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Pathophysiology of free-bullet slaughter of horses and ponies

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A B S T R A C T

Forty-six equines were observed during routine commercial slaughter in an abattoir. The animals were shot once with a .22 calibre long rifle with hollow point rounds. Indicators of sensibility/insensibility were evaluated immediately after the shot (prior to exsanguination) and the resulting pathophysiology of free-bullet injury was assessed. All animals were rendered immediately insensible, with only one pony showing signs of a shallow depth of concussion, with an intermittently positive palpebral reflex but no other signs of brainstem function. All animals (100%) had some degree of damage to the structures of the brainstem or lobes of the cerebrums, while 41 (89%) had damage to the thalamus/hypothalamus. The bullet in one pony missed the brain but still caused mild damage to the thalamus, midbrain, pons and cerebellum, this animal had no signs of sensibility. The findings confirm that free-bullet shooting is an effective dispatch method for horses and ponies.

1. Introduction

Equines are routinely slaughtered by abattoirs or dispatched by knacker/render yards in the United Kingdom (UK). In 2013, 3080 tonnes of horsemeat was exported (FAOSTAT, 2015). There have been recent concerns about the slaughter/dispatch and consumption of horsemeat in the UK and Europe. This relates to: (1) concerns about the fate of companion animals, (2) disposal of surplus animals from the racing industry, (3) humane slaughter, (4) veterinary medicines entering the human food chain, and (5) the fraudulent or accidental labelling of horsemeat as other meats (Bell, Gibson, & Gregory, 2013; Leadon, Jeffery, O'Toole, & Duggan, 2013; O'Mahony, 2013; Wise, 2013).

There has been a significant amount of research on the humaneness of different stunning/slaughter techniques for a number of livestock species (Atkinson, Velarde, & Algers, 2013; Blackmore, 1979; Fricker & Riek, 1981; Gibson, Mason, Spence, Barker, & Gregory, 2015; Gibson et al., 2009, 2012; Gibson, Whitehead, et al., 2015; Gouveia, Ferreira, Roque de Costa, Vaz-Pires, & Martins da Costa, 2009; Gregory, Lee, & Widdicombe, 2007; Gregory, Spence, Mason, Tinarwo, & Heasman, 2009; Svendsen, Jensen, Karlsen, Svalastoga, & Jensen, 2008). However, there is relatively little research on equine stunning and slaughter methods (Millar & Mills, 2000). Horses slaughtered for human consumption, are generally shot with either free-bullet firearms (rifle, shotgun or dispatch pistol) or penetrating captive bolt. Both methods are designed to produce immediate insensibility, via the transferring of kinetic energy of the moving projectile to the brain and gross physical damage to specific brain structures. However, the muzzle velocity and resulting brain damage from .22 calibre cartridge powered captive bolt guns (22–63 ms^{-1}) are significantly less than that delivered by .22 calibre free-bullet firearms (580–770 ms^{-1}) (Gibson, Mason, et al., 2015; Gibson et al., 2012; Schiffer, Retz, Richter, Algers, & Hensel, 2014).

Free-bullet firearms have been investigated as dispatch methods for a range of species. Thomson et al. (2013) reported that when shooting isolated cattle cadaver heads (12–18 months old) with various firearm/ammunition combinations (.45 pistol, .22 rifle with solid point bullets, .223 carbine and 12 gauge shotgun) shot from a distance of 3 m there were significant brainstem lesions, which could have produced insensibility. Meanwhile, they reported that the .22 rifle with hollow point rounds, and the 9 mm pistol would be ineffective in producing sufficient damage to skulls to ensure an instant death in cattle. Schiffer et al. (2014) reported for cattle that shooting (.22 Hornet and Magnum; .30–06; 9.3 × 62 calibre rounds) isolated cadaver heads in the frontal position produced more severe brain damage compared to the lateral position. Meanwhile, in sheep Finnie (1993) reported that shooting from a lateral position into the temporal region of the head of sheep with a .22 rifle (low and high velocity rounds) produced severe brain damage that resulted in death. Millar and Mills (2000) investigated bullet trajectories in horses shot with a .32 calibre dispatch pistol in relation to the recommended frontal position. They reported that although bullet entry position was similar between shots the variation in projectile angle significantly affected the level of damage to the hindbrain structures.

Despite a large body of literature examining the stunning and slaughter of other livestock species, there is limited information on the pathophysiology of free-bullet slaughter/dispatch of equines. The aim of this study was to assess the behavioural and cranial/spinal responses of horses and ponies shot with free-bullet, and examine the pathophysiology of the resulting brain damage.

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2. Materials and methods

Forty-six horses and ponies were assessed during routine slaughter at a UK abattoir. Animals were restrained with a halter with the rope held by the shooter and shot at point blank range, unless it was deemed too 'wild' or minimally handled, in which case it was shot from a distance of approximately 2 m. When shooting, the right-handed operator used two shooting locations: (1) For close quarter shots the operator used an unorthodox shooting position, which involved standing sideways, directly in front and to the left of the horse, with his left shoulder closest to the animal. The lead rope and dorsal halter noseband were held by the left hand. The rifle was held inverted at the grip by the right hand (trigger hand). While, (2) for shots at 2 m, the rifle was held in the more usual position, where the butt was supported by the right shoulder, the grip held by the right hand (trigger hand) and fore-end held by the left hand. Regardless of the shooting location the operator attempted to shoot each animal in the recommended frontal position, aiming for the middle of the forehead, 20 mm above the intersection of lines drawn from the middle of each eye to the base of the opposite ear, with the muzzle of the firearm angled towards the neck (HSA, 2005).

All animals were shot with a .22 long rifle, with velocitor .22 LR copper plate hollow point (≈2.6 g) 40 grain (gr) rounds (CCI Ammunition, Lewiston, ID, USA). Immediately after shooting, the animals were assessed for signs of sensibility/insensibility (Table 1). Animals were classified as incompletely concussed after shooting if they failed to collapse or rhythmic breathing was present and/or if at least two of the following parameters were present: positive corneal reflex, positive palpebral reflex, eyeball rotation and nystagmus. Only one eye was tested for the eye reflexes (eyeball rotation, spontaneous blinking, nystagmus, palpebral and corneal reflex), due to the difficulty of manipulating the heavy heads, when the animals were in lateral recumbency. After shooting, each animal was bled by ventral neck incision and the head removed as part of normal abattoir processing. The heads were collected and frozen for analysis at a later date.

The bullet entrance position was determined by the placement of a circular grid printed on transparent acetate over the head, with the recommend shooting position used as the central point of the grid. The point of bullet entry was then marked on the grid, and head length measured. All heads were band sawn longitudinally through or close to the bullet entry site. Postmortem examinations were conducted on both the frozen and defrosted heads of each animal. Heads were examined for damage (entrance and exit wounds, fractures, haemorrhage), skull and tissue thickness at the entry site, bullet trajectory and penetration depth. A probe was inserted into the entrance shot hole to assess the angle of passage through the brain and a protractor was used to measure the angle of entry. In the midline plane, shots perpendicular to the head were considered to be at an angle of 0°, and deviations from this were relative to 0°. While in the transverse plane, 0° was considered to be a shot in a rostral to caudal direction.

Table 1
Description of behavioural and cranial/spinal signs evaluated in horses and ponies shot with free-bullet.

Behaviour/signs	Description
Immediate collapse	Animal collapses immediately after the shot
Righting reflex	Makes co-ordinated effort to stand or lift head
Vocalisation	Vocalises independently from exhalation
Rhythmic breathing	Ribcage continuously moves in and out rhythmically
Gasping	Spasmodic sharp intake of breath with the mouth open
Leg kicking (convulsions)	Uncontrolled involuntary kicking movements
Eyeball rotation[a]	Eyes rotated, not central, sclera visible
Blinking[a]	Opens/closes eyelid without stimulation
Nystagmus[a]	Rapid involuntary movements of the eye
Palpebral reflex[a]	Involuntary blink reflex when the medial canthus is stimulated
Corneal reflex[a]	Involuntary blinking of the eyelids in response to the stimulation of the cornea

[a] Only one eye was assessed.

Table 2
Frequency of behavioural and cranial/spinal responses after the shot ($n = 46$).

Behaviour/signs	Number (%)
Immediate collapse	46 (100%)
Righting reflex	0 (–)
Vocalisation	0 (–)
Rhythmic breathing	0 (–)
Gasping	0 (–)
Leg kicking (convulsions)	23 (50%)
Eyeball rotation[a]	0 (–)
Spontaneous blinking[a]	0 (–)
Nystagmus[a]	0 (–)
Palpebral reflex[a]	1 (2%)
Corneal reflex[a]	0 (–)

[a] Only one eye was assessed.

The brains were first examined in-situ, and then removed and sliced into 7 mm sections. The brains were examined for gross damage, displacement of tissues, haemorrhage (in the third ventricle, lateral ventricles, cerebral aqueduct, fourth ventricle, subarachnoid and petechial haemorrhage), cavitation and position of bullet, and bone and skin fragments. Haemorrhage over the entire brain surface was subjectively assessed as a percentage of the overall brain surface area. Data from the left and right hemispheres were pooled to aid analysis. Severity of tissue damage to specific brain regions (occipital, temporal, parietal and frontal lobes, thalamus, hypothalamus, midbrain, pons, medulla, cerebellum and spinal cord) was subjectively assessed as none (0%), mild (1–20%), moderate (21–49%) and severe (≥50%) (Gibson, Mason, et al., 2015; Gibson, Whitehead, et al., 2015; Gibson et al., 2012).

For statistical analysis, categorical variables representing the degree of brain damage were re-categorised into binary variables: with damage (mild, moderate or severe) and without damage. Chi-square (or Fisher Exact when necessary) was used to assess the strength to which damage in each of the brain regions and bullet exiting the cavity were associated with the distance of the shot. For those associations that were significant ($P < 0.05$), a logistic regression model was built and odds ratios (OR) were obtained as measure of effect. Lineal regression was used to assess the association between penetration depth and skull thickness, head length, age, sex and shooting distance. Statistical analysis was carried out using statistical software R 3.1.3, package epicalc.

3. Results

Thirty-three (72%) of the animals were female and 13 (28%) were male. The animals were of the following breeds: 11 (24%) new forest or dales ponies, 11 (24%) thoroughbreds, 8 (17%) sports horses, 7 (15%) welsh cobs, 5 (11%) general purpose riding horses, and 4 (9%) welsh ponies. The median age of the animals was 7 years (range 1–22) and the median head length was 580 (440–700) mm.

Forty-six animals were shot with a .22 long rifle. All animals were shot once in the frontal position. Thirty-two (70%) were shot with the muzzle in near point blank range, while 14 (30%) were shot from a distance of approximately 2 m.

All animals immediately collapsed into either lateral or sternal recumbency and none displayed: righting reflexes, vocalisations, rhythmic breathing/gasping, eyeball rotation, spontaneous blinking, nystagmus or corneal reflex (Table 2). Four animals were observed having immediate foreleg and hindleg flexion into the body after the shot. One pony had an intermittently positive palpebral reflex but no other signs of brainstem function. The remaining 45 (98%) animals showed no signs of sensibility (Table 2). There were no cases of incomplete concussion. Twenty-three (50%) animals had an episode of convulsive kicking, while the remaining animals had no obvious convulsions after the shot. One pony exhibited lateral movement of the head in conjunction with leg kicking. However, this was not classified as a co-ordinated righting response.

Fig. 1 displays the distribution of bullet entrance sites relative to the recommended position. Twenty-nine (63%) and 14 (30%) of the shots were left and right of the recommend position respectively. The median deviation from the midline was 10 mm (range 0–70 mm). While, the median deviation in the sagittal plane was 23 mm (range 4–107 mm). All bullets entered left of midline in animals shot from a distance. In one pony the bullet entered the head 70 mm left of the recommended position, the bullet did not enter the cranial vault, but the animal showed no signs of sensibility. In all animals there was a well-defined circular entrance cavity in the skull. Thirteen percent of the shots produced cavitation of the inner table of the entrance cavity. The median skull (including frontal sinus) and tissue thickness at the entrance cavity was 10 mm (range 3–39 mm) and 3 mm (range 1–9 mm) respectively. Males had thicker skulls than females (median males 20 mm; females 9 mm; $P = 0.05$). There were no associations between skull thickness and age ($P = 0.09$), or breed ($P = 0.62$). The median rostrocaudal angle of trajectory of the bullets was 60° (range 40–125°), with a consistent median lateral deviation from midline (0° as perpendicular to the head) of 0° (range −20 to 20°).

Penetration depth could not be measured in 28 of the animals, as the round had passed through the head and its termination point could not be determined. In the 18 animals where penetration depth was measured, the medium penetration depth was 135 mm (range 115–155 mm). There were no associations between penetration depth and soft tissue thickness ($P = 0.58$), skull thickness ($P = 0.59$), age ($P = 0.15$), sex ($P = 0.70$) and shooting distance ($P = 0.73$). Thirty-six (78%) of the heads had an exit cavity in the cranial vault, while in 10 (22%) the main body of the bullet had not penetrated the full thickness of the brain. When present, the exit cavity was larger than the bullet entrance cavity (ranging between 14 and 50 mm along its longest length). There was a significant association between shooting distance and presence of an exit cavity (OR = 5.25 (95% CI 1.18–23.28), $P = 0.029$). Shooting at point blank range improved the odds of full penetration and exit of the bullet from the cranial vault. In 35 (76%) of heads the bullet had fragmented, however there was no association between shooting distance and fragmentation ($P = 0.79$).

All animals had damage to the brain (Table 3). Of the 45 shots that entered the cranial vault, 18 (40%), 24 (53%) and 3 (7%) entered via the frontal, parietal and occipital lobes respectively. The majority of shots at point blank range entered the parietal lobe (71%) whereas the majority of those from a distance entered the frontal lobe (79%) ($P = 0.010$). Overall 83%, 96%, 87%, 74%, 70% and 41% had damage to the thalamus, midbrain, pons, medulla, cerebellum and spinal cord, respectively. Damage to the lobes of the cerebrum was seen in the frontal (80%), parietal (85%), temporal (65%) and occipital (67%) lobes. Haemorrhage was present in the wound tract of 40% of the animals. There were no associations between damage to the brain and any behavioural signs or reflexes. In the pony where the bullet did not enter the cranial vault, the shot still caused mild damage to the thalamus, hypothalamus, midbrain, pons and cerebellum. Extrusion of cerebrum tissue out the shot entrance cavity was found in the heads of 7 (15%) animals. The severity of damage varied between the different brain regions and was related to shooting position. Animals shot from 2 m away had more severe damage in the frontal lobe (71%), compared to those shot at close quarters (28%) ($P = 0.009$). Meanwhile, animals shot from 2 m away were less likely to have severe damage to the cerebellum (OR = 0.06 (95% CI 0.01–0.27), $P < 0.001$) and the medulla (OR = 0.06 (95% CI 0.08–1.22) $P = 0.09$).

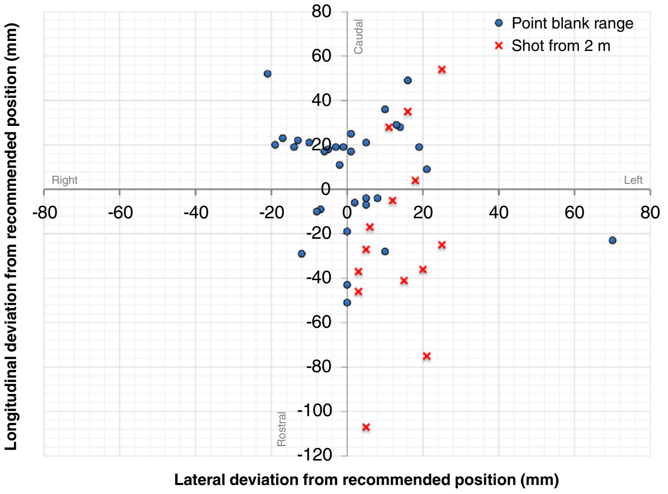

Fig. 1. Shot entrance site relative to the recommended position (0 mm). Solid circles represent animals shot at point blank range, while crosses were shot from a distance of 2 m.

Near intact bullets were recovered from 17 animals with a median weight of 1.4 g (range 0.8–2.1 g), these were all deformed. Multiple smaller bullet fragments were recovered from the brains and skulls of 35 animals, with a median weight of 1.6 g (range 0–2.3 g). Sixty percent of these fragments had a path different to the trajectory of the main body of the bullet. In 23 (50%) animals there was a well-defined cavitation tract from the main body of the bullet within the brain, which was filled with blood in 17 (74%) cases.

The median percentage of overall haemorrhage over the entire brain surface was 65% (range 45–100%), this was principally subarachnoid and subdural haemorrhages. Haemorrhage was present in the lateral ventricles (67%), 3rd ventricle (46%), cerebral aqueduct (46%) and 4th ventricle (70%). Petechial haemorrhage was found in the brains of 27 (59%) animals. This was principally in the white matter of the frontal (37%), occipital (11%) and temporal (9%) lobes, and in the cerebellum (4%), pons (4%), midbrain (2%) and thalamus (2%).

Skull fractures were present in all heads. Twenty-five (54%) and 21 (46%) skulls had single or multiple fractures respectively. Fractures generally occurred in three specific skull regions: the frontal or parietal bone in association with the entrance cavity (30%); the temporal bone, generally running longitudinally and often associated with the squamous suture (54%); and longitudinally between the lateral and basilar parts of the occipital bone (30%).

4. Discussion

This is the first study to examine pathophysiology of free-bullet shooting of horses, in terms of behavioural indicators of sensibility/insensibility and resulting brain injury. Forty-five animals were rendered irrecoverably insensible after the shot with only one pony showing a potential sign of a shallow depth of concussion (intermittent positive palpebral reflex), but with no other signs of sensibility or brainstem function. The combination of the .22 long rifle and hollow point bullets caused extensive damage to multiple brain regions resulting in irrecoverable insensibility leading to death.

The pony with an intermittently positive palpebral reflex had mild damage to the pons and moderate damage to the thalamus, midbrain and medulla. It was shot from a distance of 2 m with the bullet entering 12 mm left of the midline, angling 2° to the right. This animal showed no other signs of sensibility and the regions and severity of brain damage were similar to that found in other animals. A positive palpebral reflex can be an indicator of a shallow depth of concussion. However, it should be interpreted in reference with other behavioural and brainstem indicators when assessing sensibility. Furthermore, it is important to note that signs of a shallow depth of concussion do not necessarily indicate compromised welfare (Gregory et al., 2009). Positive brainstem reflexes, do not represent the presence or absence of consciousness, rather they are indicators of brainstem function that may be able to support the recovery or maintenance of sensibility/consciousness.

The majority of animals (70%) were shot at point-blank range, with the remaining animals shot from a distance of 2 m. There was little difference in the severity of macroscopic damage to brain structures with the different shooting locations, other than more severe damage to the cerebellum when shooting at point-blank range. In the majority of animals shot at point-blank range the bullet exited out of the cranial vault. While generally the bullet was retained within the cranium or brain in animals shot at 2 m. This suggests that irrespective of the shooting distance, the .22 rifle/hollow point bullet combination produced sufficient brain trauma to induce irreversible insensibility. These results are different to a study examining free-bullet injury in cattle heads (7–129 months old), which reported that shooting from 3 m with the .22 rifle/hollow point bullet combination was ineffective in producing reliable damage to the brain that could cause insensibility (Thomson et al., 2013). This difference could be due to the differences in skull anatomy between cattle and equines, as generally cattle have thicker skulls and frontal bones. Furthermore, only 4 steers were shot with the .22/hollow point combination and steers generally have thicker skulls than similarly matched female animals. Also as the bullet travels through the atmosphere, it decelerates due to drag (Farjo & Miclau, 1997), reducing the impact kinetic energy. Potentially, if the horses were shot at greater than 2 m there might have been less severe damage.

Importantly, unlike the current study, Thomson et al. (2013) only investigated pathological damage in isolated cadaver heads. They did not investigate the effectiveness of the different firearms tested in terms of inducing insensibility. In the current study the bullet in one pony missed the brain, but still caused mild macroscopic damage to the thalamus, hypothalamus, midbrain, pons and cerebellum, this injury was still sufficient to render the animal immediately insensible. However, in another study it was reported that horses shot with a .22 rifle from 1.5 m, that only 38% (3 out of 8) where killed with one shot (Machado et al., 2013). These animals were shot below the recommended position into the nasal and rostral frontal bones, penetrating into the frontal sinus and missing the brain. There was no information on the rounds used in that study. The combined results from Machado et al. (2013), Thomson et al. (2013) and this study suggest that provided sufficient damage and kinetic energy are imparted to the brain and the structures of the thalamus, midbrain and brainstem, the animal will be rendered immediately insensible.

During penetrative free-bullet head injury, the two major mechanisms of wounding are crushing and stretching of tissues (Hollerman, Fackler, Coldwell, & Benmenachem, 1990). When the bullet enters the brain its volume and excessive pressure build-up directly in front of the tip of the moving projectile, creating a small permanent wound cavity (cavitation), producing crushing trauma (Karger, 1995). This can be enhanced by the deformation of the bullet as it strikes the skull, fragmentation of the bullet, yaw or spin of the bullet, and secondary missiles from skull fractures. Bone and bullet fragments can produce multiple wound tracks that can increase the cross-sectional area of damage, or can have different trajectories to the main body of the bullet, producing damage in the brain regions remote from the main injury site.

Table 3
Macroscopic damage observed in brain structures during post-mortem examination in the horses and ponies ($n = 46$).

Damage to:	Severity of damage			
	None (%)	Mild (%)	Moderate (%)	Severe (%)
Thalamus	8 (17%)	11 (24%)	17 (37%)	10 (22%)
Hypothalamus[a]	9 (20%)	14 (30%)	6 (13%)	7 (15%)
Midbrain	2 (4%)	10 (22%)	18 (39%)	16 (35%)
Pons	6 (13%)	12 (26%)	11 (24%)	17 (37%)
Medulla	12 (26%)	9 (20%)	11 (24%)	14 (30%)
Cerebellum	14 (30%)	16 (35%)	13 (28%)	3 (7%)
Spinal cord	27 (59%)	14 (30%)	4 (9%)	1 (2%)
Frontal lobes	9 (20%)	5 (11%)	13 (28%)	19 (41%)
Temporal lobes	16 (35%)	13 (28%)	16 (35%)	1 (2%)
Parietal lobes	7 (15%)	14 (30%)	13 (28%)	12 (26%)
Occipital lobes	15 (33%)	15 (33%)	6 (13%)	10 (22%)

[a] Damage to the hypothalamus from brain removal could not be distinguished from shot related trauma in 10 animals.

In addition to crushing injury, behind the bullet as it passes through the brain, the kinetic energy causes tissue expansion producing a temporary cavity and movement/displacement (contrecoup) of the brain within the cranial vault. This results in radial tissue displacement and subsequent shearing, compression and stretching of tissues both focally and diffusely (Karger, 1995; Oehmichen, Meissner, Konig, & Gehl, 2004). Unlike other more elastic tissues (such as the muscle and lung), the brain is more vulnerable to damage from cavitation and stretch mechanisms, due to its relatively inelastic and incompressible nature (Farjo & Miclau, 1997). The formation of the temporary cavity in combination with the brain incompressibility results in increased pressure, which is met with counterpressure from the rigid skull (Karger, 1995; Oehmichen, Meissner, & Konig, 2000). This can cause further compression and stretch damage. Remote stretch damage can result in diffuse petechial haemorrhage. In the study petechial haemorrhage was found in the brains of 59% of animals. However, in some cases it was difficult to distinguish true petechiation from artefact introduced from the bandsaw, in these cases a conservative approach was taken and may have resulted in the underestimation of the frequency of petechial haemorrhage. After the bullet passes, the temporary cavity can expand and collapse several times for between 5 and 30 ms, prior to collapsing to the smaller permanent cavity (Aarabi & Cook, 2005; Finnie, 1997).

Unlike with livestock shot by captive bolt, where fractures are generally only associated with the bolt entrance and exit sites (direct fractures) (Gibson, Mason, et al., 2015; Gibson, Whitehead, et al., 2015; Gibson et al., 2012), in horses and ponies shot with a .22 hollow point round there were substantial skull fractures in all animals. Many of these were not associated with the bullet entrance/exit site or path (indirect fractures). The most common remote fracture was in the temporal bone (54% of animals). Fractures that occur remotely from the site of trauma are often described as linear (Anderson & McLean, 2005) or contrecoup (Hirsch & Kaufman, 1975) fractures. They generally occur when: the initial impact energy of the projectile is transferred across a wide area of the skull (Oehmichen, Auer, & König, 2009); the intracranial pressure exceeds the cranium capacity to stretch (Karger, 1995); or when the skull bends inwards at the site of entry and outwardly in the surrounding segments, producing a bending facture (Anderson & McLean, 2005; Oehmichen et al., 2009). In the study the remote fractures to the temporal lobe were generally not associated with trauma to the corresponding regions of the cerebrum. However, the remote fractures between the lateral and basilar parts of the occipital bone (30% of animals) often had corresponding damage of varying severity to the structures of the brainstem.

In the current study and those in cattle (Schiffer et al., 2014; Thomson et al., 2013), only macroscopic damage was investigated. However, substantial microscopic damage does occur which is best investigated with histopathology. Finnie (1993) reported tissue distortion (midline shift and displacement), elongated and hyperchromatic neurons and capillaries in the cerebral cortex, focal and diffuse perivascular haemorrhage and vacuolation of the neuropils in sheep shot with a .22 calibre rifle. It is highly likely that similar damage was present in the current study, potentially explaining the pony that was rendered insensible but where the bullet did not enter the cranial vault.

Unlike Thomson et al. (2013) and Schiffer et al. (2014), different weapons and projectile calibres were not tested, as the study was conducted in a commercial horse abattoir, during normal operation. The .22 rifle/hollow point bullet combination had been used by this abattoir for a number of years. Hollow point subsonic bullets are designed to deform into a mushroom shape and fragment on impact to increase surface area and severity of the wound (Farjo & Miclau, 1997; Hollerman et al., 1990; Thomson et al., 2013). An additional advantage of subsonic hollow point rounds is that unlike higher velocity or fully jacketed projectiles there is a reduced risk of ricochets or the bullet exiting the animal.

In this study the slaughterman had extensive experience of shooting horses with a rifle in the abattoir. The unorthodox close quarter shooting location, although appearing to be effective from the welfare perspective, puts the shooter at significant risk from injury from ricochets and the collapsing animal. Furthermore, although this particular slaughterman was effective with the unorthodox approach, other shooters with less experience will be likely to be less proficient. When dispatching any animal with free-bullet there is the potential for injury from ricochets either off bone or from solid objects if the bullet exits the animal. This risk is reduced, but not removed by the use of subsonic hollow point rounds. However, standing in close proximity to the muzzle increases the risk of ricochets to the operator. Additionally, when animals are shot with either free-bullet or captive bolt they often immediately flex their forelegs and hindlegs into the body (Gregory, 1991), resulting in what appears as a 'jump' where the animal is briefly unsupported in the air prior to collapse. When this occurs, the body of the animal is uncontrolled and can move forwards, falling onto the operator and crushing them.

For safe and effective dispatch of animals with free-bullet it is recommend that the: (1) animal is restrained to prevent excessive movement that could complicate the shot or result in injury to the operator(s); (2) horse is positioned so there is a solid background behind, to absorb any bullets that exit the animal; (3) operator(s) must be behind the muzzle of the firearm; (4) shooter should stand away from the animal (in front or to the side) and have a direct line of sight of the muzzle and aiming position; (5) firearms must be securely held to account for recoil and to prevent the animals head from bumping the muzzle and altering shot aiming; (6) muzzle must not touch the animal, as this could cause the animal to move its head during or before firing, which could disrupt the aiming and the shot; (7) animal is shot in the correct position for that species and the firearm is angled towards the neck to ensure maximal damage to brainstem structures and so the bullet is retained in the neck, reducing the risk to the operators; (8) the appropriate firearm and round combination should be used for the species and animal type to be dispatched; (9) spare rounds must be immediately available; and (10) a back-up rifle or captive bolt should be readily accessible. The risk of injury to operator(s) can be reduced with the use of rounds that have insufficient velocity to exit the head (Blackmore, 1985; Cooney, Chappell, Callan, & Connally, 2012; Finnie, 1993; Schiffer et al., 2014).

In conclusion, this study found that the .22 long rifle/hollow point bullet combination resulted in reliable near instantaneous irrecoverable insensibility in horses and ponies. In addition the bullet caused extensive damage to multiple brain regions. The findings confirm that free-bullet shooting is an effective dispatch method for horses and ponies.

Conflict of interest

There is no conflict of interest.

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