British Pattern 1756 Long Land Musket Bullet Performance: A Live-Fire Experimental Study to Validate Known Bullet-Struck Objects from the First Day of the American Revolution

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Introduction

This live-fire experiment was conducted to determine if we could replicate spherical ball-damaged objects surviving from April 19, 1775, the first day of the American Revolution. The standing structures damaged by gun fire on April 19 now exist amidst a modern built and modified landscape. However, those buildings and places still remain and anchor us to that past by their very existence. These places, Elisha Jones' shed, Munroe Tavern, Buckman Tavern, Marrett Munroe house, Jason Russell house, and other preserved artifacts have become "hallowed" because they either still stand or exist in collections.[1] As historic objects they were a part of a signal event, and they embody those events which they witnessed. A bullet hole in a wall is mute testimony to that past conflict but is not mute to us. Physical evidence has much to say about the past when studied in the greater context of the British retreat that was contested by organized Provincial minute and militia companies from Concord to Charlestown.

To better understand the surviving bullet-damaged structures and objects we employed an experimental approach, a live-fire validation study to determine if we could replicate the damage we observed and recorded. Experimental archaeology has emerged as a rigorous approach to the study of material reflections of human behavior. It has a rich history in the field of archaeology which has largely focused on understanding technological processes affecting environmental and cultural adaptations in the prehistoric past.[2] This is an increasingly refined field that lets archaeologists develop insights and methods for making behavioral interpretations of things in the archaeological record. Among the critics of experimental archaeology are those who argue that there needs be a greater emphasis on hypothesis development and variable control to establish what they refer to as "sound referential linkages upon which constructive analogic inferences about the past can be built."[3]

We largely agree that more rigorous studies need to be developed to achieve those lofty goals in all areas of archaeological research. Our previous experimental archaeology efforts focused on the exterior ballistic performance of projectiles and how experimental bullet impact data can inform conflict archaeology studies or any archaeological investigations of sites where firearms residue is found. This effort is a validation study of a shooting incident reconstruction we conducted on surviving bullet-damaged objects and architectural elements from April 19, 1775.

This study was done in support of a book entitled *Dreadful Were the Vestiges of War: Bullet Strikes from the First Day of the American Revolution* that will be released in early 2025. In our book, we have covered the arms and ammunition used by both Provincial and British forces, and all known bullet-struck architectural structures and objects. Using modern forensic shooting incident reconstruction methods, we have recorded all of the strikes, estimated each ball strike caliber, who fired the shots (Provincial or British), and reconstructed the shooters' approximate position. This report details the experiments that were designed as a validation study to determine if 18th century British Brown Bess muskets could have caused the damage observed in the original surviving bullet-struck objects we recorded. Incidental to this study was the opportunity to shoot and record velocity bullet strike effects of a circa 1650 English lock musket.

We shot sections of house walls that we had built using salvaged original colonial-era building materials, an indoor window shutter, interior panels that replicated bullet-damaged walls, shutters, and a powder horn. We employed human tissue simulant ballistic gelatin block and a head and bust for two of the validation studies in order to ascertain the effect of lead balls on the human body. All shots were recorded with high-speed videography focusing on the bullet strike and associated damage as well as determining the velocity of the ball when it struck the target.

To study firearms, archaeologists need to design and carry out appropriate experiments and draw on technical methods developed by firearm examiners, engineers, and physicists. Recent battlefield archaeological investigations have given new impetus to identifying the external ballistic capability of the British Brown Bess musket and its combat efficiency. This study is a follow up to experimental work we have done on colonial smoothbore fowling pieces and muskets used by both sides during the American Revolution-era.[4]

The results of this live-fire experiment with colonial firearms adds to the investigation of late pre-modern gun use and enhances our previous work on colonial-era firearms.[5]

The study goals were to collect data and conduct live-fire experiments with a faithful reproduction of a British 1756 Long Land Pattern smoothbore musket. The study activities were designed to benefit several audiences:

1) Those interested in the history of firearms;

2) Re-enactors who will use the information in creating more authentic presentations;

3) Professional historians, archaeologists, and interpreters who either deal with firearms or how firearms were used; and

4) Firearm examiners who can use the information to exclude historic bullets and cartridges that are sometimes found on crime scenes from consideration and/or correctly assess black powder and reproduction firearms that are sometimes used in shooting incidents today.

The live-fire experiments were designed to capture information on flintlock-fired lead ball performance and capabilities. These data will benefit the goal audiences in their understanding and interpretation of archaeologically recovered spherical lead balls.

This report is well-illustrated for the simple purpose of providing the reader with illustrations of the Brown Bess bullet capability to penetrate a variety of media and the damage that occurred to those media. The extensive use of figures is, we believe, important to visualize and make clear the complex elements of firearms exterior and terminal ballistics.

Principles of Firearms Exterior Ballistics; Background to the Study

Exterior ballistics is the study of the performance of a bullet after it leaves the gun. As Lucien Haag observes, there is a difference in what a ballistician and a forensic scientist, or for our purposes an archaeologist, is seeking in studying bullet performance.[6] The forensic scientist or conflict archaeologist is seeking to reconstruct a shooting incident or event based on residual physical evidence, the artifact, and knowledge of one or more types of firearm ammunitions' ballistic properties and performance.

Essentially all firearms send a projectile toward a target in a like manner.[7] The target is determined to be at a certain range, and there is a line of sight between the shooter and the target. When the bullet is fired from the firearm it has a line of departure, a bullet flight path, and an angle of fall which are affected by various physical forces; initial velocity, gravity, air resistance, wind direction, elevation, temperature, barometric pressure, and relative humidity. Each of these factors can be accounted for in one or more ballistic formulae that are used to calculate, with reasonable accuracy, how far the bullet will go before reaching a terminal velocity and return to earth. Likewise, formulae exist to calculate how much energy as foot pounds or joules, or kinetic energy a bullet will have at various ranges.[8] These data become important to understanding bullet capability to incapacitate or kill, or what may happen to a bullet that is an under or overshot. Knowing this basic information allows the archaeologist to better understand the pattern of bullet deformation observed on a battle site, the patterns in which bullets are found, and better interpret an artifact assemblage.

External ballistics for post-1900 firearms and bullets are relatively well known and is the continuing subject of analysis as new smokeless gun powders and conical bullets are developed. Datasets on external ballistics and bullet performance are limited for the soft lead spherical balls and cylindro-concodial bullets of the preceding centuries, especially the spherical lead ball. A great deal of lore and apocryphal information exists on the ranges and performance of these historical bullets. There are good summaries of test shooting, largely at pine boards and thick catalogs or telephone books to determine bullet penetration at various ranges that were conducted in the nineteenth century and well into the twentieth century.[9] These data are of limited value to the modern researcher. Thus, it becomes necessary to conduct firsthand live-fire research with a variety of weapons under controlled experimental conditions to ascertain the behavior of spherical bullets and other projectiles that will enhance our understanding of lead bullet behavior of the pre-1900 era.

Roberts et al. fired flintlock guns in an earlier experiment achieving a 1500 f/s (457.2 m/s) velocity.[10] The barrels were fired using an electrical matchhead placed in the flash pan.[11] They used a replica rolled paper cartridge with various powder charges ranging from 116 grains (7.5 grams), 154 grains (10 grams), and 231 grains (15 grams) and a .691-inch (17.4mm) lead ball. The experiment's purpose was to reach a muzzle velocity of 1500 f/s (457.2 m/s). The gun powders used were a 3A fine which is a military designation for special purpose black gunpowder and is roughly the equivalent of the U.S. FFFg black gunpowder, G12 which is roughly equivalent to U.S. Fg gunpowder, and coarse blasting powder. Each has a different burn rate resulting in different internal pressures.

The loading and firing process did account for priming the pan. They deducted 10 grains (0.65 grams) from each charge to account for priming. The experiment fired 21 shots using the three different gunpowder granulations. The firings resulted in a range of velocities based on powder charges of 427 f/s (130.2 m/s) to 1685 f/s (513.9 m/s). The 3A fine gunpowder 154 grain charge resulted in firings producing 1032.5 f/s (314.7 m/s), 925.8 f/s (282.2 m/s), and 672.2 f/s (204.9

m/s). The G12 gunpowder charge of 154 grains resulted in muzzle velocities of 427.16 f/s (130.2 m/s), 691.3 f/s (210.7 m/s), and 1080.4 f/s (329.3 m/s). The blasting grade powder at a 154-grain charge achieved muzzle velocities of 363.2 f/s (110.7 m/s), 454 f/s (138.4 m/s), and 612.2 f/s (186.6 m/s).

Roberts et al. concluded that at 1500 f/s (427.2 m/s) a bullet fired at an elevation of 35 degrees would travel 3937 feet (1200 meters) or if fired horizontally would travel 663 feet (202 meters).[12] Their work also included calculating wound effects using ballistic gelatin and penetration studies of replica eighteenth century breastplates. They found the 1500 f/s bullet penetrated period breastplate and simulated human arm tissue and bone at 150 yards (137 meters). They also observed that a shot would drag fragments of clothing into the wound as well as shatter human bone. They concluded that the Brown Bess ball would most certainly have significant wounding and lethal effect at traditional combat ranges of 100 yards (91 meters) and 75 yards (69 meters) if it were traveling at 1500 f/s (457.2 m/s).

More recent controlled replica Brown Bess experimental firings were done by Lucien Haag.[13] In these tests, Haag used a .72-caliber (18.29mm) Brown Bess with a .718-inch (18.23mm) diameter lead ball with a cotton patch. He used 100 grains (6.4 grams) of Goex FFg black powder. The firings resulted in a muzzle velocity of 951 f/s with 1108.3 ft-lbs. (337.8m) of energy at the muzzle. At 200 yards (183m) the velocity dropped to 668.4 f/s (203.7m) and the energy to 547.6 ft-lbs. (167m/s). The bullet is calculated to have dropped 100.55 inches (2.55m) over 200 yards (183m). The highest muzzle velocity reported was 1168 f/s (356m/s) with 1671 ft-lbs. (509m/s) of energy at the muzzle. At 200 yards (183m) the bullet had slowed to 747.8 f/s (228m/s) and the energy dropped to 685.3 ft-lbs. (209m/s). The bullet drop was calculated at 75.64 inches (1.921m) at 200 yards (183m).

Haag also fired a high-quality replica of a British Ferguson rifle. His test firings used a .650-inch (16.5mm) lead ball weighing 402 grains (26 grams). The powder was Goex brand of 60 grains (3.88 grams) mixed from FFg and FFFg in equal proportions. The firing produced several shots that exceeded the speed of sound, with one reaching 1237.9 f/s (377.3m/s). He also fired .610-inch balls (16.4mm) with FFFg Swiss black powder with muzzle velocities at 1000 f/s (304m/s) and below.

Shooting Incident Reconstruction: Concept and Methods

Shooting-related events are usually the purview of law enforcement agencies. Crime scene and forensic investigators employ a wide range of tools and techniques to recover and analyze evidence from a shooting scene to create a shooting incident reconstruction. In cases where a surface is struck by a projectile fired from a firearm, the impact marks left on surfaces may retain useful information that can aid in determining the type of firearm used and the original location of the shooter. That data or evidence may include the angle of impact and whether the projectile penetrated or lodged in a material, like a wall. Investigation of these marks can provide useful information on forensic questions to aid in the reconstruction of the shooting incident.[14]

The April 19th bullet-struck objects study used, including the Jason Russell house bullet hole study, both the concepts and methods used by law enforcement agencies in shooting incident reconstructions. Our study identified sixteen bullet-struck objects.

We followed the standard practice employed in crime scene investigations by using trajectory rods supplemented by a laser level, and a mobile telephone application, Theodolite©, to obtain the approximate angle at which a bullet struck an architectural element in the Jason Russell house. A bullet hole has an incident angle or trajectory angle that can be calculated using a laser or trajectory rods, and by using angle and trigrammatic functions the bullet path can be determined with a plus or minus 5-degree accuracy. The trajectory angle allows reconstruction, or back extrapolation, of the bullet path to determine the approximate angle at which the shot was taken within a degree of error.[15] The resulting rod orientation data helps determine the direction from which the shot was made and where the bullet may have struck after passing through an architectural element.

In order to back extrapolate the shooter's position, we made several basic assumptions. First, we assumed that the average height of a soldier in 1775 was between 5 feet 8 inches (68 inches or 1.72 meters) and 6 feet (1.82 meters). We are aware that Grenadier companies had taller men ranging from 5 feet 10 inches (1.77 meters) to over 6 feet (1.82 meters) in height. Light Infantry company men were generally shorter in height, averaging 5 feet 7 inches (1.7 meters). Second, we assumed the butt of the musket was held at shoulder height which is about 5 feet 3 inches (63 inches or 1.6 meters) above ground level. Unfortunately, no records of inspection dating to 1775 have been found for the regiments engaged on April 19. We chose to use an average of 63 inches (1.6 meters) for height of above ground level allowing for one standard deviation for taller or shorter men.[16] Essentially the deviation is statistically insignificant in calculating the shot angle given other variables in how a soldier held his firearm, if he flinched when firing, and the uncertainty of aiming a smoothbore musket. Using the Pythagorean theory, we used the wall as the right angle, the trajectory angle as the hypotenuse, and then calculated the third side which provides a likely distance from the hole to the shooter holding the musket butt at shoulder height.

Studies of modern jacketed conical bullets shot into various wood types demonstrate the shooting incident angle and the resulting ricochet angle are dependent on the hardness and density of the wood type being struck.[17] The relevance of these modern experiments to this study are limited due to the use of modern high-velocity jacketed bullets which do not perform in the same manner as soft lead spherical balls. The studies show that the orientation of the grain of the wood on a board influences the bullet impact and subsequent deflection.

Components of the Live-Fire Experiment

The live-fire experiment used a custom-built reproduction British Pattern 1756 Long Land flintlock musket. Other components of the experiment included the firing range, consideration of the black gunpowder used as a propellant, standardization of the lead balls, the construction of authentic style cartridges, the construction of targets, and the methods of data collection.

High-Speed Video Camera

The high-speed camera setup consisted of a Fastec Imaging TS3 Cine camera mounted on a tripod (Figure 1) and connected by various cables to a laptop computer. The camera was remotely controlled and collected data on the shot. The camera was set to record at 2500 frames per second. The data were downloaded to the computer and field processed in Cine Viewer and saved on an external hard drive. Boxer LED spotlights with appropriate filters/gels were employed as necessary to better light the targets (Figure 2). These data were backed up on two additional external hard drives after the conclusion of the shooting day.

Figure 1. The high-speed camera being calibrated for a shot at a wall panel.

Figure 2. Videographer John Beck field processing data from the high-speed camera after a shot.

Firearms Used in the Experiment

Two flintlock shoulder-fired smoothbore firearms were used in the live-fire validation experiment. One British Pattern 1756 Long Land musket, aka “Brown Bess,” in .76-caliber, represented the standard British infantry firearm used in the American Revolution (Figure 3). The Pattern 1756 and the Pattern 1769 Short Land musket were what was being carried by British enlisted men during the war. The major difference between the two arms was that the Pattern 1769 barrel was 4” shorter than the Pattern 1756.[18] The Brown Bess was used in all but one experiment. The other shoulder-fired arm was a high-quality replica of a circa 1650 English lock musket (Figure 4). It was used to fire at a wood panel meant to duplicate a sheathing panel hit by four balls during a raid by Native American warriors on the town of Billerica, Massachusetts on August 15, 1695.

The experimental firing was conducted over a two-day period, December 12 and 13, 2023 at the Whitinsville Fish and Game Club in Douglas, Massachusetts (Figure 5). The weather conditions were clear and cold with temperatures ranging from lows in the 20 degrees Fahrenheit to the mid-40 degrees Fahrenheit on both days.

Figure 3. Reproduction British Pattern 1756 Long Land Musket, barrel length 46", overall length 62 5/8", .76-inch bore**.**

Figure 4. Reproduction Circa 1650 English Lock Musket, barrel length 44", overall length 59 1/4", .77-inch bore.

Figure 5. Jay Waller preparing to fire the Pattern 1756 Long Land musket that was used during the live-fire shooting.

Firing Range

For this study, a wood target frame and large cable spool were set between 30 and 16 feet from the shooting bench. The larger distance approximated British regulars shooting positions as postulated during the shooting incident reconstruction study of the Jason Russell house. The shorter range is based on historic accounts of the mortal wounding of James Hayward on the afternoon of April 19, 1775. The range backstop is an earthen berm about 7 feet high. The berm was built with local soils that contain a significant amount of small pebble-sized local limestone and other rock.

Bullets passing through the target media embedded in the berm. To expedite bullet recovery, cardboard sheets were placed over the berm and then a blue plastic tarp was placed over the cardboard. The projectiles passed through a target, then the tarp and cardboard leaving clear impact marks. After each firing a metal detector sweep of the backstop was conducted to expedite the locating of the fired projectile. This setup gave the metal detector operators a locale where they could begin to detect and recover the balls after each shot. The berm is full of impact damaged modern bullets, mostly small caliber. The detectorist dug out the soil, passed it through a ¼ inch screen, discarded the modern lead, then replaced the soil, cardboard, and tarp after each shot. The bullet hole in the tarp was circled with a Sharpie and labeled so it would not be confused with subsequent shots.

Joel Bohy acted as range safety officer, but all shooting team participants were vigilant during the live-fire and checked on each other to ensure everyone was at a safe distance from the shooter and was wearing hearing and eye protection.

When the fired weapon was declared safe, the gun was removed from the shooting area and a bullet recovery team proceeded down range to recover the projectile. When a flintlock hang fire or "flash in the pan" occurred, the weapon was held in place for a count of 30 seconds, the pan cleaned and re-primed, then an attempt made to fire the weapon again. The range was declared clear only when the weapon was successfully discharged. Misfires or failure of the flint to spark when it struck the hammer or frizzen occurred on four occasions. In one case the flint was replaced. Each of the four misfires were subsequently successfully discharged.

Black Gunpowder Propellant

In this study, we used Swiss FFg black gunpowder as the priming and propellant charge in all weapons. Dodd[19] defines black powder as:

> "Black powder, by its very nature, is a true explosive. The smallest of sparks is sufficient to effect ignition. On ignition, a large quantity of bluish-grey smoke is generated and a characteristic sulfurous residue is deposited on both the weapon and the shooting hand. The Chinese are credited with its discovery and the discovery of the explosive properties of the mixture of substances we know as traditional gun powder — sulfur, charcoal, and saltpeter (potassium nitrate). It is suggested that gun powder may have been used in the manufacture of fireworks well before its application to firearms and warfare. Only the manufacturing process has been refined over time."

The origin of black gunpowder is still debated in academic circles, but it is largely agreed to have originated in China in the eleventh century and spread to Europe by the late thirteenth or early fourteenth centuries.[20] The first black powder was hand mixed and is referred to as serpentine powder. The black gunpowder used in this study is much more refined and is referred to as corned gunpowder. Corning, the wetting of the dry mixture, stamping, and glazing, as well as other manufacturing processes, began in the mid-1400s and largely supplanted serpentine powders by about 1550. The corning process was refined over time, but for all practical purposes corned black gunpowder was the only type used in the New World after the mid-1500s.[21] The Swiss® brand corned black gunpowder used in our experiments is considered to be among the best at producing reliable and replicable results in comparisons with other black gun powders and black powder substitutes manufactured today for sporting purposes.[22]

Historically, the amount of black gunpowder used in various weapons in the eighteenth and early nineteenth centuries varied substantially. We chose to use a 110-grain black powder charge in the .76-caliber gun including the priming charge as it most closely approximates and is consistent with known charges in surviving Revolutionary War cartridges as well as the fact that Swiss powder is probably more consistent than the powder of the 1770s. Our powder measures showed only a 1.5 grain (0.1-gram) variation in weight among any given charge size used.

Lead Spherical Balls Used in the Experiment

Information on the diameter and weight of Revolutionary War musket and fowling piece balls comes largely from the archaeological record. As a part of our study, we recorded the data from all known balls found that relate to April 19, as well as a study sample of British musket balls found on other Revolutionary War sites.

The spherical balls used in the live-fire experiment are commercially cast soft lead bullets (Figure 6). A sample of the balls were weighed, and the diameter measured during the preparation work. The experimental spherical ball weights show a minimum of 1.5 grain (0.1-gram) to a maximum of 4.6 grain (0.3-gram) weight variation. The measured nominal .69-inch ball diameters also showed very little variation, being about 0.001 to 0.003-inch among all the balls measured. They have far less variation in weight and diameter than any of the published historical ball diameters or archaeological specimens reported. The balls are less than bore size. Typically, balls were less than bore-sized to allow ease of loading, especially after multiple rounds were fired which caused black powder fouling in the bore. The common term for this is windage.

Figure 6. Lead balls used during the live-fire events.

Live-Fire Validation Study

To further test our assumptions about the bullet holes in the Jason Russell house and other extant period structures, replica exterior wall sections and interior wood panel wall sections were constructed for the live-fire testing. The materials used in the replica construction were original eighteenth century salvaged materials from colonial building demolitions. The nails used in the replica were salvaged hand wrought iron square nails. We had one original paneling board, one interior shutter, an exterior wall section with sheathing and clapboard, and one wall section with plaster, lath, sheathing, and clapboard. We also fired shots into human tissue simulant (see Tissue Simulant section).

The British 1756 Long Land Pattern musket, .76-caliber, was fired 20 times using a 110-grain charge with a paper-patched .69-inch ball. Three of those shots were test firings used to calibrate the camera. No velocity data was recorded for the test shots. The muzzle velocity ranged from 729 to 971 f/s for the remaining 17 shots. Two of the three test shot balls were recovered as were nine of the targeted shot.

Table 1. Recorded Velocity of Shots Fired During the Validation Study

Building or Object	Shot Number	Velocity, ft. per sec.	Velocity meters per sec.
Elisha Jones	1	888	237.1
Elisha Jones	2	815	248.4
Powder horn 1	1	833	253.9
Powder horn 2, graze	1	795	242.3
Powder horn 2, hit	2	856	260.9
Wall section 1 & panel	1	778	221.2
Wall section 1 & panel	2	760	231.6
House interior panel	1	853	259.9
House interior panel	2	971	295.9
Plastered wall section	1	888	270.6
Plastered wall section	2	906	276.1
Shutter	1	729	222.1
Shutter	2	880	268.2
Shutter	3	807	245.9
Shutter	4	905	275.8
Shutter	5	648	197.5

The circa 1650 English lock musket bore was .77-caliber. The ball used was .715-inch in diameter and weighed 35.52 grains (548.1 grams). The black powder charge was 120 grains. The velocity was recorded for the first two shots before the camera malfunctioned. Those two shots had recorded velocities of 930 and 935 f/s. Three of the balls were recovered.

Tissue Simulant Used in the Validation Study

Tissue simulants are materials that approximate the density of human tissue and approximate the penetration resistance of soft tissue.[23] Bullets fired into tissue simulants create a temporary and a permanent wound cavity that reasonably mimics actual wound trauma.[24] The temporary cavity can be observed using high-speed videography. The permanent cavity is what remains after the bullet passes through or is captured in the tissue simulant. A variety of studies demonstrate that tissue simulants meeting the standard BB penetration test achieve dynamic equivalence which can then be used to model wound trauma.[25] When a spherical ball enters the tissue simulant at a given velocity the gelatin begins to deform as a response to strain forces acting upon it. The gelatin deforms elastically until it reaches a critical point where it ruptures and then rebounds to near its original position. The strain forces caused by the bullet diameter, mass, and velocity create an elastic response in the gelatin that creates a wound track or cavity that expands with the initial strain and then contracts, leaving a visible but small wound track.

The live-fire experiment used Clear Ballistic® gelatin obtained from Clear Ballistics®. Clear Ballistic gelatin meets the FBI and NATO protocols for testing terminal ballistics of human tissue simulants. The protocol standard states that an acceptable calibrated gelatin must have a steel BB (.177 inch or 4.5mm in diameter) shot at 590 f/s (180 m/s) at 10 feet (3.04m) come to rest between 1.73 and 1.8 inches (4.4 and 4.6cm) into the gelatin.

A Clear Ballistics block, 6x6 inches square and 16 inches long was used for the powder horn shots. The block was placed on a wooden cable spool covered with 2 ½ inch thick foam pads. A roughly 6x6 inch square of cloth, meant to simulate the thickness and weight of average colonial era clothing, was placed on the front of the block.

The cloth squares were made up of wool cloth followed by a piece of serge to represent a coat and lining. Behind these was another piece of cloth and a piece of serge to represent a waistcoat and lining. The final piece of cloth was a square of linen representing a shirt. The cloth was replica fabric that is the same weight and weave of known historic cloth constructed of similar materials.[26]

A Clear Ballistics bust in the form of synthetic bone skull filled with synthetic blood, lower jaw, spinal column, and clavicles embedded in ballistic gelatin that was cast as a face, neck, and upper shoulders was used for one shot. The shot was an attempt to replicate the wound suffered by John Robbins at Lexington Green on the morning of April 19.

Ball Penetration and Deformation

The dynamics of bullet penetration in any media are complex and dependent on velocity at the time of impact, the density of the media it strikes, and drag or resistance on the bullet during flight. Miller and Bailey's study[27] of drag drawn from eighteenth and nineteenth cannon firing sources demonstrated that with the development of the 1868 Bashforth chronographic instrument, reasonably accurate velocity and drag measurements were attainable. They also found the earlier ballistic pendulums (ca. 1787 and ca. 1839) were less accurate than the Bashforth chronograph, but still produced reasonable data. Using modern data and mathematical formulae they created drag models for spheres ranging in velocity from Mach 0.3 to Mach 2.0. Their basic research is incorporated into the ballistic models employed in this study.

Likewise, bullet deformation is dependent on the same issues. MacPherson[28] studied and modeled bullet penetration as related to incapacitation from wound trauma. Bullet penetration in any substance, be it soil, wet or dry wood, or human tissue, is dependent on several factors including the energy it has when it strikes a substance. This is kinetic energy, and here we express it as foot/pounds (ft-lbs). A soft lead bullet traveling at a velocity has mass (weight), speed, and stored but dissipating energy as it fights resistance or drag. The object or media the bullet strikes, if soft, transfers the kinetic energy of the bullet in the form of heat. If hard, the bullet is deformed to some degree or another as a function of the laws of thermodynamics. The force that results in bullet deformation is simply Newton's Third Law of Motion, for every action there is an equal and opposite reaction. There is not an absolute direct correlation to bullet deformation since kinetic energy and damage is not due directly to energy absorption, but to the amount of force per area on the bullet and media. Bullets behave according to physical laws, and by knowing the velocity, mass (weight), and other variables, bullet deformation and penetration can be mathematically modelled.[29] Modern ballistic calculators take these variables into account when calculating muzzle velocity, changes in velocity over time, air resistance (drag), and gravity to determine bullet speed loss over distance and drop from the angle of the firearm muzzle relative to the ground surface.

In penetration studies the terms low and high-velocity have specific definitions. Low-velocity is considered to be a bullet traveling at 300 f/s or less, while high-velocity is considered to be a bullet traveling at 600 f/s or more.[30] For all practical purposes all charges fired in the arms in this experiment achieved high-velocity as used in penetration and wound trauma studies.

Bullet penetration and expansion or deformation is modelled using the principles of fluid dynamics. Bullets expand more in higher density fluids and less in lower density fluids. Lower density fluids include water, tissue, and tissue simulants. Experiments have shown that bullets penetrate and expand or deform in consistent ways in these lower density situations.[31]

Bullets yield or deform in response to the force applied on them. A ball striking a hard strong solid (e.g. rock, hard woods, etc.) will deform at relatively low velocities because the hard and rigid surface produces large forces on the bullet.[32] The diameter of the bullet and its mass (weight, usually expressed as sectional density) is another factor in the amount of deformation that occurs when a ball strikes a hard or rigid surface. Pure or dead soft lead (not pure in the chemical sense, but with impurities present as such low levels as to not be significant) is very ductile and deforms significantly based on static loading as confirmed in experiments using spherical balls and black powder loads.[33] The experiments show that lead spherical balls show slight deformation at about 690 f/s velocity and increase accordingly at higher velocities when fired into soft fluids like tissue or water.

Lucien Haag[34] conducted an experiment firing lead spherical balls from modern cartridge pistols and rifles using controlled black powder charges. He fired each shot into a water tank at velocities ranging from 360 f/s to 1026 f/s for .45-inch balls in a pistol and ranging from 1049 f/s to 1529 f/s for .45-inch balls fired from a rifle. His investigation found the higher the velocity the greater the deformation. His lower velocity impacts ranging from 630 f/s to 1026 f/s had virtually no deformation while rounds fired above 1049 f/s to 1138 f/s showed some slight flattening. Recovered balls fired between 1281 and 1336 f/s were flattened to nearly half the diameter, while the round fired at 1529 f/s was nearly completely flattened. Haag's experiments largely confirm MacPherson's previously discussed work.

One observation we have made regarding ball deformation is a result of the loading process for a smoothbore musket. When the ball is rammed down on the powder charge it may become slightly elliptical. This deformation appears to be a function of the force applied to the ramrod during the loading procedure. We have observed that balls striking soft wood media often have a difference in minor and maximum axis from a few thousandths of an inch to 1/10 of an inch. In part this may be a function related to the amount of fouling in a bore and the density of the media which the ball strikes. Banding or slight flattening of the ball where it comes into contact with the musket barrel is a common occurrence with an increased ramming force as is the presence of a ramrod mark or depression on the ball's surface.

Bullet-Struck Architectural Elements Validation Results

Test Shots

Three test shots were fired with the reproduction 1756 Pattern Long Land musket to calibrate the camera to later be able to calculate ball velocities.

Test shot 1- Ball not recovered.

Test shot 2 - Ball recovered in berm. High-velocity impact damage due to hitting a rock. The ball weighed 30.77 grams/474.8 grains. It had a loss of 1.13 grams/23.66 grains.

Test shot 3 - Ball recovered in berm. The ramrod mark is present, and it is a low-velocity impact with almost no damage. The ball weighed 31.92 grams/492.6 grains with a loss of .38 grams/ 6 grains.

Wall Section 1, Clapboard Siding, Sheathing, and Interior Panel

Wall section 1 was set up to simulate a bullet hole recorded in the Jason Russell house upstairs parlor over the kitchen (Figures 7, 8). There we found a bullet hole in the exterior wall sheathing (the exterior clapboard was replaced during restoration work) that was aligned with a bullet hole in the interior wall panel across the room. There was a bullet strike on the underside of the attic flooring that also aligned with the shot. That strike did not penetrate the wood flooring, but a lead smear is present suggesting the bullet had reached its terminal velocity after passing through the clapboard siding, wall sheathing and interior paneling, and the interior wall panel across the room.

We set wall section 1 30 feet (9.8 meters) from the shooter with the interior wall 15 feet (3 meters) from the wall section to simulate the kitchen upstairs parlor wall shot based on the hypotenuse of the shot angle (Figure 9). Two shots were fired and hit the targets passing through all four layers of wood (Figures 9, 10, 11, 12).

Shot 1 passed through clapboard, sheathing, interior wall panel and interior wall panel across the room. It was recovered in the berm at a depth of 10 inches (25.4cm). The ball struck rock and there is high-velocity impact damage to the bullet. The muzzle velocity was 726 f/s (721.28 m/s) at the time it struck the clapboard siding. The ball weighed 30.66 grams/473.1 grains. Weight loss is 1.64 grams/25.36 grains. The ball hole in the clapboard is circular and is .70-inch in diameter. The holes in the clapboard and interior wall panel tested positive for lead residue when subjected to the presumptive lead test (Figures 13, 14, 15, 16, 17).

Shot 2 passed through clapboard, sheathing, interior panel and interior wall panel across the room. It was recovered in the berm at a depth of 8 inches (20.32cm). The ball struck rock and there is high-velocity impact damage to the bullet. The muzzle velocity was 760 f/s (231.6 m/s) at the time it struck the clapboard siding. The ball weighed 31.97 grams/491.8 grains. Weight loss is .33 grams/6.66 grains. The ball hole in the clapboard is circular and is .70-inch in diameter.

Figure 7. The Jason Russell house, home of the Arlington Historical Society.

Figure 8. A bullet exit hole in the interior wall paneling of the Jason Russell house upstairs parlor. The laser dot is aligned on a trajectory rod in a bullet hole in the interior paneling across the room. There is little doubt that the wall panel hole and the interior wall paneling hole across the room originated with the same shot.

Figure 9. Wall 1 and interior paneling setup prior to shooting.

Figure 10. Still frame from the high-speed video showing wood splintering as the ball exits Wall Section 1.

Figure 11. Wall 1, shots 1 and 2 entry holes in the clapboard siding.

Figure 12. Wall 1 paneling exit holes for shots 1 and 2. Note the splintering and loss of wood around the holes as well as how closely spaced the bullet holes are.

Figure 13. Positive presumptive lead test on the Wall 1, shot 1. The hole was swabbed on the interior. The paint is modern latex.

Figure 14. Joel Bohy and Douglas Scott discussing the trajectory angle on a ball strike on an interior wall panel of the Jason Russell house downstairs parlor.

Figure 15. Interior wall panel for Wall 1 placed 15 feet (3 meters) from the wall and paneling showing entrance holes for shots 1 and 2. Note the wide spacing between the two shots compared to the comparable holes in Wall 1 clapboard. This is due to the effect of media causing the balls to deflect in their flight.

Figure 16. A positive presumptive lead test on the interior panel. This panel was never painted.

Figure 17. Exit holes on the interior wall paneling of Wall 1.

Wall Section 2, Clapboard Siding and Sheathing

Wall section 2 consisted of clapboard siding and sheathing meant to simulate the wall of the Elisha Jones shed (Figures 18, 19) that was struck by a ball on April 19. The live-fire experiment was conducted to validate our assumptions that the bullet holes in the Elisha Jones shed and in the attic of the Jason Russell House are consistent with spherical bullet strikes and their associated damage. We used a replica wall section consisting of clapboard and sheathing nailed to studs on either side (Figure 20). The materials used in the replica construction were original eighteenth century salvaged materials from colonial building demolitions. The nails used in the replica were salvaged hand-wrought iron square nails.

We fired two shots from a reproduction British Pattern 1756 Long Land .76-caliber musket using a 110-grain black powder charge with a .69-inch (17.52 mm) diameter lead ball from a distance of 30 feet (approximately 9.14 meters) from the wall section. The shots were fired from a clean bore. Both shots struck and penetrated the wall section leaving clean nearly circular holes, passing through the sheathing, and then embedding themselves in the berm backstop. Neither ball was recovered.

Both balls passed through the exterior clapboard and sheathing (Figures 21, 22). The first ball had a recorded velocity of 778 f/s (237.13 M/s) as it struck the clapboard and ball 2 had a recorded velocity of 815 f/s (248.4 m/s) as it struck. The first bullet hole had a minor axis of .634-inch (16.1 mm) and a major axis of .683-inch (17.3 mm). The second bullet hole had a minor axis of .62-inch (15.9 mm) and a major axis of .694-inch (17.6 mm). Shot 1 struck the panel near a joint between two pieces of sheathing which splintered and left a large blowout where the ball exited, mimicking the hole in the Elisha Jones shed. Both balls embedded themselves in the backstop berm.

Based upon our live-fire ballistics studies, the study of the Jason Russell house in Arlington and the Elisha Jones shed, we believe the physical traits observed on the hole in the Elisha Jones shed are consistent with other documented April 19 bullet holes.

Figure 18. The Elisha Jones shed currently attached to the original house. The bullet strike is to the immediate right of the window in the center of the image.

Figure 19. The bullet struck a sheathing feather edge joint on the Elisha Jones shed interior wall.

Figure 20. Clapboard and sheathing setup for Wall 2 to replicate the Jason Russell house attic and the Elisha Jones shed.

Figure 21. Ball strikes in Wall 2.

Figure 22. Wood splintering around the bullet holes in Wall 2. Note the extreme splintering around the lower hole near the feather edge joint which nearly duplicates that found on the interior of the Elisha Jones shed sheathing.

Wall Section 3, Wall and Plaster Panel

Wall section 3 was a section of interior wall panel with lath and plaster on the opposite side (Figures 23, 24). This wall section simulates the interior lower parlor wall of the Jason Russell house and assumes the bullets either passed through an open window or through glass panes. Two shots were fired at the interior panel and plaster wall section. Both balls were recovered. The first ball struck the panel at 888 f/s (270.6 m/s) and the second at 906 f/s (276.1 m/s). Both passed through the interior wall panel and the lath and plaster (Figures 25, 26, 27).

Wall and Plaster shot 1 was recovered buried about 10 inches in the berm. The bullet exhibits low to moderate impact damage from striking the rock-strewn earthen backstop. The bullet weighed 31.58 grams/487.6 grains for a loss of .72 grams/10.86 grains. The bullet hole has a minor axis of .617-inch (15.6 mm) and major axis of .693-inch (17.6 mm).

Wall and Plaster shot 2 was recovered about 4 inches in the berm. It struck rock and had high-velocity impact damage. The bullet weighed 31.06 grams/479.4 grains for a weight loss of 1.24 grams/19.06 grains. The bullet hole has a minor axis of .645-inch (16.4 mm) and a major axis of .744-inch (18.9 mm).

Exit damage on the plaster from both shots were semi-circular in shape. The plaster was blown away, largely as dust, with oval to round holes left in the lath and the plaster.

Figure 23. Jay Waller stands behind the interior panel side of Wall Section 3 prior to shooting.

Figure 24. The colonial-era plaster portion of Wall section 3 prior to shooting.

Figure 25. Still frame from the high-speed video showing the plaster dust and lath splinters resulting from the ball passing through Wall Section 3.

Figure 26. Exit hole around the plaster of Wall Section 3, Shot 1.

Figure 27. Detail of the exit hole in the plaster of Wall Section 3.

Panel Shots

The panel was used to simulate bullet strikes in a door panel or an interior wall panel where the bullet may have struck a door as at the Buckman Tavern or gone through an open window or a glass windowpane striking an interior wall panel, as recorded in the lower parlor of the Jason Russell house. Two shots were fired but neither ball was recovered.

Panel shot 1 – The bullet struck the panel at 853 f/s (259.9 m/s). The hole in the interior wall panel is .653-inch (16.5 mm) in the minor axis and .689-inch (17.5 mm) in the major axis.

Panel shot 2 – The bullet struck the panel at 971 f/s (295.9 m/s). The hole in the interior wall panel is .538-inch (13.6 mm) in the minor axis and .672-inch (17 mm) in the major axis.

Damage from both shots to the interior wall panel/door panel on their backsides consisted of large area of wood loss and significant splintering exhibited at the exit sites. These shots mimic those observed in the Buckman Tavern door panel and the interior wall panel at the Jason Russell house.

Shutter Shots

A salvaged indoor shutter panel was shot five times to simulate bullet holes in preserved April 19 bullet-damaged shutter panels saved from colonial-era homes that have been demolished. The original panels are part of the Arlington Historical Society collection (Figure 28). Bullets from Shots 1 and 3 were recovered. The five shots (Figure 29) have recorded velocities of Shot 1 729 f/s (221 m/s), Shot 2 880 f/s (268.2 m/s), Shot 3 807 f/s (245.9 m/s), Shot 4 905 f/s (275.8 m/s), and Shot 5 648 f/s (197.5 m/s). The bullet from shot 1 weighs 30.97 grams/477.9 grains with a weight loss of 1.33 grams/20.56 grains. The bullet hole has a minor axis of .688-inch (17.47 mm) and a major axis of .732-inch (18.6 mm). Shot 2 was not recovered but the bullet hole has a major axis of .699-inch (17.7 mm). The minor axis could not be measured as the bullet struck the shutter edge leaving an open hole. Shot 3 was recovered and weighs 31.88 grams/ 492.1 grains. Weight loss is .42 grams/6.36 grains. Shot 4 was not recovered but the bullet hole has a minor axis of .660-inch (16.7 mm) and a major axis of .738-inch (18.7 mm). Shot 5 was not recovered but the bullet hole has a minor axis of .682-inch (17.3 mm) and a major axis of .721 inch (18.3 mm). Both recovered bullets struck rock in the backstop, causing high-velocity impact damage.

The back of the shutter shows extensive wood loss and splintering around each of the bullet impact holes (Figure 30). Both the entrance holes and the exit holes as well as the bullet strike locations on the shutter mimic the holes observed and recorded on the original bullet-struck shutters in the Arlington Historical Society collection.

Figure 28. Bullet-struck interior shutters removed from their original context and now part of the Arlington Historical Society collection.

Figure 29. Five bullet strikes in a salvaged indoor window shutter that replicates bullet strikes observed in surviving shutters in the Arlington Historical Society collection.

Figure 30. Exit holes showing the wood splintering after the ball passed through the shutter.

James Hayward Bullet-Struck Powder Horn Validation Study

James Hayward (1750-1775) is mentioned in many historical publications as a 25-year-old schoolmaster from Acton. Although he may have been, a search of the Acton town records from 1770-75 do not mention him nor show him being paid as a teacher.[35] Hayward was a member of Lieutenant Simon Hunt's Acton militia company who marched on the April 19 alarm; he was at the North Bridge in Concord and fought during the British retreat.

In the early afternoon of April 19, he purportedly stopped at the Ebenezer Fiske house, approximately a mile west of Lexington center, for a drink of water from the well. An encounter with a British soldier followed with the soldier being killed and Hayward being mortally wounded. An account from someone who was alive on April 19 is from Rebekah Fiske, daughter-in-law of Ebenezer Fiske, who lived at the Fiske house in 1775 where the incident took place, and in 1827 Rebekah told her story. She had vacated her house with her elderly father-in-law to a neighbor's house to wait out the battle, and *"After the rattle of musketry had grown somewhat weaker from distance, and my heart became more relieved of its apprehensions, I resolved to return home. But what an altered scene began to present itself, as I approached the house - garden walls thrown down - my flowers trampled upon - earth and herbage covered with the marks of hurried footsteps. The house had been broken open, and on the doorstep - awful spectacle — there lay a British soldier dead, on his face, though yet warm, in his blood, which was still trickling from a bullet-hole though his vitals. His bosom and his pockets were stuffed with my effects, which he had been pillaging, having broken into the house through a window. On entering my front room, I was horror- struck. Three mangled soldiers lay groaning on the floor and weltering in their blood, which had gathered in large puddles about them. "Beat out my brains, I beg of you," cried one of them, a young Briton, who was dreadfully pierced with bullets, through almost every part of his body, "and relieve me from this agony." You will die soon enough, said I, with a revengeful pique. A grim Irishman, shot through the jaws, lay beside him, who mingled his groans of desperation with curses on the villain who had so horridly wounded him. The third was a young American, employing his dying breath in prayer. A bullet had passed through his body, taking off in its course the lower part of his powder-horn. The name of this youthful patriot was J. Haywood* [sic Hayward], *of Acton. His father came and carried his body home; it now lies in Acton graveyard. These were the circumstances of his death: being ardent and close in the pursuit, he stopped a moment at our well to slake his thirst. Turning from the well, his eye unexpectedly caught that of the Briton, whom I saw lying dead on the door-step, just coming from the house with his plunder. They were about a rod from each other. The Briton knew it was death for him to turn, and the American scorned to shrink. A moment of awful suspense ensued—when both simultaneously levelled their muskets at each other's heart, fired, and fell on their faces together. My husband drew the two Britons off on a sled, and buried them in one of our pastures, where they now lie, beneath a pine tree which has grown up out of their grave. The Irishman was the only one of the three that survived."*[36] She was there soon after the incident occurred and is the closest witness we have to the event.

Hayward's bullet-struck horn (Figure 31) became an important reminder of the fighting on April 19, and in 1835, the statesman Edward Everett was in Lexington giving an oration for the anniversary. One of the important objects brought out was Hayward's horn, *"Among the interesting mementos of the 19th of April, 1775, to which the attention of the company assembled at Lexington on Monday last, was the Powder Horn, worn by Mr. James Hayward of Acton, who was killed in Lexington, during the pursuit, and which was perforated by the ball, that entered Mr. Hayward's body. Mr. [Edward] Everett observed that he had been requested by the owner of this interesting relic, Mr. Stevens Hayward of Acton, (the nephew of the person, by whom it was worn on the 19th of April, 75) to exhibit it to the company, and to mention its history."*[37]

In 1870 an article appeared in the newspaper about the Hayward horn, which is a little confusing, but it answers some questions *"Acton, by the bequest of Edward Everett, is now in the possession of the powder-horn worn by James Hayward, who was killed at Lexington while pursuing the British from Concord. Mr. Everett, while it was in his possession, had it bound with silver, and a silver neck chain attached."*[38] An 1851 engraving of the horn in *Gleason's Pictorial Drawing-Room Companion* shows the horn with the silver-bound edge on the plug, a silver escutcheon, and chain, so it was at least done prior to the dedication of the monument in that year. The article may be confusing Edward Everett with Stevens Hayward, the grandnephew of James Hayward, who owned the horn until he died in 1868. Everett died in 1865, a few years prior to Stevens Hayward. Also in 1870, the original gravestones of Captain Isaac Davis, Private Abner Hosmer, as well as James Hayward were moved from Woodlawn cemetery and placed on the grass slope around the 1851 monument *"The tombstones erected to the memory of those named in the above transcription* [Davis, Hosmer, and Hayward] *have just been taken from the old burying ground, and will to-day be placed in the embankment at the foot of the memorial."*[39]

Reverend Artemus Bowers Muzzey, a minister who had been born in Lexington, and was at the 1835 Patriot's Day ceremony where he heard Edward Everett's oration saw the Hayward horn, *"I often heard from my grandfather the history of the encounter between James Hayward of Acton and a British soldier at a house by the foot of Fiske hill…I recalled the memorable well with new interest April 19, 1835. It was then, when the remains of the martyr soldiers were placed under the monument at Lexington, that Edward Everett, the orator of the day, exhibited the powder-horn worn by Hayward in that deadly encounter. I saw the hole made by the bullet which killed him, and was glad to learn recently that this venerated relic was bequeathed by Mr. Everett* [Stevens Hayward] *to the town of Acton, and is now deposited in that place."*[40]

Hayward's horn continued to be displayed and even removed from the town to share with others. In April 1887, Luther Conant, a state politician from Acton, brought it to Boston, *"Mr. Luther Conant of the Third Middlesex District has exhibited recently to his associates in the House a Revolutionary relic of rare historic merit. It is the powder horn worn by James Hayward of Acton, who was killed at Lexington on the 19th of April, 1775….The horn is the property of the town of Acton and his highly prized."*[41]

The horn has been on display in the back of the Acton Memorial Library for many years. In 2013, it was borrowed by the Concord Museum for an exhibition titled "April 19, 1775: The Shot Heard Round' the World." After that exhibit, it went back to the Acton Memorial Library until it was borrowed by the Museum of the American Revolution in Philadelphia and was on exhibit there until returned to Acton in the fall of 2023.

The Hayward horn is left-handed, and it would have been worn partially on his left/back side, although it could have swung down in front of his body when the shooting incident occurred. A ball passing through the horn may well have caused horrific wounds to his left back side or abdomen. The entrance hole is .70-inch diameter on the surviving horn and is consistent with the diameter of a British musket ball. There is a small piece of horn missing from the entrance hole located near the end plug, and there are a few small cracks radiating from the central bullet hole. The exit hole of the horn is blown out, taking the thicker shards of horn away and leaving a large, jagged hole. The original pine plug was probably blown out of the back of the horn when it was hit by the British ball and a later plug was installed by Stevens Hayward. It has a silver band around the edge of the horn and plug which is engraved on the plug side *"Presented to the town of Acton by Hon Stevens Hayward."* The slightly convex plug has an oval silver escutcheon marked *"James Hayward/of Acton/was killed in Lexington/on the 19th of April, 1775,/by a ball which passed through his Powder Horn/into his body*."[42] The horn is in the collection of the Acton Memorial Library.

Examination and documentation of the powder horn provided us information on which to base a shooting incident reconstruction. According to historical accounts, the event revolved around a well. The Rebekah Fiske account mentioned above states that the shooting incident was probably about 1 rod (16.5 feet, or 5 meters) from the house. We chose to use that distance for our live-fire shooting incident reconstruction. The reconstruction used two plain antique powder horns. Each horn was placed in front of a human tissue simulant, ballistic gelatin block, and each horn was shot individually.

Powder Horn 1

The horn is an antique colonial-era powder horn. The horn was placed in front of a human tissue simulant ballistic gelatin block that is 6 inches square and 16 inches long (Figure 32). Between the horn and gel block a square of layered cloth was placed to replicate a wool coat with a serge lining, a waistcoat and serge lining, and a linen shirt. Shot 1 ball was traveling at 833 f/s or 253.9 m/s when it struck the horn (Figures 33, 34, 35). The entrance hole is obvious. The ball caused the horn to shatter, breaking into large and small fragments. The wooden end plug which is fastened to the horn by hand-wrought cut brads was not dislodged. The horn body shows significant radiating fracture lines as well as loss of the horn body from the ball strike.

The high-speed video of the ball passing through the horn shows that it split into two pieces on the horn shards as it passed through the cloth and into the gelatin block. Bullet velocity was recorded as 833 f/s (253.9 m/s). The wound track or path the two pieces took is clear in the video and the ball fragments lost kinetic energy with the large piece (weighing 19.39 grams/299 grains) stopping 9 inches (22.8 cm) into the gelatin block. The smaller piece (weighing 12.7 grams/187.8 grains) stopped 7.5 inches (19 cm) into the gelatin. Both wound tracks contained fragments of cloth and horn shards weighing in total 3.1 grams (Figures 36, 37, 38). One ball fragment has cloth embedded in the ball edge as well as a horn shard piece (Figures 39, 40).

The two ball fragments weighed a total of 31.55 grams/486.9 grains. This is a total weight loss of only .075 grams/11.56 grains. This is not a substantial weight loss despite the extensive destruction of the horn and being split by the horn shards as it entered the gelatin block.

The horn was reconstructed from the fragments collected from around the target site. The shards from the wound track were not used in the reconstruction. The horn's bullet exit area (approximately 3 inches/7.5 cm by 1.5 inches/3.5 cm) could not be reconstructed due to extreme fragmentation of the horn into small shards, some of which were carried into the wound tracks (Figure 41).

Figure 31. The bullet-struck James Hayward powder horn on display at the Acton Historical Society.

Figure 32. Powder horn 1 ready to shoot. Note the cloth and ballistic gelatin block.

Figure 33. The ball, seen on the right is about to strike the horn.

Figure 34. The ball shatters the horn, is split in two, and the two wound tracks can be seen being started as the ball passes into the ballistic gelatin block.

Figure 35. The bullet pieces in the wound track and the shattered horn and cloth being pushed off the platform.

Figure 36. Horn shards and cloth fragments before removal from the ballistic gelatin wound track.

Figure 37. The split ball on the cloth square next to the holes they created passing through the cloth layers. The upper hole resulted from an earlier and unrelated live-fire experiment.

Figure 38. The split ball, cloth fragments and horn shards removed from the wound tracks in the ballistic gelatin. The cloth and horn fragments weighed 3.1 grams.

Figure 39. Photomicrograph of the edge of the split ball showing cloth fragments embedded in the lead.

Figure 40. Photomicrograph of a piece of horn embedded in the split ball body.

Figure 41. Powder horn 1 reconstructed along with the split ball, cloth, and horn shards taken from the wound track.

Powder Horn 2

A second colonial-era powder horn was also shot. It too was placed in front of the gelatin block with the cloth piece between the horn and the block (Figure 42). The ball of the first shot just grazed the horn creating a 1.25 x .75-inch (3 x 2 cm) hole on the horn's surface. The ball was traveling at 795 f/s or 242.3 m/s. The ball passed through the entire gelatin block (16 inches/40.6 cm) and was recovered in the berm. It weighs 31.67 grams/488.79 grains. The total weight loss is .63 grams/9.67 grains. The ball was examined under magnification and the surface exhibits cloth impressions where it passed through the cloth. Very small pieces of horn are also embedded in the ball surface.

The second shot passed through the horn leaving an entrance hole .5 x .75-inch (1.5 x 2 cm) in shape with an elliptical exit hole that is .75 x 1 inch (2 x 3 cm). The shot caused the horn to shatter into six large pieces and many smaller fragments. The end plug, which is fastened to the horn with wood plugs, was blown out (Figures 43, 44, 45). The ball was traveling at 856 f/s or 260.9 m/s when it hit the horn. The ball was recovered in the berm with fabric weave impressions and tiny bits of horn embedded in the ball surface (Figure 46). The ball weighs 31.22 grams/483.4 grains with a total weight loss of 1.08 grams/15.06 grains.

The horn was reconstructed with only a few small missing pieces (Figure 47). The graze hole for ball 1 and the entrance and exit hole for ball 2 are clearly visible. Like the first horn the second horn body shows significant radiating fracture lines as well as loss of the horn body from the ball strike.

Figure 42. Powder horn 2 set in position to be shot.

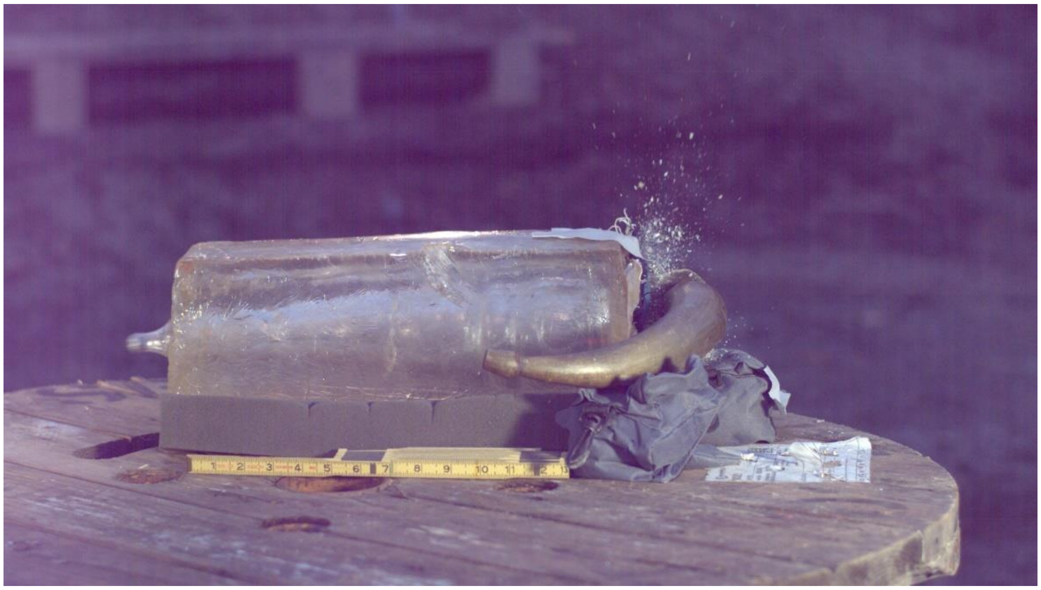

Figure 43. The ball exiting the ballistic gelatin block and powder horn 2 starting to shatter.

Figure 44. Powder horn 2 in the process of shattering after being hit by the ball. Note the cloth flying through the air, fragments of horn being dispersed, and the end plug being blown out of the horn.

Figure 45. The wound track of the powder horn 2 shot with a piece of wool yarn still dangling from the entrance hole.

Figure 46. Photomicrograph of the split ball surface showing fabric weave impressions from passing through the cloth.

Figure 47. The ball entry and exit holes in reconstructed powder horn 2. The ball that caused the damage is shown below the horn.

The original Hayward horn shows body loss and radiating fractures as a result of being struck by a ball. The old dry horns we used in the replication and validation experiment shattered and fractured when struck by the balls but they reasonably approximate the bullet damage seen on Hayward's horn. The wound effect seen in the shooting incident reconstruction study with the ball carrying cloth and horn shards into the wound is likely very similar to the wound James Hayward suffered when his horn was hit by the British ball. No doubt the horn shards entering his wound along with the ball were contributing factors to his death on April 19.

John Robbins Wound Study

Figure 48. Detail of Amos Doolittle Plate I showing Parker's militia dispersing while being fired on as they left Lexington Green (NY Public Library, digital collections).

One of the members of Captain John Parker's Lexington militia company wounded on Lexington Green (Figure 48) on the morning of April 19, 1775, was John Robbins. His name not only appears in the newspapers of the period and history books, but he was one of the men who wrote a deposition on April 24, 1775, for the Provincial Congress attesting to what happened that morning:

"I John Robins being of lawfull age, do Testify & say that on the nineteenth Inst. the Company under the Command of Capn. John Parker, being drawn up, (sometime before sun Rise) on the Green or Common, And, I being in the front Rank, there suddenly appear'd a Number of the Kings Troops, About a Thousand as I thought, at the distance of about 60, or 70 yards from us Hazzar[d]ing and on a quick pace toward us, with three officers in their front, on Horse Back and on full Gallop towards us, the foremost of which cryed, throw down your Arms ye Villains, ye Rebels, upon which said Company Disperseding. - The foremost of the three Officers orderd their Men, saying fire, by God fire, at which Moment we Received a very heavy & close fire from

them, at which Instant, being wounded I fell, Several of our men were shot Dead by one, Capn. Parkers men, I believe had not then fired a Gun and further the Deponant saith not –

John Robins"[43]

After April 19 and the Battle of Bunker Hill a few of the wounded men began to ask the state for help. Their wounds, in some cases, made them unable to work and make a living. Medical bills were also growing and with no income how could they pay the bills and provide for their families? Many of these petitions for a pension, or after December 1775 for lost and broken material, are in the collection of the Massachusetts State Archives spread through numerous volumes. The earliest petition for Robbins is from 1776. It gives a description of his wounds:

"To the Honorable the Colony Counsil & the Honorable the House of Representatives in general Court assembled

The Petition of John Robbins of Lexington Humbly Sheweth, That your Petitioner was on the memorable 19th of april 1775 most grievously wounded. by the Brittish Troops in Lexington, by a musket ball which passd by the left of the spine between his Shoulders through the length of his neck making its way through and most miserably Shattering his under jaw bone, by which unhappy Wound your Petitioner is so much hurted in the Muscles of his shoulder, that his Right arms is rendered almost useless to him in his Business and by the fracture of his under jaw the power of Mastecation is totally destroyed and by his, low Slop diet, weakness, and total loss of his right arm, and the running of his wound, his Situation is rendered truly Pitiable being unable to Contribute any thing to the Support of a wife and five small Children but is rather a Burden upon them, & has no Encouragement from his Surgeon of his being Materialy better He therefor is under the disagrable Necessity of begging relief & assistance of this Honrrable Court by a Pension or other wise as your Honors Great wisdom & compations may suggest, and your
Petitioner as in duty bound will Ever pray
Lexington 14th June 1776 John Robbins"[44]

Not only does the petition describe his ghastly wound, but he had a wife and five small children all under the age of 13 to support.[45] For the 1776 petition, Robbins is given a pension for the year:

"The Committee on the Petition of John Robbins have heard The Petitioner Examined his wounds considered his deplorable Circumstances and Report by way of Resolve----

In the House of Representatives Nov 4th 1776--Resolved that there be allowed and paid out of the Publick Trsy to and for the use of the Petitioner John Robbins the sum of thirteen Pounds six Shillings and Eight pence yearly untill the General Court Shall otherwise Order it, to Recompence him for hid sufferings by wounds which he recd on the 19th of Aprill 1775"

He submitted petitions with the same wording until 1778 when he has another addition to his family, a daughter named Hannah.[46] This time his petition also included a note from his doctor.

It seems his body was never going to recover from his awful bullet wound from the morning of April 19:

"To The honorable Council of the State of Massachusetts Bay. This Certificate humbly sheweth that the Bearer Mr John Robbins of Lexington receiv,d such a grevious Wound thro: the Muscles of his right shoulder Neck & Jaw Bone which last was miserably fractured: by which Wound the unhappy Man is yet so debilitated in his right shoulder that He is unable to perform but very little labor as Fatigue upon his small Farm for the support of a numerous Family of young Children and in the Opinion of the Subscriber who was his surgeon He is unhappily like to remain in such a weakned hopeless Condition during life and is a proper Object of the gracious Bounty of this State-----------

Watertown July 5th .1778 sign,d Marshall Spring

N.B. He was wounded in the Morning of the

19th of april 1775 at Lexington"[47]

Robbins continued to petition yearly for a pension through the war and did receive money from the state. The last listing found for him is in a newspaper article with a list of pensioners stating that a July 8, 1786 resolve of the courts placed him on a list of pensioners that the commonwealth felt could do garrison duty. He was to appear at the Commissary of Pensions for a revue.[48] After this date there does not seem to be any other info on John Robbins. But what about his wound?

John Robbin's petitions graphically describe the horrific wounds he suffered to his back, neck and mandible on Lexington Green, April 19, 1775. Could a single musket ball have done such extensive damage to cause him partial nerve damage in his arm and broken his jaw to the point of only being able to eat "low slop?" Or might he have exaggerated the effect of his wounds to obtain a larger compensation from a sympathetic audience?

Military surgeons in the late 18th and well into the 19th century described and commented on treating gunshot wounds in a variety of texts and treatises. A perusal of some of these texts as well as the pertinent sections of the Medical and Surgical History of the War of the Rebellion (Part One, Volume 2 and Part 2, Volume 2, 1875 and 1877 respectively) for wound effects of .69-caliber musket balls clearly demonstrate that these large lead balls could indeed inflict significant and lasting effects to hard and soft tissue as well as nerves. Once a ball enters the human body it can be deflected from a straight path through the tissue by any number of factors and exit the body after a torturous route. This is borne out by our recent live-fire studies of colonial-era weapons, particularly with the shooting of the Brown Bess muskets. We observed, using high-speed video recording, that a .69-caliber ball shot at a target 25 to 30 yards away had velocity and energy significant enough to pass through reproduction clothing and 32 inches of tissue simulant. That is the equivalent of the body mass of two people. The ball, on exiting the tissue simulant, still had enough velocity and energy to travel between 50 and 100 additional yards before reaching its terminal velocity.

John Robbins' pension account of his wounding provides additional clues as to why he suffered such extensive wounds. Robbins states he was in the front rank of the Parker's militiamen drawn up on Lexington Green. His account states the company started to disperse when the British regulars were ordered to fire. Assuming the accuracy of his account he may well have turned so that his back was partially toward the British line. On hearing the firing begin he may have instinctively ducked or bent forward so that the ball struck his upper right back near the spinal column. If slightly bent over, as is speculated, the ball could well have been deflected by muscle. Such deflection is consistent with the ball passing near the spinal column and traveling up the neck, shattering his mandible, and exiting the body. Robbins' right arm paralysis is consistent with bullet-caused nerve damage, as is the damage to his jaw that no longer allowed him to chew his food. His note that the wound was still "running" suggests that his wound had not fully healed, and he suffered from a residual infection. Perhaps some cloth bits or other foreign matter were still in the wound causing it to continue to fester and discharge up to at least 1776. He is lucky to have survived his wounds at all given the state of medical knowledge and treatment of the day.

The validation study employed a Clear Ballistics Loaded Ballistic Gel Bust. The busts are created using human tissue simulant gel and synthetic bone. The purpose of the product is for testing ballistics, weapons, and protection. The gelatin is made from high-quality, transparent, synthetic gelatin and offers the same mechanical properties as animal gelatin and contains a synthetic spinal column, mandible, and skull which is filled with synthetic blood.

The bust was placed on a platform with back area raised using crumpled plastic sheeting in order to simulate a person who is slightly bent over (Figure 49). The shooter used a faithful reproduction Pattern 1756 "Brown Bess" musket of .76-caliber and a spherical lead .69-inch ball weighing 33.5 grams.

Jay Waller, the shooter, fired the one and only shot at the gelatin bust from a bench rest position. The shot struck the gelatin bust at 845 f/s (256.5 m/s) in the right upper shoulder area. High-speed videography (Figures 50, 51, 52) shows the bullet passed through the shoulder, probably striking the flat part of the shoulder blade, if it had been present in the bust, passing up along the right side of the neck, then striking the lower jaw or mandible at the gonial angle (lower back edge of the mandible) shattering it into more than 30 pieces (Figure 53). The jaw broke at the center line into two large pieces and ten other smaller fragments which were used to reconstruct the jaw (Figure 54). The right condyle and ascending ramus were shattered. The many small synthetic bone pieces recovered in the gelatin are fragments of the gonial angle area that could not be completely reconstructed. The skull itself suffered extensive damage with the lower rim of the right eye orbit being fractured as well as most of the zygomatic arch. High-speed video shows the impact of the ball as it struck the jaw and passed through the gelatin. The video shows a fracture on the skull initiating in the sphenoid and temporal area and radiating upward into the right parietal area. The fracture is 5 inches (11 cm) long. Unfortunately, the ball was not recovered as it entered the berm outside of our target area and could not be found.

Figure 49. Joel Bohy positioning the bust and aligning the shot angle for the shooter.

Figure 50. The ball created a splash effect as it enters the gelatin bust.

Figure 51. The ball exiting the ballistic gelatin bust. Note the massive cavitation effect on the neck and lower jaw area.

Figure 52. The bust after the immediate cavitation ceased. The red areas are synthetic blood oozing from the fractured skull.

Figure 53. The synthetic skull and bone fragments removed from the gelatin bust.

Figure 54. The reconstructed skull and lower jaw. Note the mandible's gonial angle is missing, shattered into many small pieces by the ball as it struck the jaw.

Wounds to the lower jaw are not new, nor are studies to determine the effect of bullets to the jaw. A classic study by an army officer and physician in the early 20th century, Col. Louis LeGarde, observed that bullet wounds to the lower jaw were often accompanied by fracture of the ascending ramus and neck of the condyle as well as comminution of the bone. This, upon healing, caused anchylosis unless properly treated in time.[49] This early 20th century lower jaw bullet impact and effect to the face and bone is consistent with that described in Robbins petitions.

The high-speed videography clearly shows the ball's passage through the gelatin and the mandible being shattered into many small and some larger pieces. The skull also exhibits impact damage from the kinetic energy being dispersed as the ball passes through the gelatin. The lower eye orbit is shattered and cracks in the right parietal initiate quickly and continue up into the temporal area. The bullet path was photographed with an ersatz trajectory rod to show the bullet path. We believe this shot and its resulting damage to the mandible and skull is illustrative of the power of the British long land pattern musket's ability to incapacitate a foe. Whether the wound path and damage is entirely consistent with John Robbins' wound is a matter of conjecture, but it is likely close given the description of wounds in surviving documentary records.

1650 English Lock Musket Study

Four shots were fired from a reproduction circa 1650 English lock flintlock musket (Figure 55). The musket bore is .77-caliber and the balls fired were .715-inch (18.16 mm) in diameter. They weighed 35.52 grams/548.1 grains. The balls were fired into a salvaged early 18th century wood panel that simulated a late seventeenth century piece of sheathing that was stuck by balls during a Native American attack on the village of Billerica, Massachusetts in 1695 (Figure 56). Due to a camera failure data from the third and fourth shots was lost. The first shot struck the panel from a distance of 30 feet/9.5 meters at a velocity of 935 f/s (285 m/s). The ball was not recovered. For each shot the panel entrance hole was nearly circular (Figure 57). The back of the panel shows extensive wood loss and splintering around each of the bullet impact holes (Figure 58).

The second shot struck the panel at 930 f/s (283.4 m/s) and was recovered from the berm. The ball exhibits a ramrod mark and medium to high velocity impact damage from striking the earth and rock berm. The ball weighs 34.26 grams/528.8 grains with a total weight loss of 1.26 grams/19.3 grains. Velocity data could not be recorded for the third shot, but the ball was recovered from the berm. The ball exhibits extensive high-velocity damage from striking the earth and rock-filled berm. The ball weighs 34.03 grams/525.2 grains with a total weight loss of 1.49 grams/22.9 grains. Velocity data could not be recorded for the fourth shot but the ball was recovered from the berm. The ball exhibits extensive high-velocity damage from striking the earth and rock filled berm. The ball weighs 33.41 grams/515.5 grains with a total weight loss of 2.11 grams/32.6 grains.

Figure 55. Jay Waller prepares to fire the circa 1650 English lock musket.

Figure 56. Exit holes in sheathing from a house in Billerica that was shot by attacking Native American warriors in 1695. Billerica Historical Society collection.

Figure 57. Entrance holes in the panel board caused by the .715-inch balls fired from the 1650 English lock musket.

Figure 58. Exit holes in the panel caused by the .715-inch balls fired from the 1650 English lock musket.

Conclusions

In our first two live-fire studies, we focused on the muzzle velocity of Revolutionary War-era small arms. In this study, our focus was more on the velocity of a spherical ball as it struck an object, as well as the damage done to the objects in order to try to replicate the damage observed on surviving bullet-struck artifacts from the first day of the American Revolutions, April 19, 1775.

The December 2023 firearms live-fire experiment can be characterized as an unqualified success. The intent behind the investigation was to determine the external ballistic bullet performance of a British Pattern 1756 smoothbore musket on a specific series of targets. The general premise and research design that drove the experimental investigation was to document the fired ball performance in terms of strike velocity, penetration capability, and bullet deformation as it terminated its flight. This study not only recovered bullets fired at different media; tissue simulant and soil; it also used high-speed videography to determine initial strike velocity for each shot. The collected information was analyzed and compared to known and documented surviving bullet-struck artifacts.

Our data exhibits excellent correspondence with other ballistic performance models of Brown Bess muskets, further validating those models and allowing us to compare our data findings with various data sets. The shots fired at replica house walls, interior panels, window shutters, colonial powder horns, and a ballistic gelatin bust very closely duplicated the documented bullet strikes surviving from April 19, 1775.

The experimental effort also demonstrated, albeit with a small sample, that many cloth impressions on spherical balls originated from passing through clothing cloth. These data are only relevant to balls that are not patched.

The work we undertook was designed to aid archaeologists in gaining a better understanding of the potential information yields that can be gained from bullet analysis from archaeological sites. We have focused on one conflict zone, the British retreat route from Concord to Charlestown on April 19, 1775. The shooting incident live-fire study validated the external ballistics of the firearms and their penetrating power.

The validation study clearly demonstrates that the British Brown Bess musket had the capability to penetrate various media that is observed in the surviving architectural elements and objects. The study data is important information that expands and enhances our understanding of large caliber smoothbore musket performance and verifies their strike capability. The data also support and enhance the interpretations of the surviving bullet-struck artifacts for professional historians, archaeologists, and the public alike.

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[1] *Sacred Ground: Americans and Their Battlefields*, Edward Tabor Linenthal, 1991, University of Illinois Press, Urbana.

[2] *Archaeology by Experiment*, J. Coles, 1973, Hutchinson University Library, London, UK; Experimentation and Interpretation: *The Use of Experimental Archaeology in the Study of the Past*, D. C. E. Millson, 2011, Oxbow

Books, Oxford, UK; Experimental Archaeology, L. M. Shillito, E. Fairnell, and H. S. Williams, 2014, *Archaeology Anthropology Science*, Vol 7 1-2.

[3] Experimental Design and Experimental Inference in Stone Artifact Archaeology, Sam C. Lin, Zeljko Rezek, and Harold L. Dibble, 2018, *Journal of Archaeological Method and Theory* 25:663-688.

[4] Colonial Era Firearm Bullet Performance: A Live Fire Experimental Study for Archaeological Interpretation. Douglas D. Scott, Joel Bohy, Nathan Boor, Charles Haecker, William Rose, and Patrick Severts, 2017, https://Adademia.edu; Firearm Bullet Performance: Phase II, Live Fire Experimental Study for Archaeological Interpretation: Colonial Pistol, Colonial Fowler, Colonial Rifle, and a Civil War Rifled Musket, Douglas D. Scott, Joel Bohy, Nathan Boor, Charles Haecker, Peter Bleed, Patrick Severts, and William Lees, 2019, Found on Academia.edu.

[5] Ibid, 2017, 2019.

[6] *Shooting Incident Reconstruction*, Lucien Haag, 2006, Elsevier, Boston.

[7] Shooting Reconstruction vs Shooting Reenactment, D. H. Garrison, Jr, 1993, *Association of Firearm and Tool Mark Examiners Journal 25(2):125-127*; *Practical Analysis and Reconstruction of Shooting Incidents*, Edward E. Hueske, 2006, Taylor and Francis, New York.

[8] *Firearms, the Law, and Forensic Ballistics*, Tom Warlow, 2005, CRC Press, New York.

[9] Shot Penetration from Ballistic Data, B. N. Mattoo, 1969, *Journal of Forensic Sciences* 14(4):521-527; Blackpowder Firearms, Powder Residue, and Ball Penetration, John C. Cayton, 1984, *Association of Firearm and Tool Mark Examiners Journal 16(4):80-81*; Penetration of Round Ball, Sam Fadala, 1988, *Association of Firearm and Tool Mark Examiners Journal 20(2):135-139*.

[10] A Detailed Study of the Effectiveness and Capabilities of 18th Century Musketry on the Battlefield, N. A. Robers, J. W. Brown, B. Hammett, and P. D. F. Kingston, 2008 *Journal of Conflict Archaeology* 4:1-21.

[11] Roberts et al., pp. 7-10, 2008.

[12] Ibid, pg. 20, 2008.

[13] Lucien Haag personal communication to D. Scott, March 28, 2015.

[14] *Practical Analysis and Reconstruction of Shooting Incidents,* Edward E. Hueske, 2006, Taylor and Francis, New York and Forensic Significance of Gunshot Impact Marks on Inanimate Objects: The Need for Translational Research, Farah Ad-din Nordin, Uma Rashmika Bominathan, Ahmad Falmi Lim Abdullah, and Kah Haw Chang, 2019, *Journal of Forensic Sciences* 64(1):1-15.

[15] Haag 2006:148-160; 3D Shooting Incident Analysis and Reconstruction by Means of CloudCompare, an Open Source Software, Fabiano Riva, Lorenzo Campana, Fayçal Chidiac, Cédric Asutier, and Hervé Daudigny, 2020, *Association of Firearm and Tool Mark Examiners Journal* 52(4):239-247.

[16] We wish to thank Don Hagist for his astute analysis of British solider heights which he shared with us.

[17] Bullet Ricochets on Wood. F. A. T. Mattijssen and W. Kerkhoff, 2016, *Association of Firearm and Tool Mark Examiners Journal* 48(1):15-19; Entrance and Exit Hole Characteristics: Bullet Types, Substrates, and Firing Distances, Brienne Lukes, Ismail Sebetan, and Paul Stein, 2020, Proceedings of the 72nd Annual Scientific Meetings, American Academy of Forensic Sciences, Anaheim, Calif., pg. 587. American Academy of Forensic Sciences, Colorado Springs, Colo.

[18] For more information on these muskets, see *The Brown Bess*, Erik Goldstein and Stuart Mowbray, 2010, Andrew Mowbray Publications, Woonsocket, Rhode Island.

[19] *Terminal Ballistics: A Text and Atlas of Gunshot Wounds*, Malcom J. Dodd, 2006, Taylor and Francis, New York.

[20] *Gunpowder: The History of an International Technology*, Brenda J. Buchanan, 1996, Bath University Press, UK.

[21] Gunpowder and Early Gunpowder Weapons, Bert Hall, 1996, In *Gunpowder: The History of an International Technology* edited by Brenda J. Buchanan, pp 121-136. Bath University Press, UK; Black Powder in Mining – Its Introduction, Early Use, and Diffusion Over Europe, Tascon, Ignacio Gonzalez, Juan Carolo Jeimenez Barrientos, Dolores Romero Munoz, and Amaya Saenz Sanz, 1996, In *Gunpowder: The History of an International Technology* edited by Brenda J. Buchanan, pp 205-218. Bath University Press, UK; The Evolution of the Process of Powder Making from an American Perspective, Robert A. Howard, 1996, In *Gunpowder: The History of an International Technology* edited by Brenda J. Buchanan, pp 3-24. Bath University Press, UK.

[22] Black Powder Substitutes: Their Physical and Chemical Properties and Performance, Lucien Haag, 2001, *Association of Firearms and Toolmark Examiners Journal* 33(4):313-325; Contemporary and Historical Black

Powder: Physical and Chemical Properties of Forensic Interest, Lucien Haag, 2012, *Association of Firearm and Tool Mark Examiners Journal* 44(2):92-105.

[23] The Use of Perma-Gel Testing Medium for Comparison of Terminal Performance of Different Caliber Pistol Calibers, Mark Boackle, 2011, *The Journal of the Association of Firearm and Tool Mark Examiners* 43(2):146-153.

[24] *Bullet Penetration: Modeling the Dynamics and the Incapacitation Resulting from Wound Trauma*, pp. 68-76, Duncan MacPherson, 1994, Ballistic Publications, El Segundo, CA.

[25] Ibid, pp 74-75.

[26] *The Encyclopedia of Trade Goods, Volume 4, Clothing and Textiles of the Fur Trade*, Museum of the Fur Trade, Gail DeBuse Potter and James A. Hanson, 2014, Chadron, NE and *Suiting Everyone: The Democratization of Clothing in America*, Claudia B. Kidwell, and Margaret C. Christman, 1974, National Museum of History and Technology, Smithsonian Institution Press, Washington. D.C.

[27] Sphere Drag at Mach Numbers from 0.2 to 2.0 at Reynolds Numbers Approaching 107, Donald Miller and Allan Bailey, 1979, *Journal of Fluid Mechanics* 93:449-464.

[28] MacPherson, 1994.

[29] Ibid, pp. 111-114.

[30] Ibid, pp.72-75.

[31] Ibid, pp. 122-125 and Handgun Bullet Performance. Martin Fackler, 1988, *International Defense Review* 21(5):555-557.

[32] An Empirical Study on the Relation Between the Critical Angle for Bullet Ricochet and the Properties of Wood, Wim Kerkhoff, Ivo Alberink, and Erwin J. A. T. Mattijssen, 2015, *Journal of Forensic Sciences* 60(3):605-610 Bullet Trajectory after Impact on Laminated Particle Board, and J. A. T. Mattijssen, Wim Kerkhoff, and Marlies E. Bestebreurtje, 2018, *Journal of Forensic Sciences* 63(5):1374-1382.

[33] MacPherson, 1994, pg. 127.

[34]Lucien Haag to Douglas Scott personal communication December 15, 2004.

[35] Acton Town Records- 1735-1829, Acton%20Town%20Records%201735-1829/Acton-Town-Records-1735-1829.pdf.

[36] *The Harvard Register*, 1827-28, pp. 112-113.

[37] *Boston Daily Advertiser*, 4/28/1835.

[38] *Lowell Daily Citizen and News*, 8/12/1870.

[39] Ibid, 9/6/1870.

[40] *Springfield Republican*, 4/21/1871.

[41] *Boston Journal*, 4/20/1887.

[42] Ibid, p. 249.

[43] National Archives.

[44] 1st Petition of John Robbins, Massachusetts Archives Collection, Muster Roll Volume 70, p. 327.

[45] Lexington, Mass., Record of Births, Marriages, and Deaths to January 1, 1898, Boston, Wright & Potter Printing Company, 1898, p. 66.

[46] Ibid.

[47] Certificate from Dr. Marshall Spring for John Robbins, Massachusetts Archives Collection, Volume 230, p. 134.

[48] *American Herald*, January 15, 1787.

[49] *Gunshot Injuries: How they are inflicted, their complications, and treatment*, Louis A. LeGarde, 1991 (reprint of 1916 edition), Lancer Militaria, Mt. Ida, AR, pg. 202. Similar tissue and skeletal damage are also described in the *Medical and Surgical History of the War of the Rebellion* volumes for Civil War era gunshot injuries to the face.