Institute for Non-Lethal Defense Technologies Report:

BALLISTIC GELATIN

February 2004

PREPARED BY:

N. C. Nicholas, Ph.D.

J. R. Welsch

PENNSTATE

APPLIED RESEARCH LABORATORY

INSTITUTE FOR NON-LETHAL DEFENSE TECHNOLOGIES

INLDT

Institute for Non-Lethal Defense Technologies Report

BALLISTIC GELATIN

February 2004

PREPARED BY:

N. C. Nicholas, Ph.D.
J. R. Welsch

Applied Research Laboratory
The Pennsylvania State University

INSTITUTE FOR NON-LETHAL
INLDT
DEFENSE TECHNOLOGIES

TABLE OF CONTENTS

Ballistic Gelatin

This is a reference document for ballistic gelatin. It includes a summary discussion of ballistic gelatin's properties and utility, samples of test firings into ballistic gelatin, a set of procedures for preparing ballistic gelatin, and an extensive set of references on ballistic gelatin.

Introduction

Ballistic gelatin is designed to simulate living soft tissue. It is the standard for evaluating the effectiveness of firearms against humans because of its convenience and acceptability over animal or cadaver testing. The two issues that remain to be resolved are standards for the preparation of ballistic gelatin and the direct relation of gelatin test results to effectiveness of firearms against humans. These issues are related in the sense that gelatin can (in principle) be formulated to simulate various types of soft tissue.

Although gelatin can simulate the density and viscosity of living human tissue, it lacks the structure of tissue. Gelatin doesn't bleed or have nerves or vessels. In addition, the human anatomy contains organs, muscle, and fat and is supported by a skeleton.

Background

Ballistic gelatin's use as a tissue simulant in a variety of research scenarios over the past several decades provides numerous case histories with which to consider its efficacy. Some of the earlier efforts to use gelatin as a tissue simulant to model ballistic information date back to 1960. These models used various measurement techniques to measure the kinetic energy of a projectile (energy loss, energy deposited) as it traveled through a block of gelatin. Dzieman (1960) of the Biophysics Division, Edgewood Arsenal, used a 20% gelatin at 10°C model and high-speed photography to relate a missile's probability of incapacitation to the energy lost by the missile during passage through 1-15cm of gelatin. This energy loss criterion ($E_{1\text{-}15}$) was used to estimate bullet lethality through 1968, along with a Ballistic Research Laboratories (BRL) x-ray gelatin technique, until studies showed that a ballistic pendulum system (BRL) was more efficient and cost effective at measuring deposited energy in simulants (DKE casualty criterion). In 1975, Edgewood Arsenal proposed a more complicated mathematical model for Expected Kinetic Energy (EKE), using a 30cm block of gelatin, Dynafax high-speed photography, and a computer program for calculations (Kokinakis et al. 1979). Early models were not compared to living tissue in a quantitative or reproducible way.

Then in the mid-1980's, researchers at the Letterman Army Institute of Research (LAIR) began publishing papers in professional journals based on their model for ballistic research and, in particular, the work of Dr. Martin Fackler. These studies were based on the measurement of projectile path and the projectile tissue interaction. In the first of many papers in the mid to late 1980's, researchers at LAIR used both live swine (50-70 kg) and gelatin blocks to test bullets and subsequently compared the results. The animals were shot through the soft tissue of the hind leg from a distance of three meters, using the gelatin to ‘catch’ the bullets after they were shot through the animals. A LAIR procedure for 10% gelatin blocks at 4°C was used here and in future studies with a few refinements. Penetration of the bullet into the gelatin was measured by slicing the blocks along the bullet track. Only three blocks and five swine were used for each of two bullets tested. (Fackler et al. 1984)

Although the paper did not include specific comparisons between gelatin and animal tissue, the LAIR team and many other researchers afterward cited this published paper as the foundation for using Fackler’s gelatin model as an approximate or equivalent substitute for animal tissue (Fackler et al. Mar 1984, Fackler and Malinowski 1985, Fackler 1987, Fackler et al. 1988, Fackler 1988, Korac et al. 2002, Uzar et al. 2003, etc.). Based on the previous two Fackler papers, Fackler and Malinowski 1985 states that the depth penetration measured in living swine leg muscle was reproduced in the gelatin within 3%. It was claimed that bullet deformation and the spatial distribution of bullet fragments were also duplicated. The paper also states that (unpublished) data showed that the temporary cavity produced by an example bullet in an example swine test was reflected within 8% in the gelatin.

Fackler and Malinowski 1985 further clarifies Fackler’s 10% gelatin at 4°C model. Many researchers have used and/or currently use this gelatin model for ballistic tests, including the FBI and Secret Service (Fackler 1988 in IDR). The gelatin used is 250 A ordnance type gelatin, Kind and Knox Co., Sioux City, IA. It is molded 10% by weight aqueous solution into 25 X 25 X 50 cm blocks. The blocks are placed end to end to capture the full bullet path. They are stored in airtight plastic bags at 4°C until use and used within “a few minutes” of being removed from the refrigerator. The blocks are shot with projectiles from three meters. Measurements of the projectile’s velocity are made with a chronograph, and biplanar x-rays are used to determine bullet and fragment sites. The blocks are then cut along the bullet path to measure penetration depth, permanent cavity, and temporary cavity. A final “wound profile” is drawn to include:

- amount, type, and location of tissue disruption
- projectile mass, velocity, construction, and shape (before and after shot)
- projectile deformation and fragmentation pattern where appropriate
- scale applicable in two dimensions for comparison

Dynamics of a Bullet in Gelatin

The motion of a bullet in a dense medium such as gelatin or tissue is determined by the Newtonian and viscous forces on the bullet that are in turn influenced by the shape and composition of the bullet. The Newtonian forces are imparted to the bullet by the rapid expansion of the gases in the firing chamber. The viscous forces that slow the bullet result from the motion of the bullet through the medium in which it travels.

As the bullet moves down the barrel of the weapon it engages the raised areas of the barrel (lands) that are designed to spin the bullet to impart a gyroscopic stability to the bullet's trajectory. Ballistic gelatin is about 800 times as dense as air so that all the effects caused on the bullet in air are highly magnified in gelatin. For example, if the bullet should develop a yawing motion about its line of trajectory, that instability will increase greatly when the bullet encounters the gelatin.

Figure 1 shows the typical orientations of a rifle bullet in a dense medium as the bullet penetrates the medium and the viscous forces overcome the Newtonian forces. The passage of the bullet carves a permanent cavity and generates a temporary cavity. The temporary cavity collapses to the boundaries of the permanent cavity once the momentum imparted by the bullet to the medium contiguous to the trajectory has been overcome by the elasticity of the medium. Gunshot wounds exhibit corresponding reactions in that tissue that was in the permanent cavity is crushed while tissue in the temporary cavity suffers injury ranging from severe adjacent to the permanent cavity to more moderate as the distance from the permanent cavity increases.

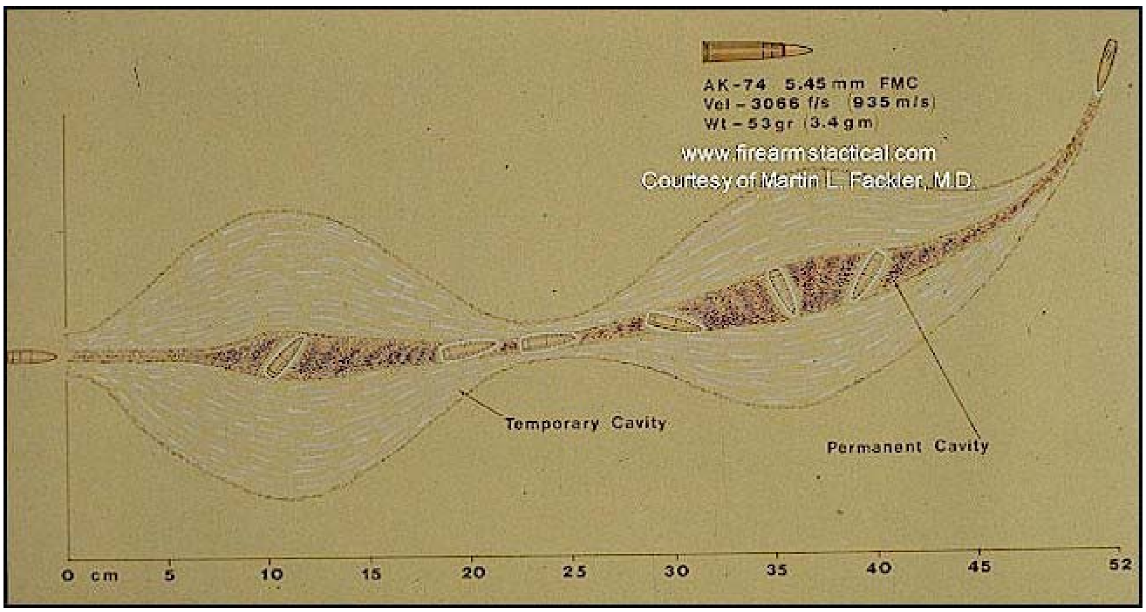


Figure 1 – Trajectory of a Rifle Bullet in Ballistic Gelatin

Figure 2 shows a bullet from a handgun in gelatin. There is only one temporary cavity and the bullet does not yaw. The muzzle velocity of handgun bullets is much lower than that of rifle bullets. For example, the muzzle velocity of the rifle bullet in Figure 1 is 3066 ft/sec while that of the handgun in Figure 2 is 880 ft/sec. This limits the penetration of the handgun bullet so that it stops before the yaw forces can cause the bullet to rotate.

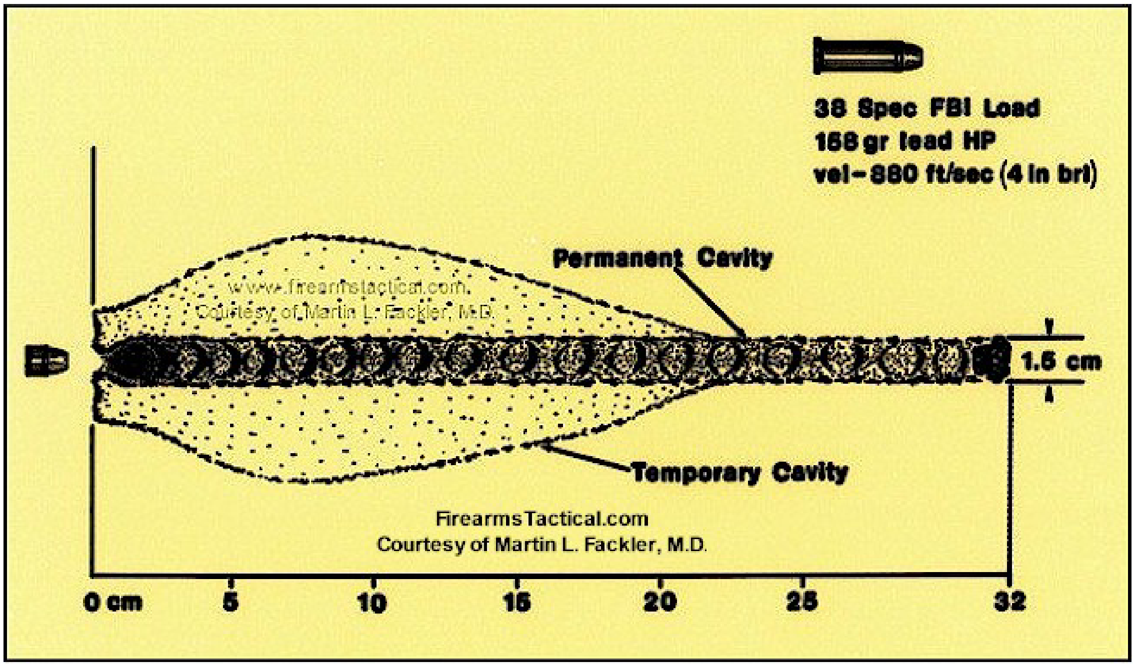


Figure 2 – Trajectory of a Handgun Bullet in Ballistic Gelatin

Additional examples of test firings in ballistic gelatin are shown in Appendix I – Fackler Wound Profiles.

Procedures for Preparing Ballistic Gelatins and Limitations

Current uses of ordnance gelatin as a tissue simulant include many models and measurement devices. Gelatin setups can include using the gelatin blocks alone or with coverings to simulate clothing, car doors, walls, etc. Gelatin is also used in conjunction with animal research. The gelatin blocks are placed post-animal to catch a projectile after it passes through the animal (Fackler, Breteau et al. 1989, Fackler et al. 1988). Gelatin is also used to suspend animal tissue such as arteries (Amato et al. 1970) and bones (Schyma et al. 1997, Orlowski et al. 1982) for ballistic tests. Devices used in measuring the results of gelatin ballistics tests have included x-ray technology and high-speed cine. New methods combine the gelatin model with computed tomography and digital processing of images to allow accurate numerical analysis of the characteristics of the permanent cavity (Korac et al. 2001 and 2002). (For current procedures and uses of ballistic gelatin see Appendix II. It includes two protocols and references for others, including the FBI mixing procedure.

One of the biggest advantages of using gelatin as a tissue simulant in ballistic research is that the gelatin model provides a visualization of the events, including the projectile path and the projectile-tissue interaction. Gelatin profiles measure bullet penetration, deformation, fragmentation, and yaw along the path, as well as tissue disruption from both crush (permanent cavity) and stretch (temporary cavity). The projectile can be easily recovered, making this model ideal for forensics, and the wound profile visualization has proved to be a tool for wound treatment.

Other reasons the gelatin model is useful involve the expense and complications associated with animal models. Some gelatin models have been calibrated to reproduce measurements observed in living animal tissue. This allows prediction of wound characteristics for a given projectile without animal testing. Gelatin can also be used in conjunction with and to enhance animal testing.

One of the major limitations of using ballistic gelatin as a tissue simulant is procedural difference among researchers. Gelatin consistency (firmness) and other properties are known to vary due to temperature and composition. Several different procedures employed vary by a few factors, leaving inconsistencies between results and difficulties in comparing data. For example, one standard is 10% gelatin at 4°C (Fackler's work), while others use 20% at 10°C (Amato et al. 1970, NATO standard circa Fackler 1988 in IDR, Celens et al. 1996, Korac et al. 2001). Physical preparation of the gelatin may cause variations. Methods have used cold or hot water to dissolve the powdered gel. It was realized later that heating the gel above 40°C weakens gel strength and viscosity (Fackler 1987, Fackler and Malinowski 1988). Also some methods are not concise. Gelatin used at 10°C is often taken from the refrigerator and allowed to "warm up" to 10°C, not accounting for differences in temperature from the outside to the inside of the block. As well, some researchers fail to calibrate tissue simulants at all.

Another area of limitation is the difficulty extrapolating the data for tissue simulants to use for living human beings. Fackler's research compares his gelatin model to live 50-70kg swine muscle and fresh (within one hour) dead swine muscle. In his comparison, original data is limited, and he sometimes references "unpublished data" to support his argument. Permanent cavities like the ones seen with fragmenting bullets in muscle are not well reproduced in gelatin. There is also less visible damage in muscle response to temporary cavity than seen in gelatin simulations. There are many more concerns with translating tissue simulation research to human muscle information, and the situation is worse yet when extended to entire living human beings. Simply put, gelatin blocks prepared correctly are homogeneous, where as living humans are heterogeneous. Differences in density and composition of human tissue such as bone and dense organs (like the liver) pose problems for the gelatin model.

Gelatin blocks used for ballistics testing are only good for one shot. As a result, some researchers find using gelatin time consuming and expensive. Additionally, the user must still interpret the data collected from wound profiles to determine projectile efficiency or lethality.

In spite of difficulties with cost and consistency, gelatin has been used for over 40 years as a tool for ballistic research. It continues to be viable as an approximation for soft, elastic animal tissue and an alternative to some animal research. But, the key to its success and future use may be the application of consistent, calibrated protocols based on proven methods and the use of caution in interpreting data for human comparison.

Works cited

Amato JJ, Billy LJ, Gruber RP, Lawson NS, and Rich NM. Vascular injuries: An experimental study of high and low velocity missile wounds. Archives of Surgery 101:167-174, Aug 1970.

Celens E, Pirlot M, Chabotier A. Terminal effects of bullets based on firing results in gelatin medium and on numerical modeling. J Trauma 40(Suppl 3): 27-30, 1996.

Cuadros JH. Terminal of non-lethal projectiles. 14th International Symposium on Ballistics proceedings. Pg 741-55, Sept 1993.

Fackler ML. Wound ballistics. A review of common misconceptions. [erratum appears in JAMA 1988 Dec 9;260(22):3279]. JAMA. 259(18):2730-6, 1988 May 13.

Fackler ML. Bullet performance misconcept/ions. International Defense Review (letters to the editor). 3:369-70, 1987.

Fackler ML. Handgun bullet performance. International Defense Review 5:555-7, 1988.

Fackler ML. Ordnance Gelatin for Ballistic Studies. Association of Firearm and Toolmark Examiners Journal 4:403-5, 1987.

Fackler ML. What's wrong with the wound ballistics literature, and why. Letterman Army Institute of Research, Report # 239, July 1987.

Fackler ML. Wound ballistics: A target for error. International Defense Review 8:895-7, 1988.

Fackler ML. Bellamy RF. Malinowski JA. A reconsideration of the wounding mechanism of very high velocity projectiles--importance of projectile shape. Journal of Trauma-Injury Infection & Critical Care. 28(1 Suppl):S63-7, 1988 Jan.

Fackler ML. Bellamy RF. Malinowski JA. The wound profile: illustration of the missile-tissue interaction. Journal of Trauma-Injury Infection & Critical Care. 28(1 Suppl):S21-9, 1988 Jan.

Fackler ML. Breteau JP. Courbil LJ. Taxit R. Glas J. Fievet JP. Open wound drainage versus wound excision in treating the modern assault rifle wound. Surgery. 105(5):576-84, 1989 May.

Fackler ML and Malinowski JA. Ordnance Gelatin for Ballistic Studies: Detrimental Effect of Excess Heat Used in Gelatin Preparation. The American Journal of Forensic Medicine and Pathology, 9(3): 218-219, 1988.

Fackler ML. Malinowski JA. The wound profile: a visual method for quantifying gunshot wound components. Journal of Trauma-Injury Infection & Critical Care. 25(6):522-9, 1985 Jun.

Fackler ML. Surinchak JS. Malinowski JA. Bowen RE. Wounding potential of the Russian AK-74 assult rifle. Journal of Trauma-Injury Infection & Critical Care. 24(2):263-66, 1984 Mar.

Fackler ML. Surinchak JS. Malinowski JA. Bowen RE. Bullet fragmentation: a major cause of tissue disruption. Journal of Trauma-Injury Infection & Critical Care. 24(1):35-9, 1984 Jan.

Kokinakis W. Neades D. Piddington M. Roecker E. A gelatin energy methodology for estimating vulnerability of personnel to military rifle systems. Acta Chirurgica Scandinavica - Supplementum. 489:35-55, 1979.

Korac Z, Kelenc D, Baskot A, Mikulic D, Hancevic J. Substitute ellipse of the permanent cavity in gelatin blocks and debridement of gunshot wounds. Military Medicine 166 (8): 689-694, Aug 2001.

Korac Z, Kelenc D, Hancecic J, Baskot A, Mikulic D. The application of computed tomography in the analysis of permanent cavity: A new method in terminal ballistics. Acta Clin Croat. 41:205-209, 2002

Korac E, Kelenc D, Mikulic D, Vukovic D, Hancevic J. Terminal ballistics of the Russian AK 74 assault rifle: Two wounded patients and experimental findings. Military Medicine 166 (12): 1065-1068, Dec 2001.

Orlowski T, Piecuch T, Domaniecki J and Bodowsky A. Mechanisms of development of shot wounds caused by missles of different initial velocity. Acta Chir Scand. Suppl 508: 123-127, 1982.

Schyma C, Bittner M, Placidi P. The MEN frangible - Study of a new bullet in gelatin American Journal of Forensic medicine and Pathology 18 (4): 325-330, Dec 1997.

Uzar AI, Dakak M, Ozer T, Ogunc G, Yigit T, Kayahan C, Oner K, Sen D. A new ballistic simulant "transparent gel candle" (experimental study). Turkish Journal of Trauma and Emergency Surgery 9(2):104-6, Apr 2003.

Additional References

Bruchey WJ JR and Sturdivan LM. An instrumented range meeting the requirements of a wound ballistic small arms program. Ballistic Research Laboratories Technical Note # 1703, 1968.

Dahlstrom D and Powley K. Comparative Performance of 9mm Parabellum, .38 Special and .40 Smith & Wesson Ammunition in Ballistic Gelatin. Technical Report published by the Canadian Police Research Centre, September 1994.

Dodson, Shawn: Reality of the Street? A Practical Analysis of Offender Gunshot Wound Reaction for Law Enforcement. Tactical Briefs, 4(2), April 2001

Dzieman AJ. A provisional casualty criteria for fragments and projectiles. Edgewood Arsenal Maryland Report #2391, 1960.

Fackler ML. Wound Ballistics Research of the Past Twenty Years: A Giant Step Backwards. Letterman Army Institute of Research. Institute Report No. 447, Presidio of San Francisco, California 94129, 14 pages, January 1990.

Fackler ML. Wound Profiles. Wound Ballistic Review 5(2): 25-38, Fall 2001.

Fackler ML. Bellamy RF. Malinowski JA. Wounding mechanisms of projectiles striking at more than 1.5 km/s. Journal of Trauma-Injury Infection & Critical Care. 26:250-4, 1986.

Fackler, Martin L., MD.: "Book Review, *Street Stoppers: The Latest Handgun Stopping Power Street Results*." *Wound Ballistics Review*, 3(1); 26-31: 1997.

Grabarek C and Herr L. X-ray mulitflash system for the measurement of projectile performance at the target. Ballistic Research Laboratories Technical Note # 1466, 1970.

Knudsen PJT, Vignaes JS, Rasmussen R, Nissen PS. Terminal ballistics of 7.62 mm NATO bullets – Experiments in ordnance gelatin. International Journal of Legal Medicine108 (2): 62-67, Oct-Nov 1995.

MacPherson, Duncan: "Bullet Penetration -- Modeling the Dynamics and the Incapacitation Resulting from Wound Trauma." Ballistic Publications, El Segundo, California. 1994

MacPherson, Duncan: "The Marshall & Sanow 'Data' - Statistical Analysis Tells the Ugly Story." *Wound Ballistics Review*, 4(2); 16-21: Fall, 1999.

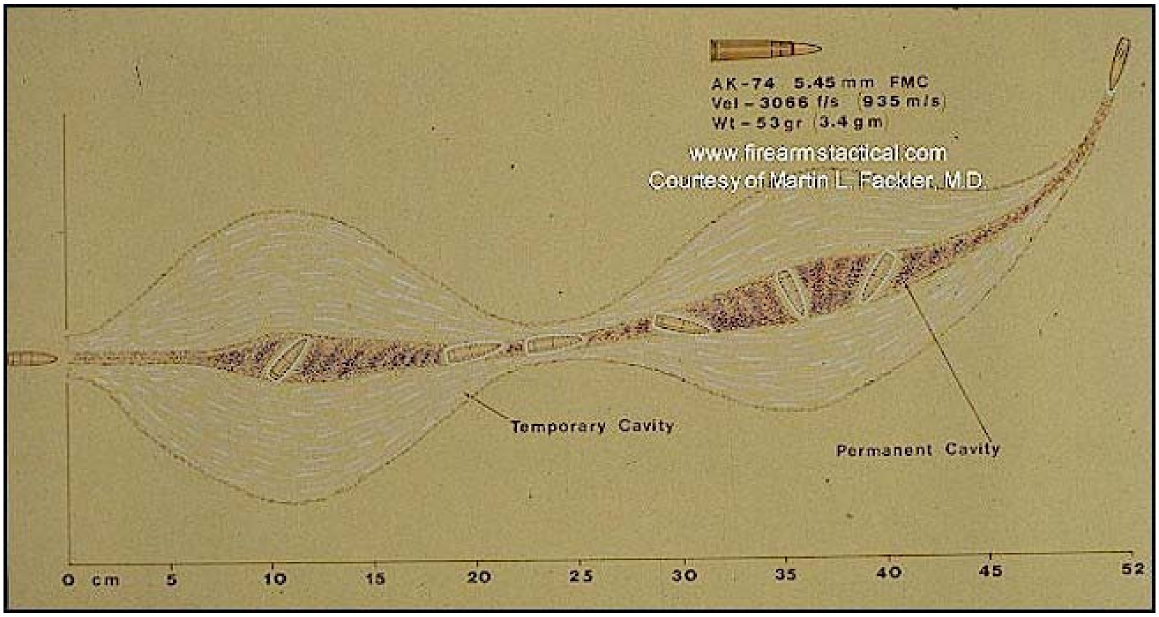
Ragsdale BD. Gunshot wounds: A historical perspective. Military Medicine 149:301-315, June 1984.

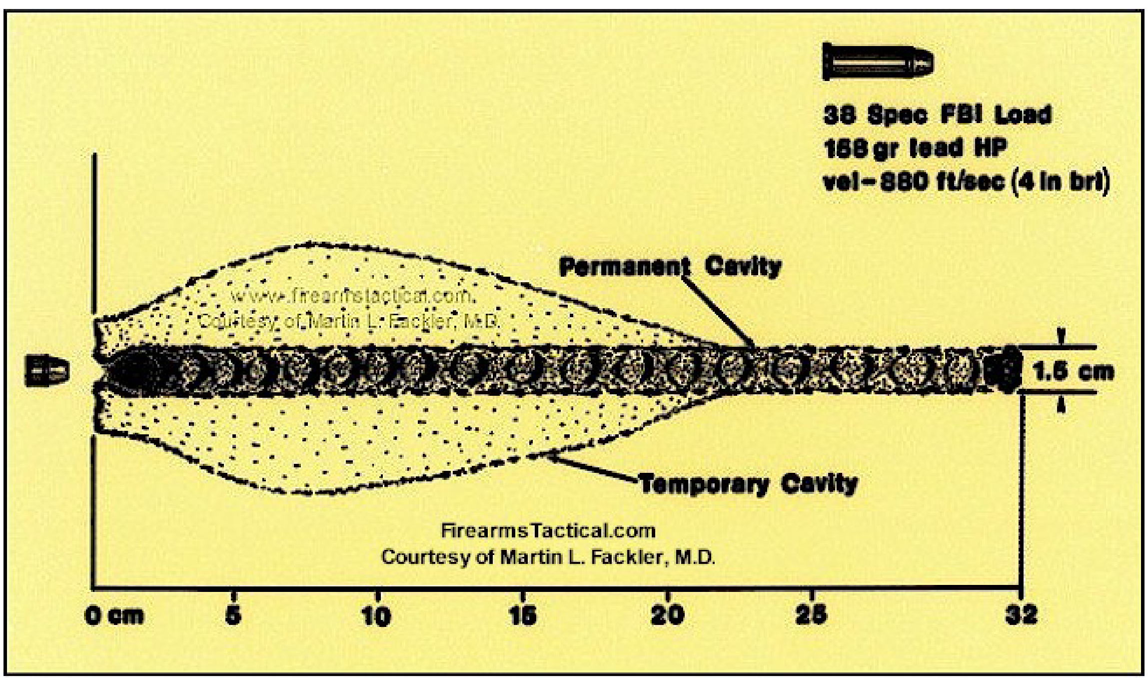
Roberts, Gary K.; Wolberg, Eugene J.: "Book Review, *Handgun Stopping Power: The Definitive Study*." Association of Firearm and Toolmark Examiners Journal, 24(4); 383-387: 1992.

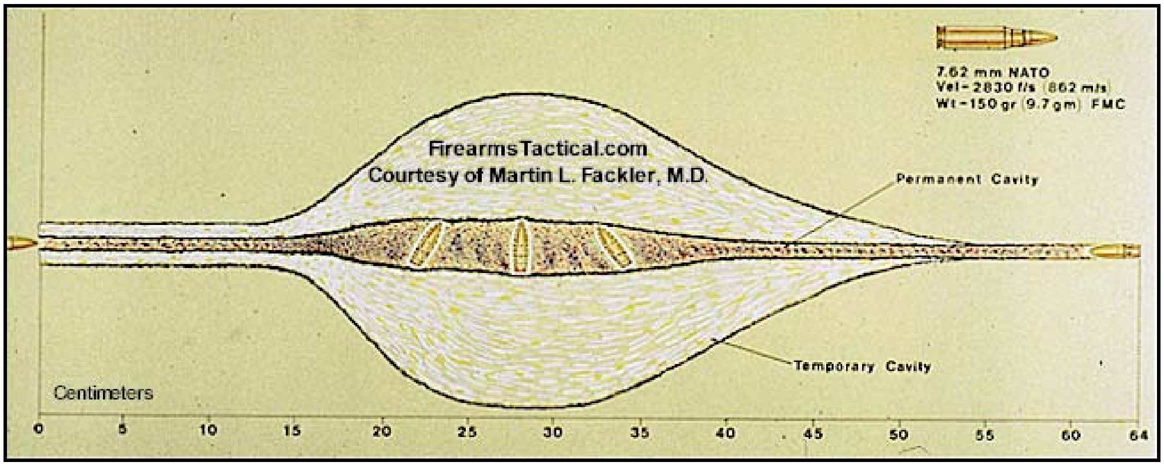
Watkins FP, Pearce BP, Stainer MC. Assessment of terminal effects of high velocity projectiles using tissue simulants. Acta Chir Scand, Suppl 508: 39-47, 1982.

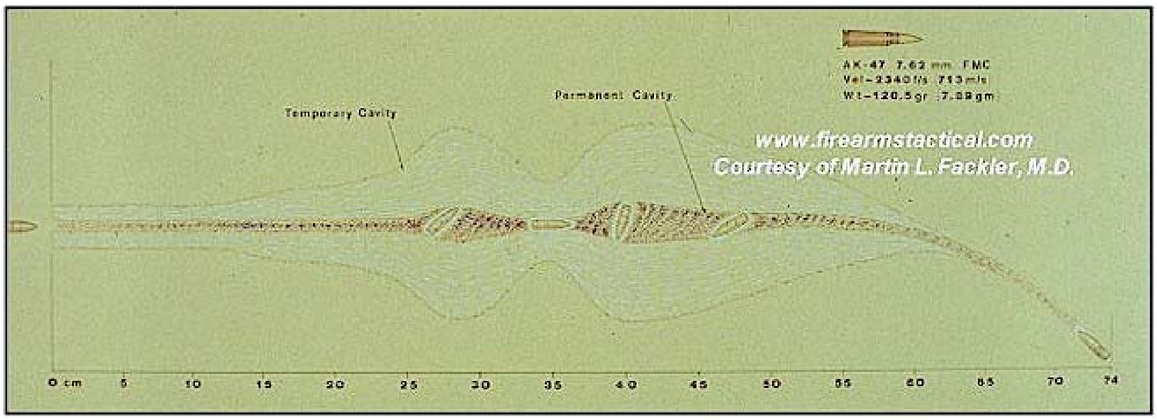
van Maanen, Maarten: "Discrepancies in the Marshall & Sanow 'Data Base': An Evaluation Over Time." *Wound Ballistics Review*, 4(2); 9-13: Fall, 1999.

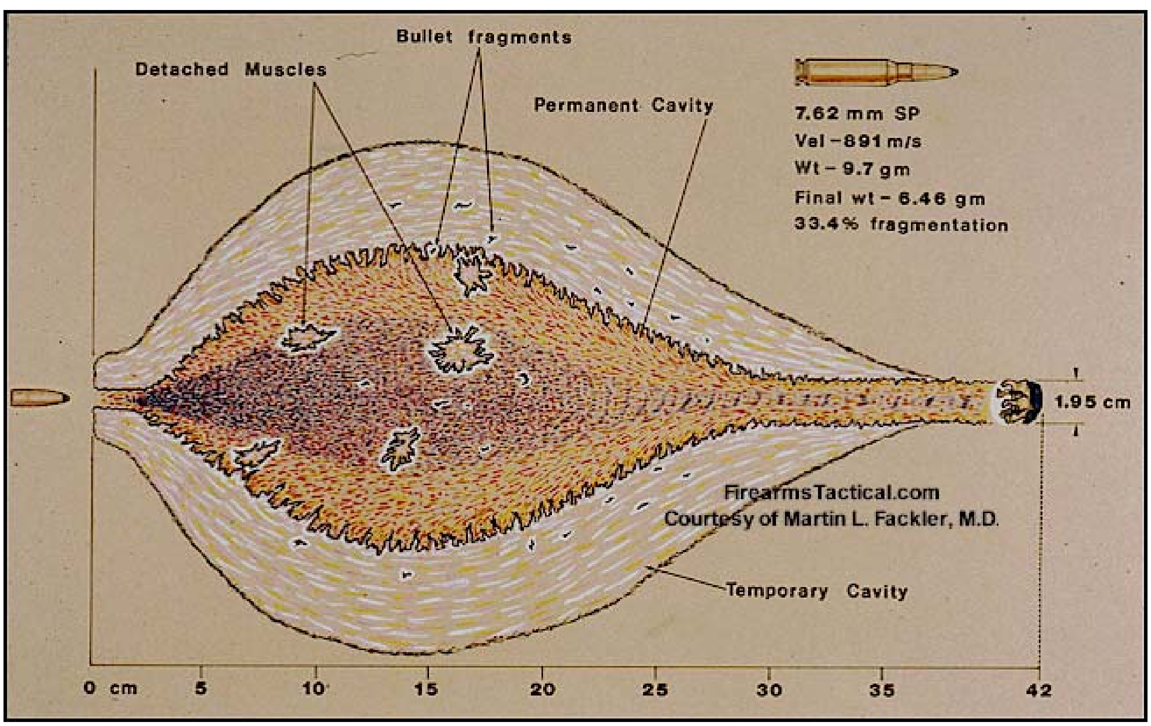
Appendix I – Fackler Wound Profiles

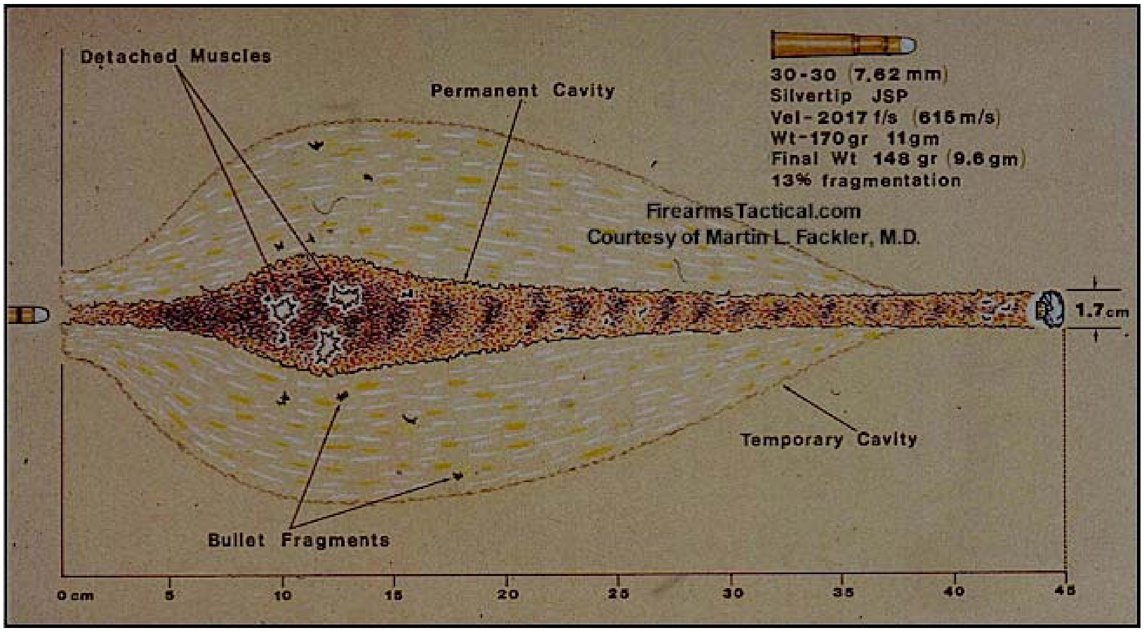


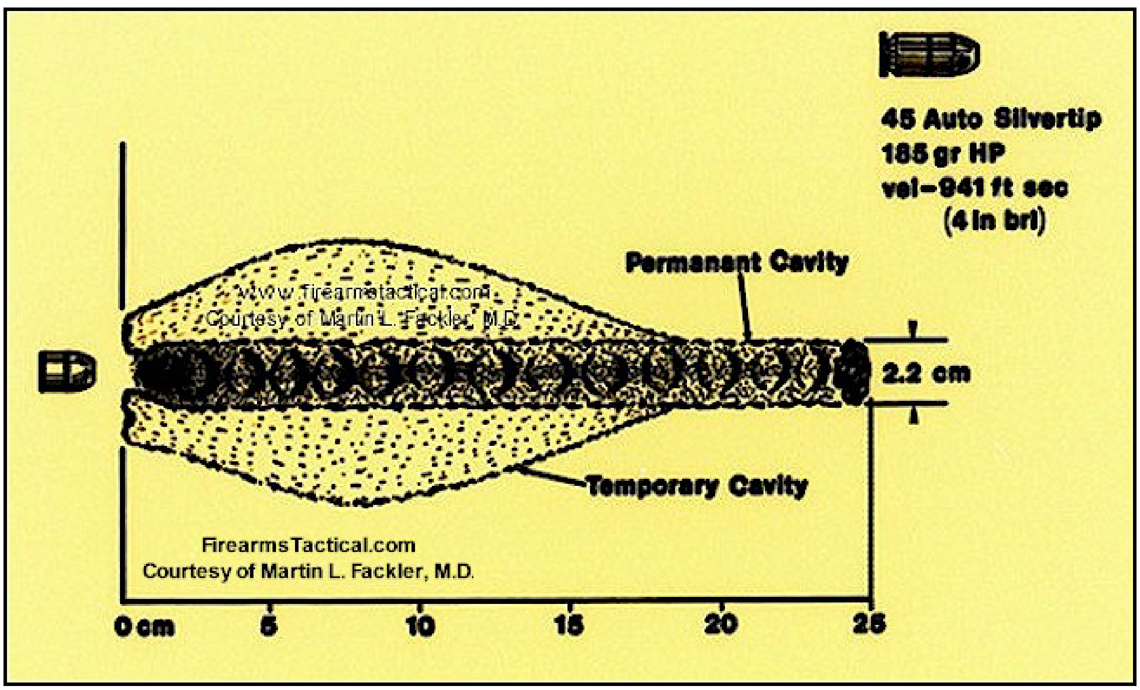


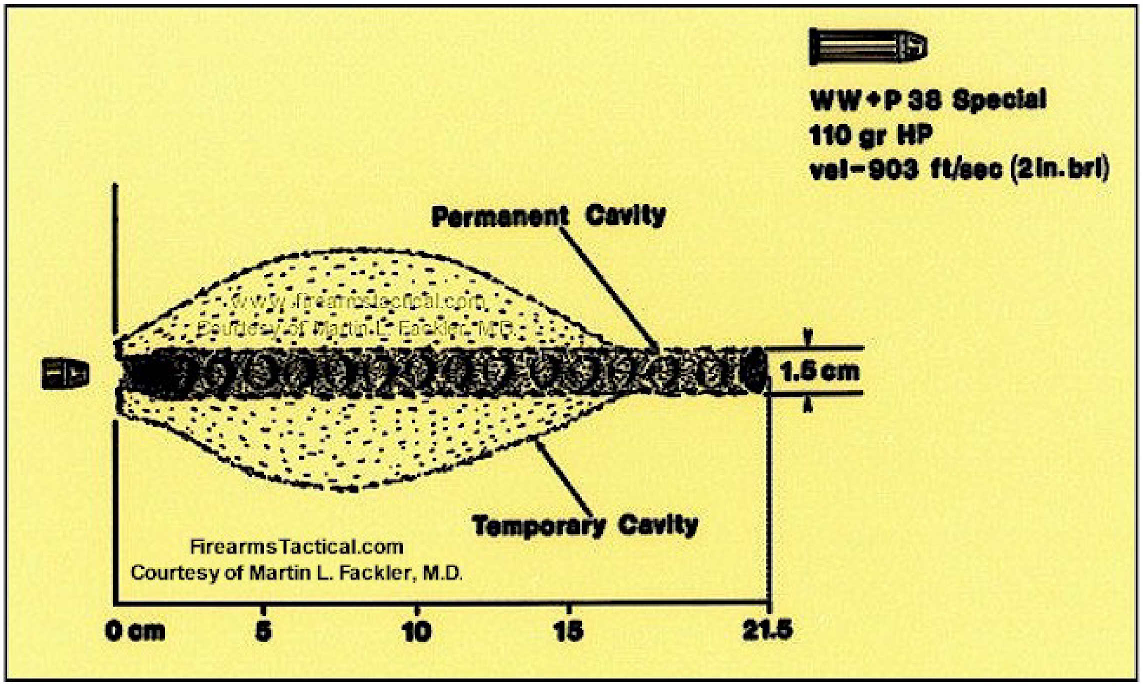

7.62 mm NATO
Vel - 2830 f/s (862 m/s)
Wt - 150 gr (9.7 gm) FMC
FirearmsTactical.com
Courtesy of Martin L. Fackler, M.D.
Permanent Cavity
Temporary Cavity
Centimeters
0 5 10 15 20 25 30 35 40 45 50 55 60 64

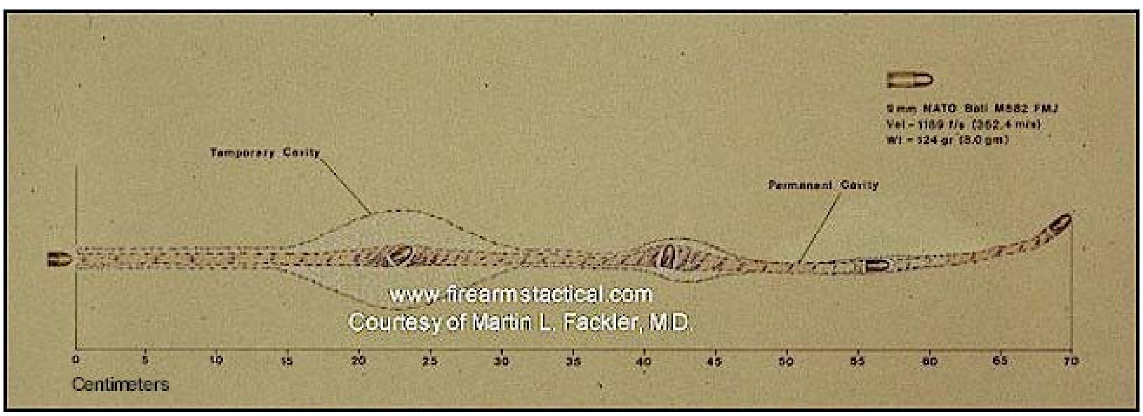

AK-47 7.62 mm FMC
Vel - 2340 f/s (713 m/s)
Wt - 120.5 gr (7.89 gm)
Permanent Cavity
Temporary Cavity
www.firearmstactical.com
Courtesy of Martin L. Fackler, M.D.
0 cm 5 10 15 20 25 30 35 40 45 50 55 60 65 70 74

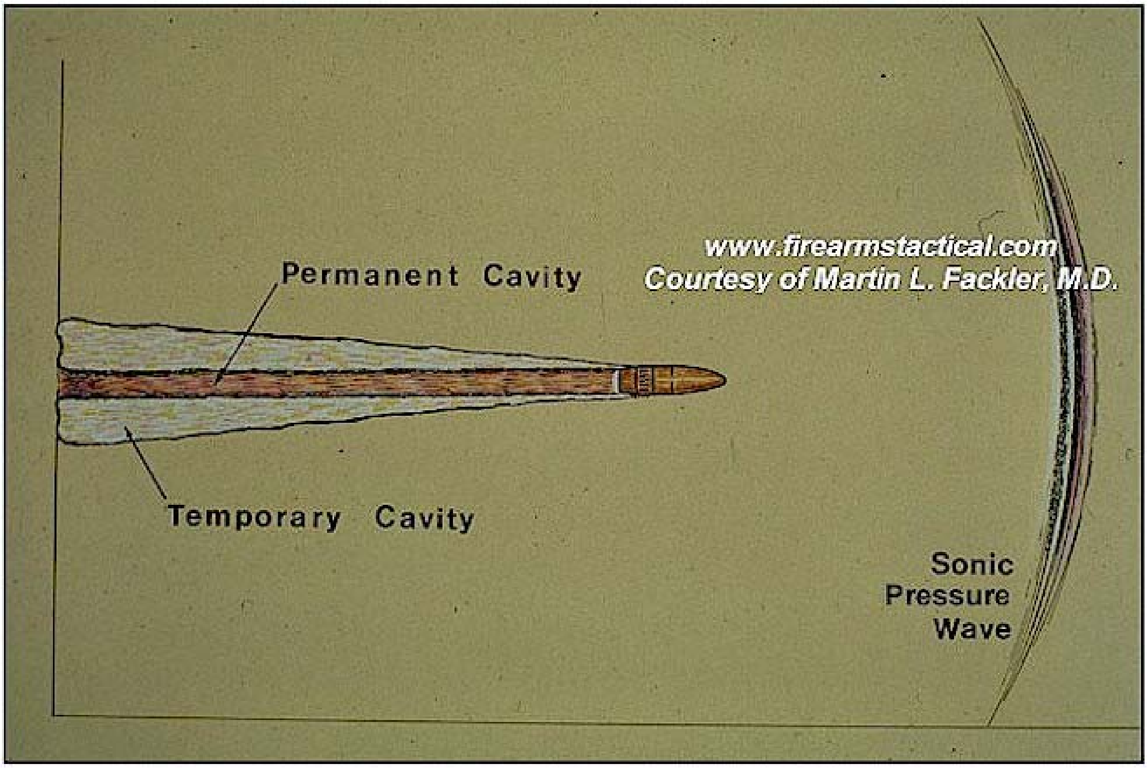

Bullet fragments
Detached Muscles
Permanent Cavity
7.62 mm SP
Vel - 891 m/s
Wt - 9.7 gm
Final wt - 6.46 gm
33.4% fragmentation
1.95 cm
FirearmsTactical.com
Courtesy of Martin L. Fackler, M.D.
Temporary Cavity
0 cm 5 10 15 20 25 30 35 42

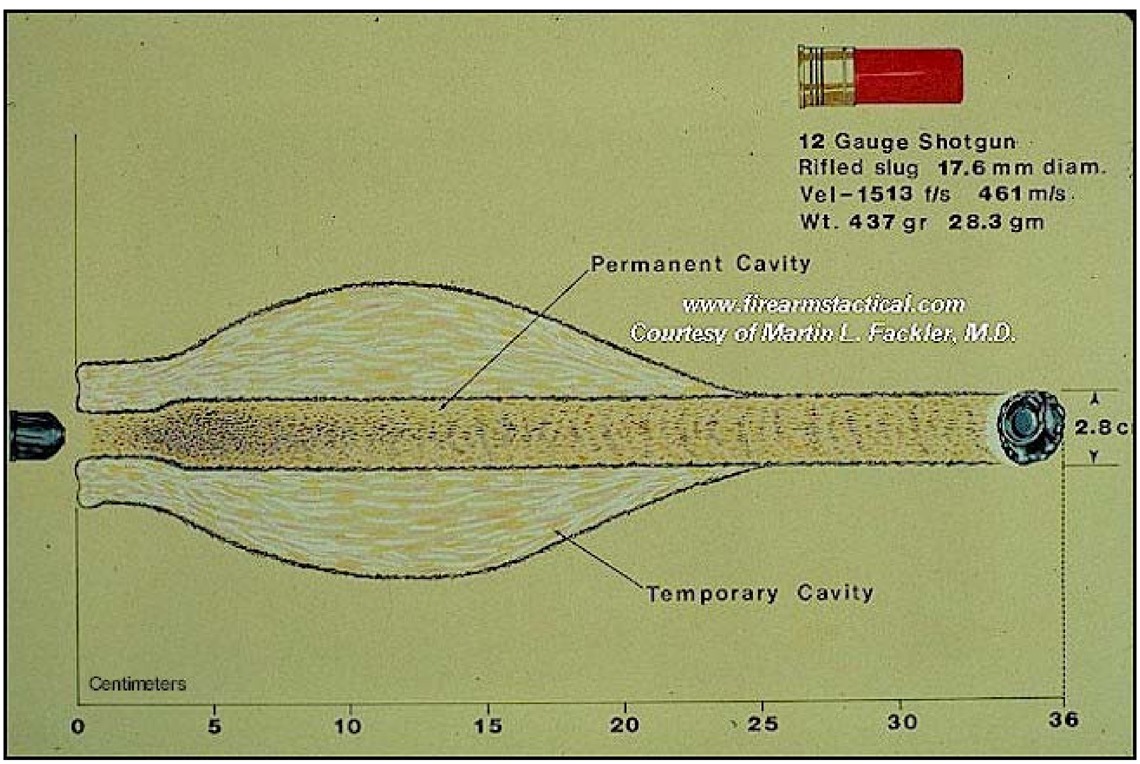

Detached Muscles
Permanent Cavity
30-30 (7.62 mm)
Silvertip JSP
Vel-2017 f/s (615 m/s)
Wt-170 gr 11 gm
Final Wt 148 gr (9.6 gm)
13% fragmentation
FirearmsTactical.com
Courtesy of Martin L. Fackler, M.D.
1.7 cm
Temporary Cavity
Bullet Fragments
0 cm
5
10
15
20
25
30
35
40
45

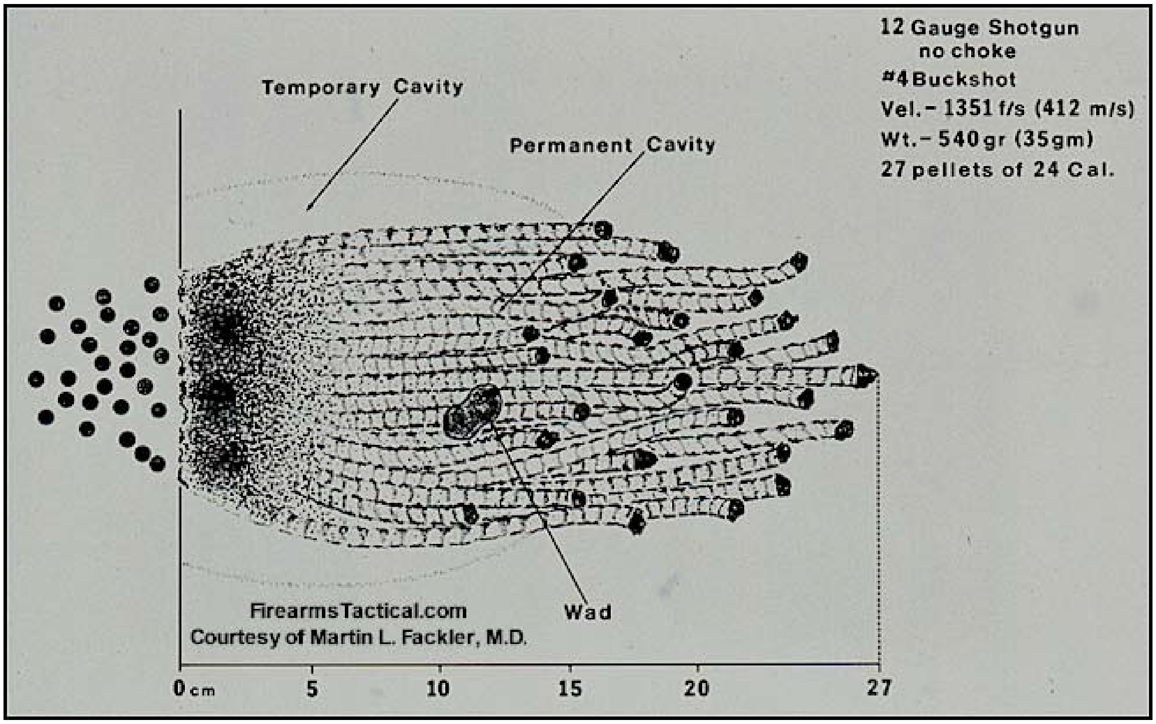

45 Auto Silvertip
185 gr HP
vel-941 ft sec
(4 in brl)
Permanant Cavity
www.firearmstactical.com
Courtesy of Martin L. Fackler, M.D.
2.2 cm
Temporary Cavity
FirearmsTactical.com
Courtesy of Martin L. Fackler, M.D.
0 cm
5
10
15
20
25


WW+P 38 Special
110 gr HP
vel-903 ft/sec (2in.brl)
Permanent Cavity
1.5 cm
Temporary Cavity
www.firearmstactical.com
Courtesy of Martin L. Fackler, M.D.
FirearmsTactical.com
Courtesy of Martin L. Fackler, M.D.
0 cm
5
10
15
21.5


9 mm NATO Ball M882 FMJ
Vel - 1189 f/s (362.4 m/s)
Wt - 124 gr (8.0 gm)
Temporary Cavity
Permanent Cavity
www.firearmstactical.com
Courtesy of Martin L. Fackler, M.D.
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
Centimeters


Permanent Cavity
Temporary Cavity
www.firearmstactical.com
Courtesy of Martin L. Fackler, M.D.
Sonic
Pressure
Wave


12 Gauge Shotgun
Rifled slug 17.6 mm diam.
Vel-1513 f/s 461 m/s
Wt. 437 gr 28.3 gm
Permanent Cavity
www.firearmstactical.com
Courtesy of Martin L. Fackler, M.D.
Temporary Cavity
Centimeters
0 5 10 15 20 25 30 36


12 Gauge Shotgun
no choke
#4 Buckshot
Vel. - 1351 f/s (412 m/s)
Wt. - 540 gr (35 gm)
27 pellets of 24 Cal.
Temporary Cavity
Permanent Cavity
Wad
FirearmsTactical.com
Courtesy of Martin L. Fackler, M.D.
0 cm
5
10
15
20
27

Appendix II - Fackler Gelatin Model

Fackler's 10% gelatin at 4°C:

- 250 A ordnance type gelatin, Kind and Knox Co., Sioux City, IA
- molded 10% by weight aqueous solution into 25 X 25 X 50 cm block (placed end to end to capture full bullet path)
- stored in airtight plastic bags at 4°C
- shot from 3 meters at 4°C (within "a few minutes" of being removed from the refrigerator
- measurements
    - velocities measured with a chronograph
    - biplanar x-rays to determine bullet and fragment sites
    - blocks cut along bullet path to measure penetration depth, permanent cavity and temporary cavity
    - all produce "wound profile"
        - amount, type and location of tissue disruption
        - projectile mass, velocity, construction and shape (before and after shot)
        - projectile deformation and fragmentation pattern where applicable
        - scale included for comparison
- (Fackler and Malinowski 1985)

Appendix III – Gelatin Resources

Gelatin ordering information

Vyse Gelatin Co.

http://www.vyse.com/vysehomepage.htm

5010 N. Rose St.
Schiller Park, IL 60176

Phone Numbers:

1-800-533-2152
1-847-678-4780

Fax Number:
1-847-678-0329

Email:

Sales: sales@vyse.com
Tech Help: techhelp@vyse.com
Information: info@vyse.com

Vyse sells to the FBI, regional police departments, test labs, ammunition manufacturers.

Prices depend on quantities sold, for example:

25 lbs. is $4.65 per pound plus freight
50 lbs. is $4.50 per pound plus freight
100 lbs. is $4.35 per pound plus freight

GELITA USA Inc.

http://www.gelita.com/DGF-deutsch/gruppe/gruppe_standorte_nord_amerika_usa_sc.html?reload_coolmenus

Mailing:
P.O. Box 927
Sioux City, IA 51102, USA
Plant:
2445 Port Neal Industrial Rd.
Sergeant Bluff, IA 51054, USA

Tel: +1 (712) 943-5516
Fax: +1 (712) 943-3372
sales contact: Lanette Falk Ext.623

Formerly Kind and Knox (name change 6/3/2003)

Price approx. $5 per pound depending on order size

Appendix - Ballistic gelatin blocks
http://www.hpwhite.com/601-02.pdf

Appendix - A Practical guide and specification for preparation of 10% ballistic gelatin
http://www.logicsouth.com/~lcoble/dir5/gelprep.txt

Appendix - Ed Harris recipe
http://www.recguns.com/Sources/XD3.html

Appendix - FBI Ballistic gelatin mixing procedure (Vyse)
http://www.vyse.com/gelatin_for_ballistic_testing.htm

Appendix - FBI Ballistic Test Protocol
http://greent.com/40Page/general/fbitest.htm

Appendix - FBI penetration testing (Vyse)
http://www.vyse.com/FBI PENETRATION TESTING.htm

Appendix - INS National Firearms Unit Ballistic Gelatin Test Protocol
http://www.firearmstactical.com/tacticalbriefs/volume4/number1/article412.htm

Appendix - Vyse Gelatin Co MSDS data sheet
http://www.vyse.com/MSDSgelatin.htm

Applied Research Laboratory

PENNSTATE

1855