued to about 45cm. Total penetration was 52cm.
- 7.62x51 NATO Spitzer rounds began to tumble at 16cm and finished at 35cm. Total penetration depth was around 64cm. German steel jacketed rounds began tumbling at 8cm, traveled 58cm overall and showed considerable fragmentation.
- A c.30 calibre round-nose rifle bullet could be expected to tumble between 37cm and 63cm, 50cm being the average.

Expanding Rifle Bullets.

Hollowpoint and softpoint rifle bullets have far more energy available than pistol rounds so mushrooming tends to be more reliable. The large quantities of energy that can be transferred into a target by rifle bullets often causes the stretch cavity to cause permanent damage.

The 5.56x45mm bullet.

The 5.56mm bullet does have a characteristic that is not that well known –its main mechanism for causing tissue damage is not tumbling but by fragmentation.

http://www.fen-net.de/norbert.arnoldi/army/wound.html
http://home.snafu.de/l.moeller/military_bullet_wound_patterns.html
http://matrix.dumpshock.com/raygun/basics/pmrb.html

When the bullet tumbles it begins to fragment, and the channels that these fragments cut weakens the surrounding tissue and makes it more susceptible to damage from stretching. The result is a large volume wound cavity that may be 7cm across at its widest. The important consideration here is that both M193 and M855 bullets are less likely to fragment at below 2700fps and **do not** fragment if they strike at a velocity of less than 2500fps. For a 20" barreled weapon rounds will fragment out to 140-200m range and for a 16" barreled weapon out to 95-150m range. At ranges under 200m the lighter M193 round has been claimed to have a 200fps velocity over the M855 at the same range, so has a greater likelyhood of fragmenting. This actual value can be called into question, given the specifications for the M193 call for a a muzzle velocity of 3,250 +/- 40 fps from a 20 inch test barrel measured 15 feet from the muzzle and for the M855 3,100 +/- 40 fps from a 20 inch test barrel measured 15 feet from the muzzle. Certainly at under 200m the M193 has a higher velocity than a M855. A rule of thumb seems to be that a M193 will fragment at 50m greater range than a M855.

Fragmentation range of M1093 and M855
http://www.firearmstactical.com/images/Wound%20Profiles/M855.jpg
AR-15 Ammo FAQ

Shorter barreled assault rifles have a muzzle velocity below the critical level so rounds fired from these will not fragment and will produce reduced wounding and incapacitation. There is some evidence that these bullets will not tumble either, and behave like small calibre FMJ pistol rounds. Mimimum barrel length for use with FMJ rounds seems to be 14.5”. Tests show a 55gr M193 fired from a M4 with a 14.5” barrel has a muzzle velocity 2,850fps and fragments. The same round fired from a G36K with a 12.5” barrel has a muzzle velocity of 2,650fps and very little fragmentation. Note that the current issue M855 62gr round has a lower muzzle velocity than a M193. Range at which fragmentation will occur with either round from 14.5” barrels is probably less than 100m.

The table here shows that a 14.5” barrelled weapon has a fragmentation range of less than a 100m with M193 and 50m with M855 -a difference of 50m compared to the same rounds fired from a 16” barrelled weapon. A 11.5” barrelled weapon has a fragmentation range of only 12-45m, making it considerably less effective than a pistol calibre SMG.

The Ammo-Oracle page linked to above appears to be corrupted in certain places so I'll reproduce the table here.

Distance to 2700 fps	20” Barrel	16” Barrel	14.5” Barrel	11.5” Barrel

M193	190-200m	140-150m	95-100m	40-45m
M855	140-150m	90-95m	45-50m	12-15m

Remember that velocity will also vary with temperature, altitude and humidity.

Another factor to consider is that when a rifle bullet leaves the muzzle it is usually yawing, and only stabilises after 10m or so. This is why against certain materials bullets exhibt greater penetration at medium range than short, despite lower velocity. At very close range a 5.56mm bullet may display tumbling and fragmentation, even though it is travelling slower than 2500fps. Range at which this happens is very short however -a Colt commando or similar shorty might be an sufficient room clearer, but wouldn't be a street fighter. A 16" or 20" barrelled weapon is still going to wound a target more effectively. Shorter barrelled versions of assault rifles are marketed as CQB weapons, so it is worth realizing that such guns will have reduced stopping power in the very role that they need it most. This is why I propose the adoption of the 9x39mm round or .300 Whisper® for CQB even though it means supplying an extra cartridge.

Why SBRs are not suitable for LEOs

Fragmentation ranges with varying barrel lengths
M193 ballistic data for 20" and 16" barrels
Ballistic comparison between the M193 and M855/SS109
An alternate set of tables, including other rounds

Note that these findings about the effectiveness of short barrelled 5.56mm weapons mainly apply to when FMJ ammunition is used. Short barrelled weapons are claimed to work somewhat better with rounds that do not rely on fragmentation such as the Federal 55gr Tactical JSP round.

Another consideration about the 5.56mm round for hunters is that most rounds, including FMJ ammo will not penetrate more than 14", which may make them unsuitable for humane kills on some game.

http://www.firearmstactical.com/briefs13.htm

The 55-grain M193 cartridge used in the M16 and M16A1 is not sensitive to rifling twist rate and can be fired in rifles with twist rates of 1 in 7" to 1 in 12" . The M855 (M16A2) cartridge is best used with a rifling twist rate of 1 in 7" or 1 in 9". If the M855 is fired from a rifle with a slower rate of twist the longer 62-grain bullet can yaw up to 70 degrees in free trajectory through the air, substantially degrading accuracy.

One of the above sources makes the statement that 5.56mm rounds are less likely to inflict serious injury after penetrating interior walls than pistol calibre rounds. The author of this paper *(published in "Police Marksman")* came to the conclusion that the 5.56mm was a safer round for police use than pistol rounds and this opinion has been repeated in other publications.

The actual results published call this conclusion into question. In the original paper **ONLY TWO** loads tested showed reduced wounding after being fired through a wall :- the M885 and the Win 69gr JHP. Six of the nine rounds tested showed no change in terminal effects after passing through walls, while the M193 displayed deeper flesh/gelatin penetration but about a third less fragmentation. All of the rounds tested completely penetrated the simulated interior wall they were fired against! If we also consider that a stray 5.56mm is likely to travel five to eight times further than a pistol round then the statement that any 5.56mm load is preferable for general police applications is at best highly irresponsible.

Refs.
Another Article by Dr. Fackler Mainly written from a clinical perspective.
Trajectory and Exterior ballistics of the M855, M193 and 7.62x39mm

Notes.
For the metrically challenged:-
Metres can be converted into yards by multiplying by **0.915.**
There are **3.28** feet in a metre.
Centimeters can be converted into inches by dividing by **2.54.**
There are **15.485 grains** in a gram.

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1. Most 22 hollow point rounds are intended for use against small game and this may limit their penetration depth when

used for self-defence against humans. Obviously if you are resorting to using a 22 or 25 for self defence things are dire and any loading is better than none at all.

Back

2. The Hague convention 1899. http://www.yale.edu/lawweb/avalon/lawofwar/dec99-03.htm

Back

3. British officers used a wide variety of revolvers and during the close range fighting it became apparent that weapons such as the .36 Navy Colt had considerably less stopping power than large bore weapons such as the Adams. Several decades later US forces in the Philippines found that their .38 Long Colt revolvers often failed to stop Moro fighters. This lead to re-issue of .45 Colt revolvers.

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4. Many modern .45 autos are not the bulky hand cannons that the term still invokes for some shooters. Weapons such as the Colt Officer's Model, S&W CS45, Para-ordnance .45s and Glock 30 and 36 are compact and easily concealable weapons. Some of these weapons can use the .45 Super® round, which with a 230gr bullet has a 22% increase in velocity and 50% increase in energy.

Back

5. After World War One the UK began to phase out the .455 revolver in favour of a lighter weight .38 design that it was felt it would be easier to train conscripts in the use of (pistol training in this era usually being formal target work). It was admitted that the .38 would be less effective, but interestingly the load adopted was a 200gr Lead round.

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6. Tests have proven the 7.62x25mm Tokarev/ 7.63mm Mauser round to have impressive penetration against body armour, leading to the suggestion that it may be an effective anti-animal round. Veral Smith's formulae indicates that in this role it is unlikely to penetrate any more than a 9mm Luger or .45ACP and will create a smaller channel. In combat the round often overpenetrates. Capt. Fairbairn was familiar with the round from his time with the Shanghai police force and recommended firing at shoulder level with this round to increase the chances of hitting bone and creating secondary missiles. This advice is probably good for other FMJ pistol rounds.

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7. Several manufactures offer 7 or 8 shot medium framed revolvers in .357/38. The revolver has several points to recommend it as a defense against animals –it will still fire if the muzzle is pressed against a mauling beast, and it can be fired repeatedly under water in the event of crocodilian attack. Many 10mm Automatic pistols are externally similar to .45 automatics. The 400 Cor bon round was a 10mm bullet mounted in a .45 case and could be fired from any .45 auto simply by changing the barrel. Ballistically the 400 Cor Bon was a "hot" .40 S&W but it may have been possible to get 10mm performance from the round. The 9x23mm Win will also fit in a weapon designed for .45s, and offers .357 type performance with an increase in magazine capacity- The Paraordnance P18-9 holds 18 rds.

Back

8. For smaller "thin skinned" animals such as coyote, feral/wild dogs and the smaller big cats such as cougar or leopard expanding anti-personnel rounds may prove quite effective. I've seen bears included in the thin skin category –this may work for Black bears but for their larger cousins I'd prefer more penetration. There is no reason why a gun could not have a mixed magazine or cylinder loaded with alternate expanding and high penetration rounds.

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