Title: Determining the efficacy and safety of differing caliber/ammunition combinations for the humane euthanization and subsequent mass depopulation of market weight pigs. **NPB# 20-115** **-** revised

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Industry Summary:

The global pandemic attributable to the COVID-19 virus has severely disrupted the U.S. pork supply chain over the past few months as many packer/processors have closed and(or) restricted their scope of operations due to a limited labor force. As a consequence, the production flow of millions of market weight pigs has been stymied as producers now have few to no options for marketing animals that are quickly outgrowing their finishing barns and(or) taking the place of young pigs intended to move into these facilities. Tragically, producers are now faced with the decision of mass euthanasia and the subsequent depopulation of their finishing barns. Knowing this, it is imperative that producers are provided with a number of viable options for the safe and efficacious euthanization of market weight pigs, one of which is gunshot.

As on-farm mass depopulation of market weight pigs increases, many producers are turning to the use of a firearm as an approved method of euthanasia.[1] There is an abundance of historical information on the general considerations of humane euthanasia, human safety considerations, and proper firearm placement.[1,2] More recently, scientific data has been generated to further define proper caliber and ammunition selection to achieve a minimum of 300 feet-pound (ft-lb) for predictable humane euthanasia by gunshot (for animals up to 400 pounds).[3] Nevertheless, there is little to no information illustrating both the efficacy and safety of the use of a firearm when using the multiple caliber/ammunition combinations currently available (.22 LR, .22 Mag, .38 Special, 9mm) nor is there a definitive methodology for assessing said efficacy and safety concerns. This lack of information has been exacerbated by a recent yet unpredictable increase in consumer demand for the lead round nose (LRN) and jacketed hollow point (JHP) bullets leaving the full metal jacket (FMJ) bullet as the only readily available option in each of the aforementioned calibers. Hence, a "proof of concept" exercise predicated upon the ability to conceptualize and subsequently evaluate the effectiveness and safety of multiple caliber/ammunition combinations is in fact warranted and of need to the swine industry now and in the event of a future foreign animal disease outbreak.

Key Findings:

1) Application of the novel methodologies described within this report generated valid data to define efficacy and safety considerations when using a firearm to euthanize market weight pigs.

2) The measurable trauma area of the brain was greater for the 9mm and .38 Special bullets when compared to both the .22 LR or .22 Mag bullets.

3) The .22 LR FMJ bullet fired from a 16-inch barrel (at ~140 ft-lb energy) can provide predictable humane euthanasia by gunshot in market weight pigs with minimal risk of contralateral emergence.

4) .38 Special and 9mm FMJ bullets (at >300 ft-lb energy) created saftey concerns as bullets emerged from the contralateral side of the head.

5) Under ideal conditions in which each head was securely fastend to a solid surface, anatomical anomalies and subtle differences in bullet placement resulted in a 95% success rate of brain penetration.

Conclusions:

The information obtained from this proof of concept exercise illustrates the ability to consistently evaluate and subsequently quantify the effectiveness of a FMJ bullet fired into the forehead of a market weight pig using each of four caliber rifles (.22 LR, .22 Mag, 0.38 Special, 9mm). Moreover, these findings demonstrate 1) the variation in penetrative depth and bullet conformational change both among and within a given caliber/ammunition combination and 2) the relative safety or lack thereof when using firearms as a means of mass euthanization. Further work is needed to ascertain differences in euthanization efficacy and safety when using not only the full metal jacket (FMJ) but also the lead round nose (LRN) and jacketed hollow point (JHP) bullets. Of note, the observed anatomical differences in brain size and location would suggest that proper placement of a firearm and(or) captive bolt gun as directed using current scientific literature and industry recommendations may in fact not render an animal unconscious and insensible to pain one hundred percent of the time (95% effectiveness under the ideal conditions of this study).

Keywords: mass depopulation, euthanasia, gunshot, .22 LR, .22 Mag, .38 Special, 9mm

Scientific Abstract:

The use of a firearm is generally considered both a safe and efficacious means of euthanizing market weight pigs. That said, there is little to no scientific evidence demonstrating the aforementioned factors when considering the multiple caliber/ammunition combinations that are readily available for use in mass depopulation events. Moreover, no tangible procedural guidelines have been developed in so that proper and consistent assessments of both efficacy and safety can be measured and quantified. Heads of an equal number of barrows and gilts (n = 64) were collected from a federally inspected packing facility and randomly assigned to one of four caliber/ammunition combinations consisting of the .22 LR (A), .22 Mag (B), 0.38 Special (C) and 9mm (D). Fully jacketed ammunition was discharged from each of the four unique firearms while ensuring that the distance from the muzzle to the forehead was consistent (5-inches). A hammer block malfunction occurred in the firearm firing the 0.38 Special bullet on day two of assessment lessening the total heads available for assessment (n = 60). The MIXED procedure of SAS (SAS Inst. In., Cary, NC) was used to test the fixed effects of sex (barrow, gilt), caliber (.22 LR, .22 Mag, 0.38 Special, 9mm), and a lack of skin at the point of bullet placement (0, 1) while the DIFF option was used to separate differences in LSMEANS. Differences in least squares means were deemed significant at $P \leq 0.05$. Head weight significantly differed among sexes (P = 0.05) yet was accounted for via randomization to caliber/ammunition and insignificant when assessing treatment groups (P = 0.28). A lack of skin at the point of bullet placement did not significantly influence (P > 0.10) any measured variable other than head weight (P = 0.003). No differences in skull thickness existed between sex (P = 0.32) or caliber/ammunition combination (P = 0.34). There was no difference in entrance wound diameter between the .38 Special and the 9mm (P = 0.15) yet the entrance wound diameter of the .38 Special and 9mm was significantly larger than both the .22 LR and .22 Mag (P < 0.0001). There was no difference in the distance the bullet traveled into the head for any caliber/ammunition combination (P = 0.91). The 9mm bullets traveled further into the ballistic gel (P < 0.0001) and the furthest total distance (P < 0.0001). Bullets from the .38 Special traveled further into the ballistic gel and a further total distance than both the .22 LR and .22 Mag (P <0.0001). There was no difference in the surface area of the bifurcated brains when measured in square inches (P = 0.44) nor was there a significant difference in the measurable trauma area of the brain for the 9 mm bullets compared to .38 Special bullets (P = 0.83). The measurable trauma area of the brain was greater for the 9 mm bullets and the .38 Special bullets when compared to .22 LR or .22 Mag, respectively (P < 0.0001). There was no difference in the measurable trauma area of the brain for the .22 LR bullets compared to .22 Mag bullets (P = 0.12). The measurable trauma area of the brain was greater in males than females (P = 0.03).

Introduction:

Humane euthanasia of livestock is sometimes necessary, and it is important to recognize that it be conducted skillfully to quickly render the animal unconscious and insensible to pain while being mindful of personal safety. This has never been more important given the recent challenges attributable to the COVID-19 virus as pork producers are forced to consider mass euthanasia and the subsequent depopulation of their finishing barns. Important considerations when determining the most appropriate method of humane euthanasia include: human safety, animal welfare, practicality, cost limitations, aesthetics, and technical skill requirments.[1]

A gunshot to the head is an effective method of euthanasia of swine if done correctly.[1] The impact caused by the penetrating bullet causes concussion and damage to vital areas of the brain of the pig. The current available literature does not provide information on caliber and bullet considerations for larger pigs (market weight animals) nor does it quantify the damage inflicted by said caliber/ammunition combinations. Trained professionals are now facing decisions of on-farm mass depopulation and many times do not have the personal experience or a reference to assist them in choosing the appropriate combination of both caliber and ammunition to ensure a proper outcome.

Project Objectives:

1) Fire a full metal jacket (FMJ) bullet into the skull of market weight pigs using the following caliber rifles (16-in barrel length):
    a. .22 LR
    b. .22 Mag
    c. .38 Special
    d. 9mm

2) Determine bullet penetration and variation of penetration for the selected ammunition used in each caliber. Penetration depth and variation will be measured by opening the skull to observe and subjectively assess the trauma to the skull, sinuses, and brain.

3) Generate preliminary research to serve as a proof of concept for a much more detailed, multi-disciplinary assessment of gunshot efficacy taking into consideration much heavier ending live weights, sex, and genotype.

Materials and Methods:

Raw Material Acquisition, Transport, and Preparation:
Heads from an equal number of barrows and gilts (n = 64) were collected from the harvest floor of a federally inspected packing facility, wrapped in plastic, and placed within cardboard boxes for delivery to a ballistic range located in central Missouri (429 mi) over the course of two collection days. Upon arrival, heads were removed from their packaging and randomly assigned to one of four caliber/ammunition combinations consisting of the .22 LR (A), .22 Mag (B), 0.38 Special (C) and 9mm (D). All bullets were fired from rifles with a barrel length of 16-inches. Once the caliber/ammunition combinations were determined, heads were placed upon a table fitted with a wooden reinforcement bracket that provided support to both the left and right temporal regions. A rubber tarp strap was then positioned over the snout and securely fastened to each side of the table to ensure further stability of the target. Two ballistic gel blocks (16L x 6H x 6W) were placed directly posterior to the head and stacked with a 2-inch off-set (top block closest to head) in so that the total ballistics gel distance of the stack was 20 inches from top diagonal to bottom diagonal (Figure 1). These stacked ballistic gel blocks provided support of the head and captured many but not all bullets that penetrated the contralateral side of the skull.

Firearm/Bullet Placement and Discharge:
Bullet placement and proper distance from the target was determined using a 5-inch jig (mounted to the end of the barrel of each firearm) that served to position the barrel of each firearm in a fixed distance from the head when fired (Figure 1). During the first day of assessment (May 28), bullet placement was determined by the ballistics expert (Rooster Industries LLC, Columbia, MO) in an effort to replicate an on-farm scenario in which the anatomical target is known yet envisioned. Albeit bullet placement was not an issue when assessing the skull and brain during this first assessment, proper location was identified with paint in the second assessment (June 11) in an effort to reassure the ballistics experts of placement location. Of note, each caliber/ammunition combination accounted for sex (8 barrow heads and 8 gilt heads) yet further accountability in head variability was needed as a portion of the heads obtained by the federally inspected facility were skinned. Because of this, an effort was made to include an absence in skin (0, 1) as a variable within each caliber and to mirror this phenomenon equally between both sex and caliber/ammunition combination. Immediately following firearm discharge, penetration depth into the ballistic gel was determined for each bullet that remained after leaving the skull (not all bullets were contained by the gel and some bullets fragmented). Each head was then identified with a unique animal identification number (1-64) and letter indicating the caliber utilized (A = .22 LR, B = .22 Mag, C = .38 Special, D = 9mm). An unexpected hammer block malfunction occurred in the rifle firing the 0.38 Special bullet resulting in less total heads available for assessment with this caliber and lending credence to the need for a backup firearm when performing these evaluations and when conducting mass depopulations in the field.

Skull and Brain Evaluation:
Heads were chilled (~ 39°F) for 12 hours following bullet placement and prior to dissection and assessment of both the skull and brain. Approximately 24 hours postmortem, heads were weighed to the nearest .10 lb and the lower portion of the jaw was removed to better facilitate the longitudinal sawing of heads into equal halves (from tip of snout to back of skull). Prior to bifurcation of the skull, the diameter of the bullet entry wound was measured with a WorkZone digital caliper (Batavia, IL). Entry wound measurements were taken from the furthest margin on the skin to account for skin contraction after bullet penetration (Figure 2). In the event that skin was not present, diameter was determined by measuring the inside margin of exposed bone. Heads were then marked with an Irwin straight classic chalk reel (Huntersville, NC) creating a chalk line from the center of the snout to the center of the head behind the ears. A Milwaukee Sawzall saw (Brookfield, WI) with an 8-inch all-purpose blade was used to cut the heads into equal halves by following the pre-chalked line (Figure 3). Once the skulls were bifurcated, the thickness of the skull was measured from the point of bullet entry to the dorsal margin of the brain cavity (Figure 4). Skull penetration depth was measured with a probe following the path of the bullet from the point of entry to the point of exit or to the location where the bullet or fragments were identified (Figure 4). Penetration depth into the ballistics gel was also measured if in fact it occurred and reported as a combined penetration depth of skull and ballistics gel. Not all bullets exited the skull and not all bullets that exited the skull could be retrieved (some went beyond the gel and some fragmented).

A plastic loin eye area (LEA) grid was utilized to obtain measurements of the exposed brain (both halves) by placing said grid over each section and counting the number of dots covering the brain surface (Figure 5). An average of the LEA grid dot score was then divided by 20 to determine the surface area of the exposed brain (in^2). This procedure was repeated for the larger caliber ammunition where damaged brain tissue was evident. Damaged tissue was accounted for when assessing brain surface area and used to determine a percentage score of damaged brain tissue. Each half of the brain was then carefully dissected from the skull and weighed to determine brain weight to the nearest gram.

When possible, bullets were retrieved from the head or ballistic gel (36 of 60 bullets retrieved or 60% retrieval rate). For the bullets and fragments retrieved, bullet weight (grains), and diameter (in) were recorded (Figure 6). These values were then compared to manufactured weights and pre-measured diameters to calculate bullet expansion and weight loss following penetration of the skull (and ballistic gel when applicable).

Chronograph Data Acquisition:
A Caldwell ballistic precision chronograph (Columbia, MO) was utilized to determine the actual velocity of five bullets in each caliber fired from a 16-inch barrel. Additional chronograph data was obtained from five Winchester .38 Special bullets fired from a 4-inch barrel. An average of the five chronograph velocity values was utilized to determine the bullet energies utilizing the formula: (velocity x velocity x bullet weight)/450240. The average of chronograph velocity findings and calculated energy values are reported in Table 7 along with the manufacturer reported energy values.

Statistical Analysis:

The MIXED procedure of SAS (SAS Inst. In., Cary, NC) was used to test the fixed effects of sex (barrow, gilt), caliber (.22 LR, .22 Mag, 0.38 Special, 9mm), and a lack of skin at bullet placement (0, 1) while the DIFF option was used to separate differences in LSMEANS. Assessment day was considered a random variable. Differences in least squares means were deemed significant at $P \leq 0.05$.

Results:

Head Weights:
Random selection of heads from a federally inspected packing facility resulted in a significant difference in head weight between barrows and gilts (14.30 lbs vs 15.09 lbs; $P < 0.05$). No significant sex x skin interaction existed further supporting this difference in head weight independent of skinning. Randomization of allocation to caliber/ammunition combination eliminated this difference when assessing safety and efficacy ($P = 0.28$).

Forehead Skinning:
Other than head weight ($P = 0.003$), the fixed effect of skin at bullet placement (0, 1) was not significant ($P > 0.05$) among any of the variables measured within each of the four caliber/ammunition combinations. Nevertheless, future research in this area should include only heads with forehead skin intact if at all possible.

Entrance Wound Diameter:

There was no difference in entrance wound diameter between the .38 Special and the 9mm (P = 0.15). As expected, the diameter of the .38 Special and 9mm was significantly larger than both the .22 LR or .22 Mag ($P < 0.0001$) while the entrance wound diameter of the .22 Mag was larger than the .22 LR ($P < 0.05$).

Skull Thickness:
There was no difference in skull thickness among any of the four caliber/ammunition combinations evaluated ($P = 0.34$) nor was there a significant difference in skull thickness between barrows and gilts ($P = 0.32$).

Penetration Depth of Skull and Ballistic Gel:
There was no difference in the distance the bullet traveled into the head for any caliber/ammunition combination ($P = 0.91$). The 9mm bullets traveled further into the ballistic gel ($P < 0.0001$) and the furthest total distance ($P < 0.0001$). Bullets from the .38 Special traveled further into the ballistic gel and a further total distance than both the .22 LR and .22 Mag ($P < 0.0001$). There was no difference in the distance traveled into the ballistic gel (P = 0.68) or total distance traveled for the .22 LR compared to .22 Mag ($P = 0.61$).

Brain Surface Area and Measurable Brain Trauma:
There was no difference in the surface area of the bifurcated brains when measured in square inches ($P > 0.10$) nor was there a significant difference in the measurable trauma area of the brain for the 9 mm bullets compared to .38 Special bullets ($P = 0.83$). The measurable trauma area of the brain was greater for the 9 mm bullets and the .38 Special bullets when compared to .22 LR or .22 Mag, respectively ($P < 0.0001$). There was no difference in the measurable trauma area of the brain for the .22 LR bullets compared to .22 Mag bullets ($P = 0.12$). The measurable trauma area of the brain was greater in males than females ($P = 0.03$).

Recovered Brain Weights:
There was no difference in brain weight between barrows and gilts ($P = 0.10$) yet differences were in fact observed in brain weights between caliber/ammunition combinations tested (P = 0.001). It is believed that caliber selection would not have had an impact on brain weights suggesting that the sample size was too small in this proof of concept exercise to account for normal brain weight variation.

Discussion:

This proof of concept exercise was initiated in response to an urgent need to obtain scientific information on firearm and ammunition selection for both the humane and safe mass depopulation of market weight pigs. It was the desire of the authors to advance the science of humane euthanasia when utilizing a firearm in market weight pigs and demonstrate a novel methodology for quantifying efficacy while concomitantly addressing safety concerns in multiple caliber/ammunition combinations.

The application of the described methods generated valid data to define efficacy and safety considerations when using firearms in market weight pigs for the calibers chosen in this exercise

(.22 LR, .22 Mag, .38 Special, 9mm). The calibers studied here were selected due to their published energy data and relative availability. The manufacturer's bullet energy data for the .22 Mag, .38 Special, and 9mm was approximately 300 ft-lb which is considered appropriate for the efficacious euthanization of market weight pigs[2] while the .22 LR served as a low energy control firearm (139 ft-lb) with an expectation that it would not penetrate as deeply as the aforementioned ammunition/caliber combinations.

Generalized summaries of the literature[2] involving the .22 caliber suggests that if a .22 caliber firearm is used for euthanasia it is best fired from a rifle. The initial findings of this particular study would suggest that the .22 LR in a FMJ is effective at penetrating the skull and brain to render a market weight pig unconscious and insensible to pain with 31 of the 32 bullets effectively passing through the brain tissue. The energy of the .22 LR: Aguila .22 Super Extra: 40gr Copper Plated bullet utilized in this study is reported as 139 ft-lb. This reported energy value is much less than the proposed 300 feet-pound (ft-lb) required for predictable humane euthanasia[2] yet these findings suggest that 300 ft-lb is not required for market weight pigs if using this particular ammunition type (FMJ). The energy of the .22 Mag: CCI Maxi Mag 22 MWR: 40gr FMJ bullet utilized in this study is reported as 312 ft-lb. The data collected on the .22 Mag did not demonstrate superior differences from the .22 LR. Fragments from four of the .22 LR FMJ bullets exited the contralateral side of the head and fragments from eight of the .22 Mag FMJ bullets exited the contralateral side of the head. Those .22 bullet fragments that exited the head penetrated the ballistic gel < 2.5 inches. All .22 caliber bullets fragmented to some degree in the skull creating greater opportunity for brain penetration and damage. The apparent performance similarity of the two .22 caliber bullet types (FMJ) would not necessitate the use of .22 Mag bullets for euthanasia of market weight pigs. Of note, the single .22 Mag bullet that did not penetrate the brain tissue was resultant an improper angle toward the lower jaw causing it to pass through the skull rostral to the brain.

The manufacturer reported energy for the Winchester .38 Special: 130gr FMJ bullet was 185 ft-lb when fired from a <u>4-inch barrel</u>. The chronograph calculated energy value of the Winchester .38 Special bullet fired from a 4-inch barrel was determined to be 197 ft-lb and the chronograph calculated energy of this same bullet fired from a 16-inch barrel was determined to be 321 ft-lb. These bullet energy findings are consistent with the contralateral emergence of the bullets we observed in this proof of concept exercise.

The reported energy for the 9mm: CCI Blazer Brass 9mm Luger: 115gr FMJ bullet is 323 ft-lb. At a bullet energy greater than 300 ft-lb, 100% of the .38 Special bullets exited the skull penetrating the ballistic gel from 2.0 to 14.0 inches and 100% of the 9mm bullets exited the skull (nine of these bullets penetrated the entire 20 inches of available ballistic gel). Those 9mm bullets that remained in the gel penetrated the gel 9.25 to 20.00 inches, with 20.00 inches being the maximum measurable distance traveled through the gel.

It was determined during head dissection that two bullets (one .22 Mag caliber and one 9mm caliber) did not make contact with the brain due to operator error. The .22 Mag bullet was placed between the eyes yet at an improper angle directed toward the lower jaw and not the back of the head causing it to pass through the skull rostral to the brain. The 9mm bullet was placed 1.4 inches above the line between the eyes and passed caudal to the brain due to inadvertent operator error. Notably, an additional 9mm bullet missed the brain entirely due to an anatomical malformation of the brain cavity (Figures 7 & 8). This specific finding is of interest not only to the producer but also the packer/processor as it suggests that operator error is not necessarily the singular reason for a failed attempt to render an animal unconscious and insensible to pain. When considering proper firearm placement, the variation of skull conformation within species can be as important as the variation between species. Under the conditions of this study, success or failure to penetrate brain tissue did not appear to be related to firearm or bullet characteristics but more to the selection of the ideal anatomical site and bullet placement. Three brain misses out of 60 shots would suggest a 5% failure rate under relatively ideal conditions.

Conclusions:

The information obtained from this proof of concept exercise illustrates the ability to consistently evaluate and subsequently quantify the effectiveness of a FMJ bullet fired into the forehead of a market weight pig using each of four caliber rifles (.22 LR, .22 Mag, 0.38 Special, 9mm). Moreover, these findings demonstrate 1) the variation in penetrative depth and bullet conformational change (Appendix A) both among and within a given caliber/ammunition combination and 2) the relative safety or lack thereof when using firearms as a means of humane euthanization during a mass depopulation event. The .22 LR FMJ bullet (at ~140 ft-lb energy) can provide predictable humane euthanasia by gunshot in market weight pigs with minimal risk of contralateral emergence. The .38 Special and 9mm FMJ bullets (at 300 ft-lb energy) created safety concerns of bullets emerging from the contralateral side of the head. Albeit each of the selected caliber/ammunition combinations were effective in this instance, there is little doubt that 300 feet-pound (ft-lb) is not required for predictable humane euthanasia. Under ideal conditions firearm placement and observed anatomical anomalies (brain size and location) resulted in a 95% success rate of brain penetration.

The intended purpose of this ongoing research is to provide reference materials that trained professionals can utilize when selecting the proper caliber/ammunition combination needed to properly euthanize market weight pigs on an individual basis or during mass depopulation events. Given the lack of information illustrating both the efficacy and safety of using one or more caliber/ammunition combinations when euthanizing market weight pigs, further work is needed to ascertain differences in efficacy and safety when using not only the full metal jacket (FMJ) but also the lead round nose (LRN) and jacketed hollow point (JHP) bullets fired from the .22 LR, .22 Mag, .38 Special, and 9mm. In addition, the pork industry would benefit from broadening the size and scope of this research to include market pigs at heavier ending live weights (> 350 lbs), sex (gilts, barrows, sows, and boars), and genotype.

Literature Cited:

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[3]National Pork Board. 2020. Understanding Muzzle Energy (Energy) when Selecting an Appropriate Firearm for Humane Euthanasia.

TABLE 1. SIMPLE STATISTICS_ ALL CALIBERS

Variable	N	Mean	Std Dev	Minimum	Maximum
Skull Thickness, in	60	0.913	0.294	0.400	2.200
Head Weight, lbs	60	15.027	1.675	11.800	19.000
Entrance Wound Diameter, in	60	0.271	0.085	0.045	0.472
Bullet Distance_Head, in	57	4.758	0.647	2.200	6.000
Bullet Distance_Gel, in[§]	55	6.560	7.760	0.000	20.000
Bullet Distance_Total, in	54	11.427	7.772	2.200	25.500
Brain Surface Area_Total, in^2	60	4.463	0.645	2.950	6.300
Measurable Trauma Area_in^2	55	0.137	0.176	0.000	0.550
Recovered Brain Weight, g	60	88.150	12.885	53.000	116.000

[§]Maximum measurable distance into gel was 20.00 inches

TABLE 2. SIMPLE STATISTICS_CALIBER = .22 LR

Variable	N	Mean	Std Dev	Minimum	Maximum
Skull Thickness, in	16	0.969	0.351	0.400	1.700
Head Weight, lbs	16	15.038	1.865	11.800	17.600
Entrance Wound Diameter, in	16	0.191	0.300	0.157	0.248
Bullet Distance_Head, in	14	4.768	0.857	3.200	5.900
Bullet Distance_Total, in	13	4.885	1.078	3.200	7.000
Brain Surface Area_Total, in^2	16	4.469	0.452	3.750	5.200
Measurable Trauma Area_in^2	16	0.000	0.000	0.000	0.000
Recovered Brain Weight, g	16	88.875	9.919	70.000	108.000
Bullet Weight_Original[Ψ], gr	16	40.000	0.000	40.000	40.000
Bullet Weight_Retrieved, gr	5	28.932	9.323	15.000	37.300
Bullet Weight_Difference, gr	5	11.068	9.323	2.700	25.000

[Ψ]Original weight as reported by the ammunition manufacturer

TABLE 3. SIMPLE STATISTICS_CALIBER = .22 MAG

Variable	N	Mean	Std Dev	Minimum	Maximum
Skull Thickness, in	17	0.947	0.363	0.500	2.200
Head Weight, lbs	17	15.565	1.517	13.600	19.000
Entrance Wound Diameter, in	17	0.225	0.050	0.045	0.271
Bullet Distance_Head, in	16	4.819	0.823	2.200	6.000
Bullet Distance_Total, in	16	5.421	1.334	2.200	7.580
Brain Surface Area_Total, in^2	17	4.276	0.796	2.950	6.300
Measurable Trauma Area_in^2	17	0.068	0.141	0.000	0.550
Recovered Brain Weight, g	17	78.824	14.749	53.000	106.000
Bullet Weight_Original$^{\Psi}$, gr	15	40.000	0.000	40.000	40.000
Bullet Weight_Retrieved, gr	5	32.140	5.157	23.100	36.000
Bullet Weight_Difference, gr	5	7.860	5.157	4.000	16.900

$^{\Psi}$Original weight as reported by the ammunition manufacturer

TABLE 4. SIMPLE STATISTICS_CALIBER = .38 SPECIAL

Variable	N	Mean	Std Dev	Minimum	Maximum
Skull Thickness, in	11	0.764	0.119	0.600	0.900
Head Weight, lbs	11	14.382	1.310	12.800	16.200
Entrance Wound Diameter, in	11	0.365	0.062	0.266	0.472
Bullet Distance_Head, in	11	4.809	0.316	4.300	5.500
Bullet Distance_Total, in	10	14.309	3.809	7.000	18.750
Brain Surface Area_Total, in^2	11	4.468	0.588	3.200	5.350
Measurable Trauma Area_in^2	8	0.313	0.138	0.000	0.450
Recovered Brain Weight, g	11	90.818	9.662	75.000	104.000
Bullet Weight_Original$^{\Psi}$, gr	11	130.000	0.000	130.000	130.000
Bullet Weight_Retrieved, gr	7	128.600	0.648	127.900	129.900
Bullet Weight_Difference, gr	7	1.400	0.600	0.100	2.100

$^{\Psi}$Original weight as reported by the ammunition manufacturer

TABLE 5. SIMPLE STATISTICS_CALIBER = .9MM

Variable	N	Mean	Std Dev	Minimum	Maximum
Skull Thickness, in	16	0.925	0.216	0.600	1.300
Head Weight, lbs	16	14.888	1.818	11.800	17.200
Entrance Wound Diameter, in	16	0.336	0.045	0.262	0.415
Bullet Distance_Head, in	16	4.653	0.404	4.100	5.500
Bullet Distance_Total, in	15	21.583	4.364	13.450	25.500
Brain Surface Area_Total, in^2	16	4.650	0.669	3.350	5.650
Measurable Trauma Area_in^2	14	0.279	0.154	0.100	0.550
Recovered Brain Weight, g	16	95.500	9.920	80.000	116.000
Bullet Weight_Original$^{\Psi}$, gr	15	115.000	0.000	115.000	115.000
Bullet Weight_Retrieved, gr	3	115.233	0.153	115.100	115.400
Bullet Weight_Difference, gr	3	0.233	0.153	0.100	0.400

$^{\Psi}$Original weight as reported by the ammunition manufacturer

TABLE 6. LEAST SQUARES MEANS

Variable	N	Caliber				Sex		*P*-Value[§]		
		.22 LR	.22 Mag	.38 Special	9mm	Barrow	Gilt	SEM	Caliber	Sex
Skull Thickness, in	60	0.94	0.92	0.74	0.90	0.91	0.84	0.11	0.34	0.32
Head Weight, lbs	60	14.70	15.31	14.23	14.55	14.3[a]	15.09[b]	0.59	0.28	0.05
Entrance Wound Diameter, in	60	0.20[a]	0.23[b]	0.37[c]	0.34[c]	0.28	0.28	0.02	< .0001	0.86
Bullet Distance_Head, in	57	4.78	4.83	4.82	4.67	4.78	4.77	0.27	0.91	0.98
Bullet Distance_Gel, in	55	0.41[a]	0.84[a]	9.75[b]	17.22[c]	7.18	6.93	1.17	< .0001	0.75
Bullet Distance_Total, in	54	5.11[a]	5.68[a]	14.58[b]	21.89[c]	11.97	11.67	1.24	< .0001	0.71
Brain Surface Area_Total, in^2	60	4.45	4.26	4.45	4.63	4.55	4.35	0.26	0.44	0.25
Measurable Trauma Area_in^2	55	0.01[a]	0.07[a]	0.30[b]	0.29[b]	0.20[a]	0.13[b]	0.05	< .0001	0.03
Recovered Brain Weight, g	60	87.90[a]	78.16[b]	90.51[a]	94.52[a]	85.34	90.20	4.40	0.001	0.10

[§]Other than head weight ($P = 0.003$), forehead skinning or the lack thereof was not significant for any other measured variable ($P > 0.10$).

TABLE 7: FMJ BULLET ENERGY VALUES REPORTED AND DETERMINED BY CHRONOGRAPH

		Manufacturer			Chronograph	
Ammunition Type§	**Barrel Length**	**Weight**	**Velocity**	**Energy**	**Calculated Energy**	**Velocity (Avg)¥**
Aguila .22 Super Extra: 40gr Copper Plated	16"	40	1255	139	138.95	1250.60
CCI Maxi Mag 22 MWR: 40gr	16"	40	1875	312	311.14	1871.40
Winchester .38 Special: 130gr	4"	130	800	185	196.90	825.80
Winchester .38 Special: 130gr	16"	130	800	185	321.49	1055.20
CCI Blazer Brass 9mm Lugar: 115gr	16"	115	1145	323	380.91	1221.20

§Full metal jacket

¥Average of five fired FMJ bullets for each caliber firearm

TABLE 8. RECOVERED BULLET DESCRIPTION§¥

	Recovered		Exited Skull		Fragmented	
Variable	**Number**	**%**	**Number**	**%**	**Number**	**%**
.22 LR (FMJ)	9 of 16	56	4 of 16	25	16 of 16	100
.22 Mag (FMJ)	10 of 16	62.5	8 of 16	50	16 of 16	100
.38 Special (FMJ)	10 of 11	91	11 of 11	100	0 of 16	0
9mm (FMJ)	7 of 16	44	16 of 16	100	0 of 16	0

§Description of bullets recovered (when available) from skulls or ballistic gel

¥100% of bullets penetrated skull and 9 of 16 bullets penetrated both skull and 20" of ballistic gel

TABLE 9. BULLET WEIGHT (GRAINS)

	Weight Decrease[¥]		Weight Differences[§]		
Variable	**Number**	**%**	**Beginning**	**Ending**	**Difference**
.22 LR (FMJ)	9 of 9	100	40	28.24	-11.76
.22 Mag (FMJ)	10 of 10	100	40	27.51	-12.49
.38 Special (FMJ)	0 of 10	0	130	128.69	-1.31
9mm (FMJ)	0 of 7	0	115.5	115.46	-0.04

[§]Bullet weight differences were determined when an identifiable bullet was retrieved
[¥]Weight decrease of > 3 grains

TABLE 10. BULLET DIAMETER (FMJ)[§]

	Diameter (Expansion > 10%)		Diameter Differences		
Variable	**Number**	**%**	**Beginning**	**Ending**	**Difference**
.22 LR (FMJ)	9 of 9	100	0.221	0.360	0.14
.22 Mag (FMJ)	10 of 10	100	0.221	0.376	0.16
.38 Special (FMJ)	1 of 10	10	0.348	0.376	0.03
9mm (FMJ)	0 of 7	0	0.349	0.357	0.01

[§]Diameter measurements of recovered bullets

TABLE 11 BULLET LENGTH

Variable	Length (Compression > 45%) Number	%	Length Differences Beginning	Ending	Difference
.22 LR (FMJ)	9 of 9	100	0.496	0.242	-0.254
.22 Mag (FMJ)	10 of 10	100	0.451	0.190	-0.261
.38 Special (FMJ)	0 of 10	0	0.530	0.504	-0.026
9mm (FMJ)	0 of 7	0	0.582	0.549	-0.033

Appendix A_Bullet Data:
Reported in Tables 8-11 are the results of the data obtained on the FMJ bullet conformational changes following passage through the skull and ballistic gel (when it occurred). The lead portion (bullet) of each cartridge was removed/pulled from non-fired intact cartridges to determine pre-firing weights, lengths, and diameters of all calibers. These pre-firing measurements were then used to compare post firing bullet compositional status.

Table 8: The bullet recovery rate for the .22 LR was 56% (9/16 bullets), the .22 Mag was 62.5% (10/16 bullets), the .38 Special was 91% (10/11 bullets), and the 9mm was 44% (7/16 bullets). Bullets were recovered from either the skull or ballistic gel.

Table 9: Bullet weight loss was determined when an identifiable bullet was retrieved. Bullet weight retention was a measurement intended to capture bullet conformation and reflects the degree of fragmentation for all calibers (when not completely fragmented, especially in .22 LR and .22 Mag calibers). Bullets from both .22 calibers fragmented resulting in an average weight loss of 29.5% (11.8/40 grains) for the .22 LR and 31.25% (12.5/40 grains) for the .22 Mag. The average bullet weight loss for the .38 Special was 1.0% (128.7/130 grains) and no fragmentation was observed while the average bullet weight loss for the 9mm was 0.0% (115.5/115.5 grains).

Table 10: Bullet expansion of both .22 calibers was greater than 160% (0.336/0.21 inches) when fragmentation was not complete. Bullet expansion of the .38 special was 8% (0.376/0.348 inches). Bullet expansion of 9mm was 2% (0.357/0.349 inches).

Table 11: Bullet length compression was measured and is reported here as the percentage of original conformation. For the .22 LR caliber conformation was 49% (0.242/0.496 inches) and 42% (0.191/0.451 inches) for the .22 Mag. Bullet length conformation of the .38 Special was 95% (0.504/0.530). Bullet length conformation of the 9mm was 94% (0.549/0.582).

Figure 1: Ballistics Gel Off-Set & Jig

Figure 2: Measurement of Entrance Wound

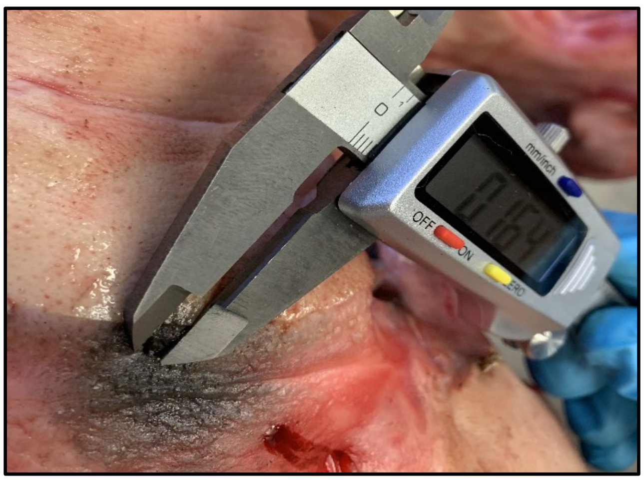

Figure 3: Bifurcated Skull

Figure 4: Bullet Trajectory

Figure 5: Trauma Assessment Tools

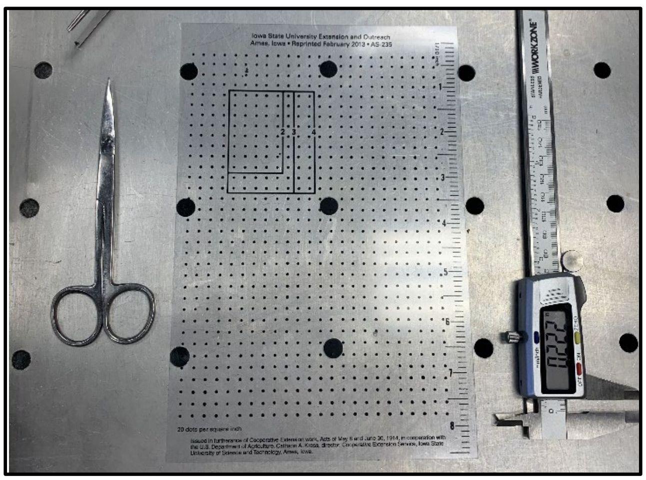

Figure 6: Pre-Fired/Retrieved Ammunition

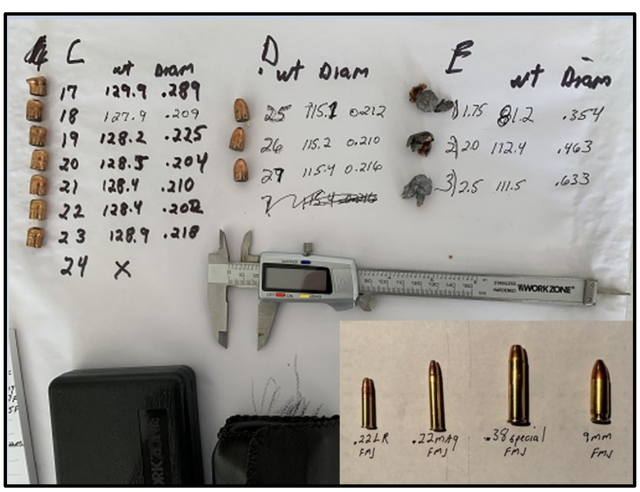

Figure 7: Bullet Placement Anotomical Anomaly

Figure 8: Bullet Placement Anotomical Anomaly