Evaluating the efficacy and safety of differing gun caliber and ammunition combinations for the euthanasia or depopulation of market-weight pigs

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Summary

Objective: Evaluate the effectiveness and safety of firearm caliber and ammunition combinations that could be used on farm for euthanasia of market-weight pigs.

Materials and methods: Heads from 64 market-age pigs (32 barrows and 32 gilts) were collected from a federally inspected slaughter facility. Heads were randomly assigned to one of 4 caliber and ammunition combinations: .22 long rifle (LR), .22 Magnum (Mag), .38 Special, and 9 mm. The fully jacketed ammunition was discharged from each of the 4 unique firearms (each with a 16-in barrel length) while ensuring a consistent muzzle to forehead distance of 12.7 cm.

Results: The 9 mm bullets traveled further through the head and into the ballistic gel ($P < .001$) and the furthest total distance ($P < .001$). Bullets from the .38 Special traveled further into the ballistic gel and a further total distance than both the .22 LR and .22 Mag ($P < .001$). The trauma area of the brain was greater for the 9 mm and the .38 Special bullets when compared to .22 LR or .22 Mag, respectively ($P < .001$). There was no difference in the trauma area of the brain for the .22 LR bullets compared to .22 Mag bullets ($P = .12$).

Implications: This proof-of-concept study generated data to define efficacy and safety considerations when using a firearm to euthanize market-weight pigs and demonstrated that the .22 LR full metal jacket bullet could provide predictable euthanasia in market-weight pigs with minimal risk of contralateral emergence.

Keywords: swine, depopulation, euthanasia, gunshot, ammunition

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Resumen - Evaluación de la eficacia y seguridad de diferentes combinaciones de calibre de arma y municiones para la eutanasia o despoblación de cerdos de peso de mercado

Objetivo: Evaluar la efectividad y seguridad de las combinaciones de calibre de arma de fuego y municiones que podrían usarse en una granja para la eutanasia de cerdos de peso de mercado.

Materiales y métodos: Se utilizaron 64 cerdos en edad de mercado (32 machos castrados y 32 hembras) de un rastro inspeccionado por el gobierno federal. Los animales fueron asignados aleatoriamente a una de las combinaciones de calibre 4 y municiones: .22 rifle largo (LR), .22 Magnum (Mag), .38 Especial, y 9 mm. La munición completamente encamisada se descargó de cada una de las 4 armas de fuego (cada una con una longitud de cañón de 16 pulgadas) al mismo tiempo que se aseguraba una distancia constante del cañón a la frente de 12.7 cm.

Resultados: Las balas de 9 mm viajaron más lejos a través de la cabeza y en el gel balístico ($P < .001$) y la distancia total más lejana ($P < .001$). Las balas del .38 Especial viajaron más lejos en el gel balístico y a una distancia total mayor que el .22 LR y el .22 Mag ($P < .001$). El área de trauma del cerebro fue mayor para las balas 9 mm y .38 Especial en comparación con .22 LR o .22 Mag, respectivamente ($P < .001$). No hubo diferencia en el área de trauma del cerebro para las balas .22 LR en comparación con las balas .22 Mag ($P = .12$).

Implicaciones: Este estudio de prueba de concepto generó datos para definir las consideraciones de eficacia y seguridad al usar un arma de fuego para sacrificar cerdos de peso de mercado y demostró que la bala con cubierta metálica completa .22 LR podría proporcionar una eutanasia predecible en cerdos de peso de mercado con un riesgo mínimo de emergencia contralateral.

CAS: Food Animal Consultation & Testing Services, Des Moines, Iowa.

TJF: Huvepharma Inc, Peach Tree City, Georgia.

JTF: Independent Consultant, Kansas City, Missouri.

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Résumé - Évaluation de l'efficacité et de la sécurité de différentes combinaisons de calibres d'armes à feu et de munitions pour l'euthanasie ou le dépeuplement de porcs de poids de marché

Objectif: Évaluer l'efficacité et la sécurité des combinaisons de calibres d'armes à feu et de munitions qui pourraient être utilisées à la ferme pour l'euthanasie des porcs de poids de marché.

Matériels et méthodes: Des têtes de 64 porcs d'âge commercial (32 castrats et 32 cochettes) ont été prélevées dans un abattoir inspecté par le gouvernement fédéral. Les têtes ont été assignées au hasard à l'une des quatre combinaisons de calibre et de munitions: .22 long rifle (LR), .22 Magnum (Mag), .38 Special, et 9 mm. Les munitions entièrement gainées ont été déchargées de chacune des quatre armes à feu uniques (chacune avec une longueur de canon de 16 pouces) tout en garantissant une distance constante entre le museau et le front de 12.7 cm.

Résultats: Les balles de 9 mm ont voyagé plus loin à travers la tête et dans le gel balistique ($P < .001$) et la distance totale la plus éloignée ($P < .001$). Les balles du .38 Special ont voyagé plus loin dans le gel balistique et une distance totale plus longue que les .22 LR et .22 Mag ($P < .001$). La zone traumatique du cerveau était plus grande pour les balles 9 mm et .38 Special par rapport à .22 LR ou .22 Mag, respectivement ($P < .001$). Il n'y avait aucune différence dans la zone traumatique du cerveau pour les balles .22 LR par rapport aux balles .22 Mag ($P = .12$).

Implications: Cette étude de preuve de concept a généré des données pour définir les considérations d'efficacité et de sécurité lors de l'utilisation d'une arme à feu pour euthanasier des porcs de poids commercial et a démontré que la balle à enveloppe métallique .22 LR pouvait fournir une euthanasie prévisible chez les porcs de poids commercial avec un risque minimal d'émergence controlatérale.

Euthanasia of livestock is sometimes necessary, and it is important that it be conducted skillfully to quickly render the animal unconscious and insensible to pain while being mindful of personal safety. Important considerations when determining the most appropriate method of 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 conducted correctly.[1] The impact caused by the penetrating bullet causes concussion and damage to vital areas of the market-weight pig brain. When faced with on-farm depopulation of market-weight pigs, many producers use a firearm as an approved method of depopulation.[2] There is an abundance of historical information on the general considerations of euthanasia, human safety, and proper firearm placement.[1,3] More recently, scientific data has been generated to further define proper caliber and ammunition selection to achieve a minimum energy of 300 foot-pounds (ft-lb) for a predictable, humane death by gunshot for animals weighing up to 400 pounds.[4] Nevertheless, there is little to no information illustrating both the efficacy and safety of firearms when using the multiple caliber and ammunition combinations currently available: .22 long rifle (LR), .22 Magnum (Mag), .38 Special, or 9 mm. Nor is there a definitive methodology for assessing said efficacy and safety concerns. This lack of information was exacerbated by an unpredictable increase in consumer demand for lead round-nose and jacketed hollow-point bullets, leaving the full metal jacket (FMJ) bullet as the only readily available option in each of the aforementioned calibers during the summer of 2020. Hence, a proof-of-concept exercise predicated upon the ability to conceptualize and evaluate the effectiveness and safety of multiple caliber and ammunition combinations is warranted and of need to the swine industry now and in the event of a foreign animal disease outbreak.

Animal care and use

This proof-of-concept study is exempt from animal care and use approval as no live animals were used. Heads from market-weight pigs were obtained from a federally inspected slaughter facility subject to the US Humane Methods of Slaughter Act.

Materials and methods

Raw material acquisition, transport, and preparation

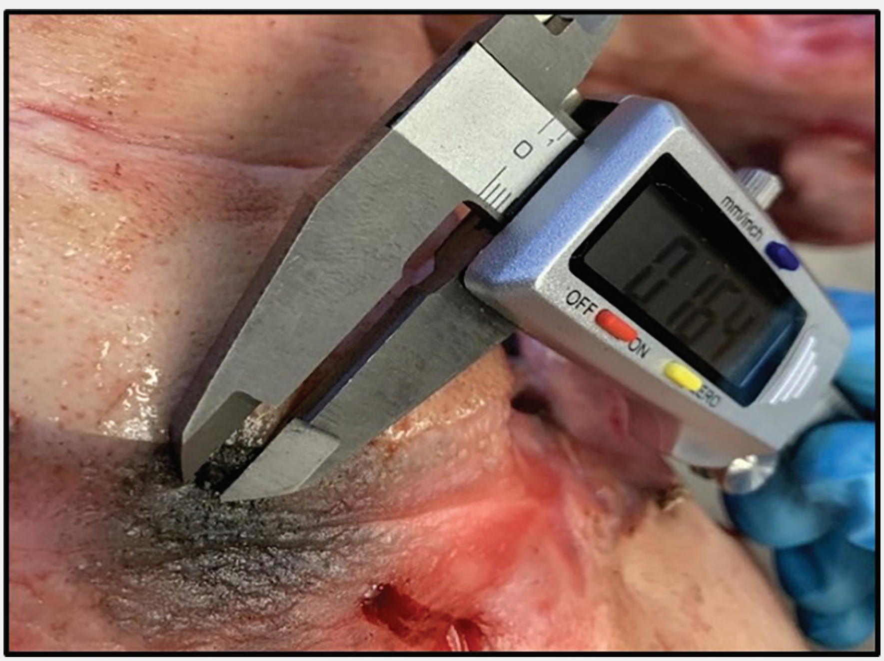
Heads (N = 64) from an equal number of market-weight barrows and gilts were collected from the harvest floor of a federally inspected slaughter facility, wrapped in plastic, placed within cardboard boxes, transported for 7 hours at ambient temperature, and delivered to a ballistic range located in central Missouri over the course of 2 collection days. Upon arrival, heads were removed from their packaging and randomly assigned to one of 4 caliber and ammunition combinations consisting of the .22 LR, .22 Mag, .38 Special, and 9 mm. All bullets were fired from rifles with a 16-in barrel length. Once the caliber and ammunition combinations were randomly assigned, heads were placed upon a table fitted with a wooden reinforcement bracket that provided support to the left and right temporal regions. The table height was adjusted so that the forehead height was 76.2 cm from the ground, which closely approximates the head height of a market-weight pig. A rubber tarp strap was positioned over the snout and securely fastened to each side of the table to ensure further stability of the target. Two ballistic gel blocks (40.6 cm long × 15.2 cm high × 15.2 cm wide) were placed directly posterior to the head and stacked with a 5.0-cm offset with the top block closest to the head so that the total ballistics gel distance of the stack was 50.8 cm from top diagonal to bottom diagonal (Figure 1). These stacked ballistic gel blocks also provided support for the head.

Firearm placement and ammunition discharge

Professionals trained as ballistic experts from Rooster Industries LLC (Columbia, Missouri) provided the firearms and fired the rounds into the skulls. Firearm placement and proper distance from the target was determined using a 12.7-cm jig mounted to the end of the barrel that served to position the barrel of each firearm in a fixed distance from the head when fired (Figure 1). Each caliber/ammunition combination accounted for sex (8 barrow and 8 gilt heads). Further head variability occurred as a portion of the heads obtained from the federally inspected slaughter facility were skinned. Because of this, an effort was made to include presence or absence of skin (0, 1) as a variable equally within each caliber/ammunition combination and between both sexes. Immediately following firearm discharge, penetration depth into the ballistic gel was determined for each

Figure 1: Stabilization of head and demonstration of 12.7-cm jig used for positioning muzzle distance. A rubber tarp strap was positioned over the snout and securely fastened to each side of the table to ensure further stability of the target. Two ballistic gel blocks (40.64 cm long × 15.24 cm high × 15.2 cm wide) were placed directly posterior to the head and stacked with a 5.08-cm offset with the top block closest to head so that the total ballistics gel distance of the stack was 50.80 cm from top diagonal to bottom diagonal. These stacked ballistic gel blocks also provided support for the head.

Figure 2: Measurement of entrance wounds were taken from the furthest margin on the skin to account for skin contraction after bullet penetration using a digital caliper.



bullet that remained after leaving the skull (not all bullets were contained by the gel and some bullets fragmented). Each head was 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 = 9 mm).

Skull and brain evaluation

Heads were chilled at approximately 39°F for 12 hours following bullet placement and prior to dissection and assessment of both the skull and brain. Chilling of the heads prior to dissection was conducted to solidify brain tissue and allow for accurate grid measurements of brain tissue following ballistic trauma. Approximately 12 hours after chilling, heads were weighed to the nearest .05 kg and the lower portion of the jaw was removed to better facilitate the longitudinal sawing of heads into equal halves from tip of the snout to back of the skull. Prior to bifurcation of the skull, the diameter of the bullet entry wound was measured with a digital caliper (WorkZone). Entry wound measurements were taken from the furthest margin on the skin to account for skin contraction after bullet penetration (Figure 2). If skin was not present, entry wound diameter was determined by measuring the inside margin of exposed bone. Heads were marked with a chalk line from the center of the snout to the center of the head behind the ears using a straight classic chalk reel (Irwin). A Sawzall reciprocating saw (Milwaukee Tool) with a 20.3-cm all-purpose blade was used to cut the heads into equal halves by following the 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 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 as some went beyond the gel and some fragmented.

Figure 3: A Sawzall saw (Milwaukee Tool) with a 20.32-cm all-purpose blade was used to cut the heads into equal halves.

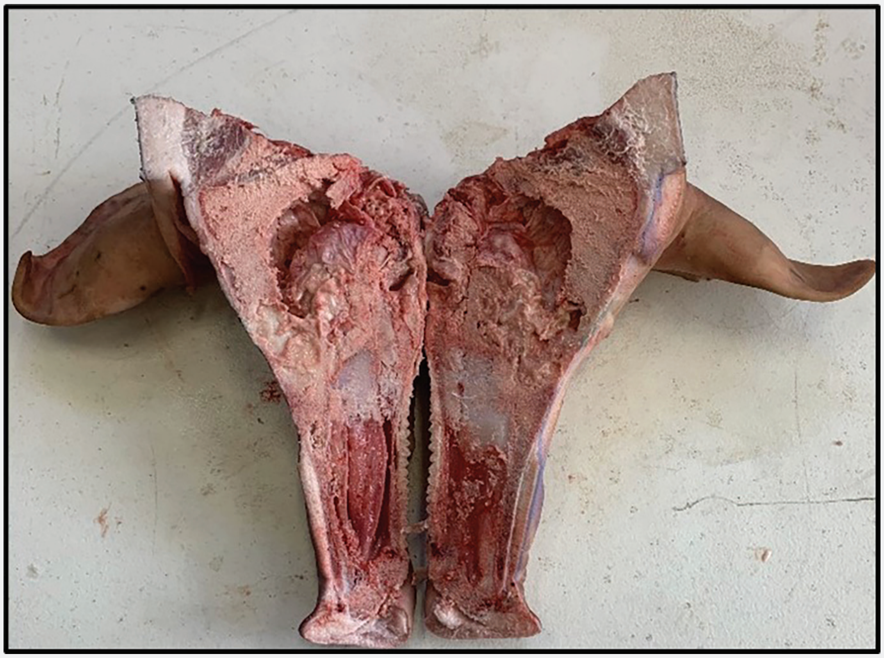


Figure 4: Skull thickness was measured from the point of bullet entry to the dorsal margin of the brain cavity. Skull penetration depth was measured with a probe following the path of the bullet from the point of entry to the point of exit or to the location where the bullet or fragments were identified.

A plastic loin eye area grid (Ames, Iowa) was used to obtain measurements of the exposed brain (both halves) by placing this grid over each section and counting the number of dots covering the brain surface (Figure 5). The mean grid dot score was divided by 20 to determine the surface area (in^2) of the exposed brain. The surface area value was then converted to cm^2. The percentage of damaged brain tissue was also measured with the grid. Each half of the brain was carefully dissected from the skull and weighed to the nearest gram to determine brain weight.

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

Chronograph data acquisition

A ballistic precision chronograph (Cladwell Shooting Supply) was used to determine the actual velocity of 5 bullets in each caliber fired from a 16-in barrel. The mean of the 5 chronograph velocity values was used to determine the bullet energies with the following formula[3]: ($velocity^2 \times$ bullet weight)/450240.

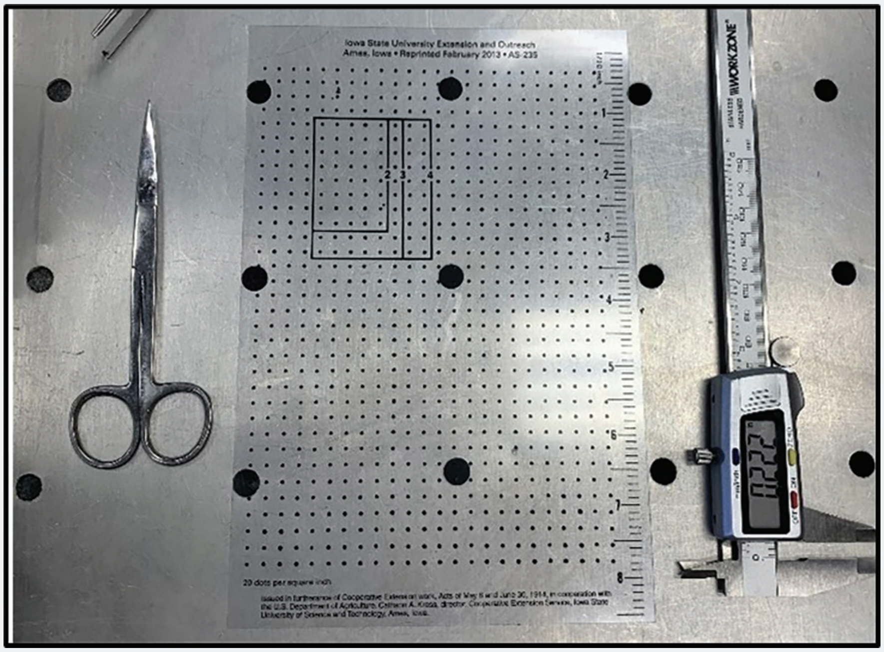
Bullet data

When possible, bullets were recovered from the back of the skull or the ballistics gel. The recovered FMJ bullets were evaluated for conformational changes following passage through the skull and ballistic gel. These conformational changes in the bullet were then compared to a nonfired bullet from each caliber. The lead portion (bullet) of each cartridge was removed from nonfired intact cartridges to determine prefiring weights, lengths, and diameters of all calibers. These prefiring measurements were used to compare post-firing bullet changes.

Statistical analysis

The MIXED procedure of SAS (SAS Institute Inc) was used to test the fixed effects of sex (barrow, gilt), caliber (.22 LR, .22 Mag, .38 Special, 9 mm), and the presence or absence of skin at the point of bullet placement (0, 1). The DIFF option was used to separate differences in LSMEANS. Differences in least squares means were deemed significant at $P < .05$.

Figure 5: Brain trauma was assessed using a plastic loin eye area grid (Ames, IA) to measure both halves of the exposed brain by placing this grid over each section and counting the number of dots covering the brain surface.



Results

Chronograph data, firearm placement, and ammunition discharge

The mean chronograph velocity findings and calculated energy values are reported in Table 1 along with the manufacturer reported energy values. For each individual caliber, the summary statistics are reported in Table 2. Measured parameters for each caliber included skull thickness (cm), head weight (kg), entrance wound diameter (cm), bullet distance head (cm), bullet distance gel (cm), total bullet distance (cm), trauma area (cm^2), and recovered brain weight (g). Table 3 provides a summary of measured parameters for all calibers.

Head weight

Random selection of heads from a federally inspected slaughter facility resulted in a significant difference in head weight between barrows and gilts (6.49 kg vs 6.84 kg; $P < .05$). No significant sex × skin interaction existed further supporting the difference in head weight was independent of the presence of skin. Randomization of allocation to caliber/ammunition combination eliminated this difference in head weight between barrows and gilts when assessing safety and efficacy ($P = .28$). A summary of the least squares means for all calibers is reported in Table 4.

Forehead skin

Other than head weight ($P = .003$), the fixed effect of skin at bullet placement (0, 1) was not significant ($P > .05$) among any of the variables measured within each of the 4 caliber/ammunition combinations (Table 4). Nevertheless, future research in this area should include only heads with forehead skin intact if possible.

Entrance wound diameter

There was no difference in entrance wound diameter between the .38 Special and the 9 mm ($P = .15$). As expected, the entrance wound diameter of the .38 Special and 9 mm was significantly larger than both the .22 LR or .22 Mag ($P < .001$) while the entrance wound diameter of the .22 Mag was larger than the .22 LR ($P < .05$; Table 4).

Skull thickness

There was no difference in skull thickness among any of the 4 caliber/ammunition combinations evaluated ($P = .34$) nor was there a significant difference in skull thickness between barrows and gilts ($P = .32$; Table 4).

Penetration depth of skull and ballistic gel

Stacked ballistic gel blocks were used to capture bullets emerging from the contralateral side of the skull (Figure 1). Bullets emerging in this gel could be dangerous to a technician, employee, or other animals within proximity to the euthanasia procedure. Ballistic gelatin closely simulates the density and viscosity of human and animal muscle tissue and is used as a standardized medium for testing the terminal performance of firearms ammunition.

The stacked ballistic gel blocks captured many, but not all, bullets that penetrated the contralateral side of the skull. There was no difference in the distance the bullet traveled into the head for any caliber/ammunition combination ($P = .91$) as all bullets remaining in the head were found at the base of the skull (Table 4). The 9 mm bullets traveled the furthest into the ballistic gel ($P < .001$) and the furthest total distance ($P < .001$). The 323 ft-lb energy of the Cascade Cartridge Inc (CCI) Blazer Brass 9 mm Luger 115 grain FMJ bullet and the 321 ft-lb energy of the Winchester .38 Special FMJ 130 grain bullet appeared to be an excessive energy level resulting in contralateral emergence of the bullet (Table 4). At a bullet energy greater than 300 ft-lb, 100% of the .38 Special bullets exited the skull and penetrated the ballistic gel 5.0 to 35.6 cm and 100% of the 9 mm bullets exited the skull (9 of these bullets penetrated the entire 50.8 cm of available ballistic gel). Those 9 mm bullets that remained in the gel penetrated the gel 23.5 to 50.8 cm, with 50.8 cm being the maximum measurable distance traveled through the gel. Bullets from the .38 Special traveled further into the ballistic gel and a further total distance than both the .22 LR and .22 Mag ($P < .001$). There was no difference in the distance traveled into the ballistic gel ($P = .68$) or total distance traveled for the .22 LR compared to .22 Mag ($P = .61$; Table 4).

Brain surface area and measurable brain trauma

There was no difference in the surface area (cm^2) of the bifurcated brains ($P > .10$) nor was there a significant difference in the trauma area of the brain for the 9 mm bullets compared to .38 Special bullets ($P = .83$; Table 4). The trauma area of the brain was greater for the 9 mm bullets and the .38 Special bullets than the .22 LR or .22 Mag ($P < .001$). There was no difference in the trauma area of the brain for

Table 1: Full metal jacket bullet mean energy values reported by the manufacturer and determined by chronograph

Ammunition type, FMJ	Barrel length, in	Manufacturer			Chronograph	
		Weight, grain	Velocity, ft/s	Energy, ft-lb	Calculated energy, ft-lb	Velocity*, mean, ft/s
Aguila .22 super extra: copper plated	16	40	1255	139	138.95	1250.60
CCI maxi mag 22 WMR	16	40	1875	312	311.14	1871.40
Winchester .38 Special	16	130	NA	NA	321.49	1055.20
Winchester .38 Special	4	130	800	185	197.21	826.10
CCI blazer brass 9 mm luger	16	115	1145	323	380.91	1221.20

* Mean of 5 fired FMJ bullets for each caliber firearm.

FMJ = Full Metal Jacket; CCI = Cascade Cartridge Inc; WMR = Winchester Magnum Rimfire; ft-lb = foot-pound; NA = not applicable.

the .22 LR bullets compared to .22 Mag bullets ($P = .12$). The trauma area of the brain was greater in males than females ($P = .03$; Table 4).

Recovered brain weight

There was no difference in recovered brain weight between barrows and gilts ($P = .10$) yet differences were observed in recovered brain weight between caliber/ammunition combinations tested ($P = .001$; Table 4).

Bullet data

The bullet recovery rate was 56.3% (9 of 16 bullets) for the .22 LR, 62.5% (10 of 16 bullets) for the .22 Mag, 90.9% (10 of 11 bullets) for the .38 Special, and 43.8% (7 of 16 bullets) for the 9 mm. Bullets were recovered from either the skull or ballistic gel (Table 5).

Bullet weight loss was determined when an identifiable bullet was retrieved. Bullet weight retention was a measurement intended to capture bullet conformation and reflect 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 a mean weight loss of 29.5% (11.8 of 40 grains) for the .22 LR and 31.3% (12.5 of 40 grains) for the .22 Mag. The mean bullet weight loss for the .38 Special was 1.0% (128.7 of 130 grains) and no fragmentation was observed while the mean bullet weight loss for the 9 mm was 0.0% (115.5 of 115.5 grains; Table 6).

Bullet expansion of .22 LR was increased by 62.9% (from 0.56 to .0.91 cm) and .22 Mag increased by 58.3% (from 0.56 to 0.96 cm) when fragmentation was not complete. Bullet expansion of the .38 Special was 8% (from 0.88 to 0.96 cm). Bullet expansion of 9 mm was 2% (from 0.89 to 0.91 cm; Table 7).

Bullet length compression was measured and is reported here as the percentage of original conformation. For the .22 LR, caliber conformation was 48.4% (0.61 of 1.26 cm) and 42.7% (0.49 of 1.15 cm) for the .22 Mag. Bullet length conformation of the .38 Special was 94.8% (1.28 of 1.35 cm). Bullet length conformation of the 9 mm was 93.9% (1.39 of 1.48 cm; Table 8).

Discussion

This proof-of-concept study was initiated in response to an urgent need to obtain scientific information on firearm and ammunition selection for the humane and safe depopulation of market-weight pigs. It was the desire of the authors to advance the science of euthanasia when using 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 study (.22 LR, .22 Mag, .38 Special, and 9 mm). 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 9 mm is approximately 300 ft-lb, which is considered appropriate for the efficacious euthanasia of market-weight pigs[3] 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 cartridges.

Generalized summaries of the literature[3] involving the .22 caliber suggests that if used for euthanasia, it is best fired from a rifle. The findings of this study would suggest that the .22 LR in a FMJ fired from a rifle was effective at penetrating the skull and brain with 31 of the 32 bullets effectively passing through the brain tissue. The energy of the .22 LR Aguila .22 Super Extra 40 grain copper plated bullet used in this study is reported to be 139 ft-lb. This reported energy value is much less than the proposed 300 ft-lb required for euthanasia,[3] yet these findings suggest that 300 ft-lb is not required for market-weight pigs if using a FMJ ammunition type. The energy of the .22 Mag CCI Maxi Mag 22 MWR 40 grain FMJ bullet used in this study is reported to be 312 ft-lb. The data collected on the .22 Mag did not demonstrate superior differences from the .22 LR. Fragments from 4 of the .22 LR FMJ bullets exited the contralateral side of the head and fragments from 8 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 < 6.35 cm. All .22 caliber bullets fragmented to some degree in the skull creating greater opportunity for energy transfer and brain damage. The apparent performance similarity of the two .22 caliber FMJ bullet types 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 resulted from 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 130 grain FMJ bullet was 185 ft-lb when fired from a 4-in barrel. The chronograph calculated energy value of the Winchester .38 Special bullet fired from a 4-in barrel was determined to be 197 ft-lb versus 321 ft-lb when this same bullet was fired from a

Table 2: Simple statistics summary of variables measured for each caliber of firearm

Variable	.22 Long rifle				.22 Magnum				.38 Special				9 mm			
	N	Mean (SD)	Min	Max	N	Mean (SD)	Min	Max	N	Mean (SD)	Min	Max	N	Mean (SD)	Min	Max
Skull thickness, cm	16	2.46 (0.89)	1.02	4.32	17	2.41 (0.92)	1.27	5.59	11	1.94 (0.30)	1.52	2.29	16	2.35 (0.55)	1.52	3.30
Head wt, kg	16	6.82 (0.85)	5.35	7.98	17	7.06 (0.69)	6.17	8.62	11	6.52 (0.59)	5.81	7.35	16	6.75 (0.83)	5.35	7.80
Entrance wound diameter, cm	16	0.49 (0.76)	0.40	0.63	17	0.57 (0.13)	0.11	0.69	11	.93 (0.16)	0.68	1.20	16	0.85 (0.11)	0.67	1.05
Bullet distance head, cm	14	12.11 (2.18)	8.13	14.99	16	12.24 (2.09)	5.59	15.24	11	12.22 (0.80)	10.92	13.97	16	11.82 (1.03)	10.41	13.97
Total bullet distance, cm	13	12.41 (2.74)	8.13	14.99	16	13.77 (3.39)	5.59	19.25	10	36.35 (9.68)	17.78	47.63	15	54.82 (11.09)	34.16	64.77
Brain surface area, cm^2	16	28.83 (2.92)	24.19	33.55	17	27.59 (5.14)	19.03	40.65	11	28.83 (3.77)	20.65	34.52	16	30.00 (4.32)	21.61	36.45
Trauma area, cm^2	16	0.00 (0.00)	0.00	0.00	17	0.44 (0.91)	0.00	3.55	8	2.02 (0.89)	0.00	2.90	14	1.80 (0.99)	0.65	3.55
Recovered brain wt, g	16	88.88 (9.92)	70.00	108.00	17	78.82 (14.75)	53.00	106.00	11	90.82 (9.66)	75.00	104.00	16	95.50 (9.92)	80.00	116.00
Original bullet wt*, gr	16	40.00 (0.00)	40.00	40.00	15	40.00 (0.00)	40.00	40.00	11	130.00 (0.00)	130.00	130.00	15	115.00 (0.00)	115.00	115.00
Retrieved bullet wt, gr	5	28.93 (9.32)	15.00	37.30	5	32.14 (5.16)	23.10	36.00	7	128.60 (0.65)	127.90	129.90	3	115.23 (0.15)	115.10	115.40
Δ bullet wt, gr	5	11.07 (9.32)	2.70	25.00	5	7.86 (5.16)	4.00	16.90	7	1.40 (0.60)	0.10	2.10	3	0.23 (0.15)	0.10	0.40

* Original weight as reported by the ammunition manufacturer.
wt = weight; gr = grain.

Table 3: Simple statistics of variables measured for all firearm calibers

Variable	N	Mean (SD)	Min	Max
Skull thickness, cm	60	2.32 (0.75)	1.02	5.59
Head wt, kg	60	6.82 (.76)	5.35	8.62
Entrance wound diameter, cm	60	0.69 (0.22)	0.11	1.20
Head bullet distance, cm	57	12.09 (1.64)	5.59	15.24
Gel bullet distance*, cm	55	16.66 (19.71)	0.00	50.80
Total bullet distance, cm	54	29.03 (19.74)	5.59	64.77
Brain surface area, cm^2	60	28.79 (4.16)	19.03	40.65
Trauma area, cm^2	55	0.88 (1.14)	0.00	3.55
Recovered brain wt, g	60	88.15 (12.89)	53.00	116.00

* Maximum measurable distance into the ballistics gel was 50.80 cm.
wt = weight; gr = grain.

Table 4: Least squares means of variables measured for caliber and sex

		Caliber				Sex		*P*	
Variable	N	.22 LR	.22 Mag	.38 Special	9 mm	Barrow	Gilt	Caliber	Sex
Skull thickness, cm	60	2.39	2.34	1.88	2.29	2.31	2.13	.34	.32
Head wt, kg	60	6.67	6.94	6.45	6.60	6.49[d]	6.84[e]	.28	.05
Entrance wound diameter, cm	60	0.51[a]	0.58[b]	0.94[c]	0.86[c]	0.71	0.71	< .001	.86
Head bullet distance, cm	57	12.14	12.27	12.24	11.86	12.14	12.12	.91	.98
Gel bullet distance, cm	55	1.04[a]	2.13[a]	24.77[b]	43.74[c]	18.24	17.60	< .001	.75
Total bullet distance, cm	54	12.98[a]	14.43[a]	37.03[b]	55.60[c]	30.40	29.64	< .001	.71
Brain surface area, cm^2	60	28.71	27.48	28.71	29.87	29.35	28.06	.44	.25
Trauma area, cm^2	55	0.06[a]	0.45[a]	1.94[b]	1.87[b]	1.29[d]	0.84[e]	< .001	.03
Recovered brain wt, g	60	87.90[a]	78.16[b]	90.51[a]	94.52[a]	85.34	90.20	.001	.10

[a,b,c] Numbers with differing superscripts within rows are statistically significant for caliber.
[d,e] Numbers with differing superscripts within rows are statistically significant for sex.
LR = long rifle; Mag = Magnum; wt = weight.

Table 5: Description of full metal jacket bullets recovered from either the skull or ballistic gel

	Recovered bullets		Exited skull		Fragmented bullets	
Caliber	Number	%	Number	%	Number	%
.22 Long rifle	9 of 16	56.30	4 of 16	25	16 of 16	100
.22 Magnum	10 of 16	62.50	8 of 16	50	16 of 16	100
.38 Special	10 of 11	90.90	11 of 11	100	0 of 16	0
9 mm*	7 of 16	43.80	16 of 16	100	0 of 16	0

* 100% of bullets penetrated the skull and 9 of 16 bullets penetrated both the skull and 50.80 cm of ballistic gel.

Table 6: Mean full metal jacket bullet weight change and fragmentation*

	Weight decrease†		Weight differences, grains		
Caliber	Number	%	Beginning	Ending	Difference
.22 Long rifle	9 of 9	100	40.00	28.24	-11.76
.22 Magnum	10 of 10	100	40.00	27.51	-12.49
.38 Special	0 of 10	0	130.00	128.69	-1.31
9 mm	0 of 7	0	115.50	115.46	-0.04

* Bullet weight loss was determined when an identifiable bullet was retrieved. Bullet weight retention was a measurement intended to capture bullet conformation and reflect the degree of fragmentation for all calibers.

† Weight decrease > 3 grains.

Table 7: Mean full metal jacket bullet diameter of recovered bullets

	Bullets with expansion > 10%		Bullet diameter, cm		
Caliber	Number	%	Starting	Ending	Difference
.22 Long rifle	9 of 9	100	0.56	0.91	0.35
.22 Magnum	10 of 10	100	0.56	0.96	0.40
.38 Special	1 of 10	10	0.88	0.96	0.08
9 mm	0 of 7	0	0.89	0.91	0.02

Table 8: Full metal jacket bullet compression and mean length of recovered bullets

	Bullet compression > 45%		Bullet length, cm		
Caliber	Number	%	Starting	Ending	Difference
.22 Long rifle	9 of 9	100	1.26	0.61	-0.65
.22 Magnum	10 of 10	100	1.15	0.48	-0.67
.38 Special	0 of 10	0	1.35	1.28	-0.07
9 mm	0 of 7	0	1.48	1.39	-0.09

16-in barrel. These bullet energy findings are consistent with the contralateral emergence of the bullets we observed in this proof-of-concept study. Furthermore, a 130 grain FMJ bullet fired from a 4-in barrel of a .38 Special will provide an energy of approximately 185 ft-lb. However, this same bullet and caliber fired from a 16-in barrel would demonstrate an increased energy of 321 ft-lb.

The reported energy of 323 ft-lb for the CCI Blazer Brass 9 mm Luger 115 grain FMJ bullet and the 321 ft-lb of the Winchester .38 Special FMJ 130 grain bullet appeared to be an excessive energy level resulting in contralateral emergence of the bullet. These results suggest that a bullet energy greater than 300 ft-lb is excessive for the safe application of firearms for euthanizing market-weight pigs.

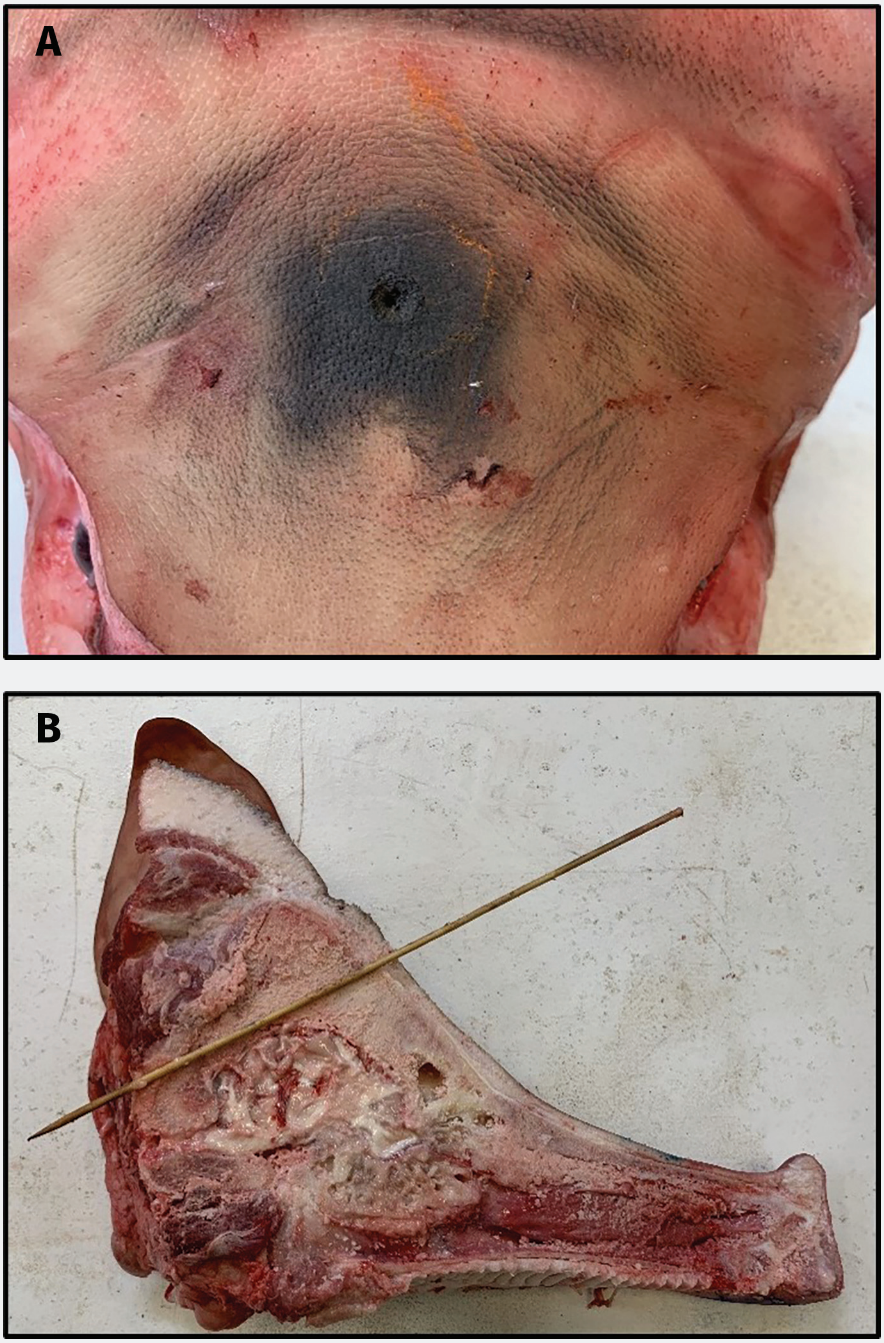
Brain weight differences were observed in the general population of 60 pigs. However, sex or trauma caused by ammunition caliber did not impact the brain weight difference. The authors suggest that a larger number of heads is required to assess the impact of sex or trauma caused by ammunition caliber on brain tissue given the natural variation that exists within individual brains.

An unexpected hammer block malfunction occurred in the rifle firing the .38 Special bullet resulting in less total heads available for assessment with this caliber and reducing the total head count from 64 to 60. This event lends credence to the need for a backup firearm when performing these evaluations and when conducting euthanasia or depopulation in the field.

It was determined during head dissection that 2 bullets (one .22 Mag caliber and one 9 mm caliber) did not contact the brain due to operator error. The .22 Mag bullet was placed between the eyes but at an improper angle directed toward the lower jaw rather than the back of the head causing the bullet to pass through the skull rostral to the brain. The 9 mm bullet was placed 3.6 cm above the line between the eyes and passed caudal to the brain due to inadvertent operator error. Notably, an additional 9 mm bullet missed the brain entirely due to an anatomical malformation of the brain cavity. Figure 6A demonstrates the proper placement of the firearm and bullet entry into the skull. Figure 6B demonstrates the path of the bullet above the brain cavity and demonstrates the anatomical anomaly of the location of the brain lower in the skull. The authors are uncertain of the incidence of anatomical malformations of brain placement that could occur within a population of pigs. This specific finding is of interest not only to the producer but also the slaughter facility 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 of 60 shots missed the brain and would suggest a 5% failure rate under relatively ideal conditions.

The information obtained from this proof-of-concept study 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 4 caliber rifles (.22 LR, .22 Mag, .38 Special, 9 mm). Moreover, these findings demonstrate the variation in penetrative depth and bullet conformational

Figure 6: One pig had an anatomical malformation of the brain cavity resulting in the bullet missing the brain entirely. **A)** The proper placment of the firearm and 9 mm bullet entry into the skull. **B)** The path of the bullet was above the brain cavity due to an anatomical anomaly of the brain being lower in the skull.



change both among and within a given caliber/ammunition combination and the relative safety or lack thereof when using firearms as a means of euthanasia or depopulation. The .22 LR FMJ bullet (energy at approximately 140 ft-lb) can provide predictable euthanasia by gunshot in market-weight pigs with minimal risk of contralateral emergence. The .38 Special and 9 mm FMJ bullets (energy at 300 ft-lb) 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 ft-lb is not required for predictable euthanasia of market-weight pigs. Under ideal conditions, firearm placement and observed anatomical anomalies (brain size and location) resulted in a 95% success rate of brain penetration. Additional research is required to better understand and measure the effects of firearm placement in live animals.

The intended purpose of this research is to provide reference materials that trained professionals can use when selecting the proper caliber/ammunition combination needed to properly euthanize market-weight pigs on an individual basis or during 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 FMJ, lead round-nose, and jacketed hollow-point bullets fired from the .22 LR, .22 Mag, .38 Special, and 9 mm firearms. In addition, the pork industry would benefit from broadening the size and scope of this research to include market pigs at heavier live weights (> 350 lb), sex (gilts, barrows, sows, and boars), and genotype.

Implications

Under the conditions of this study:

- A .22 LR FMJ bullet (139 ft-lb) penetrated the skull with low risk of passthrough.
- The .38 Special and 9 mm FMJ bullets (> 300 ft-lb) created human saftey concerns.
- Head anomalies and bullet placement reduced successful brain penetration to 95%.

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Conflict of interest

None reported.

Disclaimer

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* Non-refereed references.

Conversion tables

Weights and measures conversions

Common (US)	Metric	To convert	Multiply by
1 oz	28.35 g	oz to g	28.35
1 lb (16 oz)	0.45 kg	lb to kg	0.45
2.2 lb	1 kg	kg to lb	2.2
1 in	2.54 cm	in to cm	2.54
0.39 in	1 cm	cm to in	0.39
1 ft (12 in)	0.3 m	ft to m	0.3
3.28 ft	1 m	m to ft	3.28
1 mi	1.6 km	mi to km	1.6
0.62 mi	1 km	km to mi	0.62
1 in^2	6.45 cm^2	in^2 to cm^2	6.45
0.16 in^2	1 cm^2	cm^2 to in^2	0.16
1 ft^2	0.09 m^2	ft^2 to m^2	0.09
10.76 ft^2	1 m^2	m^2 to ft^2	10.8
1 ft^3	0.03 m^3	ft^3 to m^3	0.03
35.3 ft^3	1 m^3	m^3 to ft^3	35.3
1 gal (128 fl oz)	3.8 L	gal to L	3.8
0.26 gal	1 L	L to gal	0.26
1 qt (32 fl oz)	0.95 L	qt to L	0.95
1.06 qt	1 L	L to qt	1.06

Temperature equivalents (approx)

°F	°C
32	0
50	10.0
60	15.5
61	16.1
65	18.3
70	21.1
75	23.8
80	26.6
82	27.7
85	29.4
90	32.2
102	38.8
103	39.4
104	40.0
105	40.5
106	41.1
212	100.0

°F = (°C × 9/5) + 32

°C = (°F - 32) × 5/9

Conversion calculator available at: amamanualofstyle.com/page/si-conversion-calculator

Conversion chart, kg to lb (approx)

Pig size	Lb	Kg
Birth	3.3-4.4	1.5-2.0
Weaning	7.7	3.5
	11	5
	22	10
Nursery	33	15
	44	20
	55	25
	66	30
Grower	99	45
	110	50
	132	60
Finisher	198	90
	220	100
	231	105
	242	110
	253	115
Sow	300	136
	661	300
Boar	794	360
	800	363

1 tonne = 1000 kg
1 ppm = 0.0001% = 1 mg/kg = 1 g/tonne
1 ppm = 1 mg/L