A REVIEW OF THE DIAGNOSIS AND TREATMENT OF GUNSHOT TRAUMA IN BIRDS

Brett Gartrell
New Zealand Wildlife Health Centre
Institute of Veterinary, Animal and Biomedical Sciences
Palmerston North, New Zealand

This paper reviews the diagnosis and treatment of gunshot trauma in birds. A primer on basic ballistic theory as it applies to the pathophysiology of gunshot wounds is included, and in particular the difference in wounds caused by high and low energy impacts. The currently recommended treatment for soft tissue, orthopaedics and antibiotic treatment of gunshot trauma in human medicine and surgery is outlined and discussed as to how this might apply to birds. The complications of gunshot injury in humans and birds and the issues around post mortem diagnosis and forensic investigation of these cases are discussed.

INTRODUCTION

Gunshot trauma is seen commonly in wild birds and rarely in aviary and companion birds. For example, in Canada, gunshot injury was detected in 6.4% of 4805 wild raptors admitted to rehabilitation networks in Quebec between 1986 and 2007, although the incidence decreased in later years (Desmarchelier et al. 2010). Many wild birds survive with embedded ammunition from previous injury. There is scant information in the avian medical literature on this subject, so extrapolations from the extensive literature on gunshot wounds in humans are necessary. Birds will differ in their response to gunshot trauma due to their size and anatomical differences. However, the basic principles of ballistics, and tissue response to gunshot wounds should be broadly similar between humans and birds.

Much of human medical knowledge of gunshot injury was based on military grade weaponry and so was dominated by the effects of high calibre weapons which because of their widespread soft tissue damage and tendency of the ammunition to fragment necessitate aggressive surgical therapy (Farjo and Miclau, 1997). Recently, the rise in civilian gunshot injuries, particularly in the USA has led to a greater understanding of low calibre weapon injuries and a different approach to treatment of these injuries is advisable (Ganocy Ii and Lindsey, 1998). Terminal ballistics describes the impact of ammunition on its target and a working knowledge of this is useful in both diagnosis and treatment decisions (Volgas et al., 2005). Complications of inadequate treatment of gunshot injuries in people are recorded as rhabdomyolysis or infection, while over-treatment has resulted in needless amputation or destructive debridement (Volgas et al., 2005).

A BASIC PRIMER ON TERMINAL BALLISTICS

The tissue damage induced in a gunshot injury is dependent on the weapon used (especially the muzzle exit velocity), the type of ammunition and its degree of fragmentation, and the attributes of the tissue affected. major determinant of tissue wounding is the kinetic energy released to the target, described by KE = MV2, (where KE = kinetic energy, M = mass and V = velocity) (Volgas et al., 2005). A bullet that exits the target does not transfer all its kinetic energy, and relatively minor tissue damage may result. Ammunition that is designed to fragment on impact is more likely to release all of its kinetic energy and cause greater tissue damage (Maiden, 2009).

Other determinants of tissue damage include sonic wave formation, temporary cavitation and permanent cavitation. Figure 1 (Farjo and Miclau, 1997) illustrates these phenomena. Sonic wave formation is a sonic pressure wave that precedes the projectile following impact and travels at 1463 m/s (4800 ft/s) but only lasts a few microseconds. Its effects on tissue is thought to be minimal but there are some recent controversial suggestions that the sonic waves may disrupt neural function, even at sites distant to that impacted by the bullet (Farjo and Miclau, 1997).

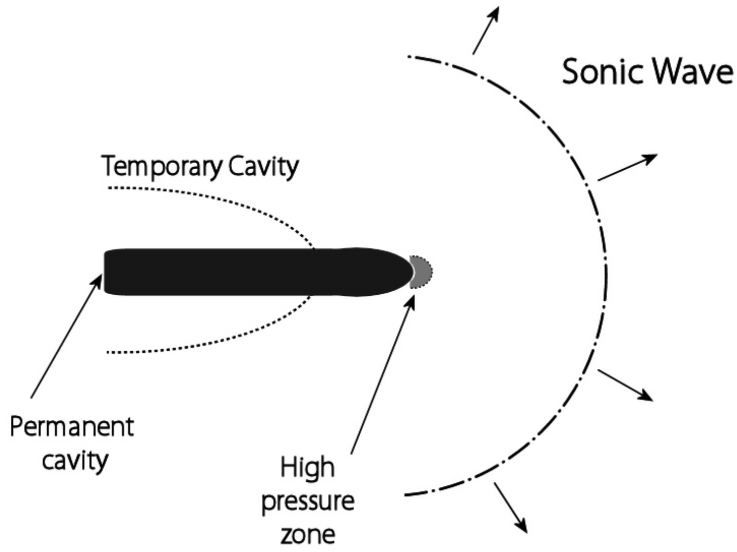

Figure 1. Terminal ballistic tissue pressure phenomena caused by bullet entry. From Farjo and Miclau (1997)

The permanent cavity produced by a bullet is a result of tissue crushed by the passage of the bullet. The volume of the permanent cavity depends on the tumbling or yaw of the bullet. A bullet that tumbles on entry will create a much larger permanent cavity than the entry wound. Bullet size is also important, with a larger slower moving bullet creating a larger permanent cavity than a smaller fast moving bullet. Bullet deformation and fragmentation will also create a large permanent cavity along the path of the wound (Farjo and Miclau, 1997).

Radial stretching of structures adjacent to the bullet's path creates the temporary cavity behind the path of the bullet caused by the release of kinetic energy. The size of the temporary cavity can be up to 30 x the diameter of the bullet. Elastic structures can absorb the stretching forces with minimal damage, however inelastic structures, such as liver, or those tissues that are contained, such as the brain is contained by the skull will be seriously damaged by this force. A larger cavity is better able to absorb these forces than smaller ones (Volgas et al., 2005), a serious consideration when extrapolating the effects of these wounds from humans to birds. The force of the temporary cavitation can be enough to shatter nearby bone without the bullet actually touching the bone. Higher energy projectiles cause a larger temporary cavity than low energy ones. Finally, the temporary cavity behind a bullet creates a vacuum effect that draws foreign material into the wound (Farjo and Miclau, 1997).

Rifles tend to produce high energy wounds, handguns produce less velocity, kinetic energy and accuracy because of their shorter barrels. Shotguns cause a wide variety of wounds from relatively minor to massive damage depending on the range from the target they are fired at. At close range, a shotgun injury is typical of a wound from fragmenting ammunition. Air guns have low energy compared to other weapons but at close range have penetrated the skull and abdomen of people causing fatal injuries (Farjo and Miclau, 1997). Airgun injuries generally have minimal cavitation associated with the wounds due to the low velocity of the missiles (Saukko and Knight, 2004).

The ammunition used is a major determinant of the wound created. Jacketed bullets (Figure 2) do not fragment as much as unjacketed bullets and so cause less cavitation, but are capable of higher velocity. Hollow point ammunition is the term for ammunition that is designed to fragment within the wound, increasing drag and thereby tissue damage in both permanent and temporary cavitation (Figure 3) (Farjo and Miclau, 1997).

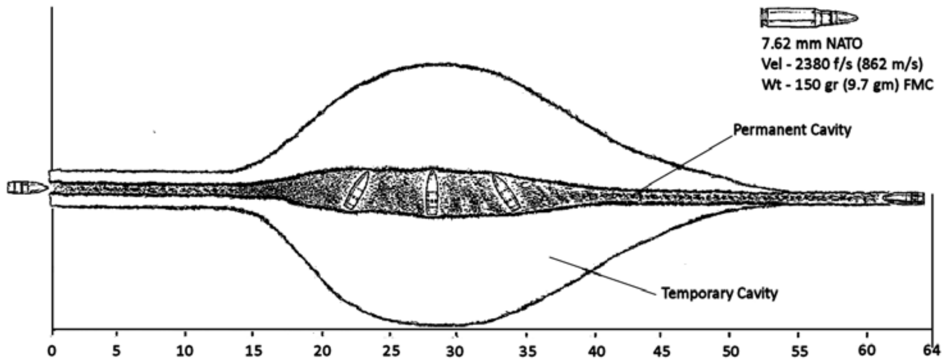

Figure 2. **The wound profile for a jacketed 7.62mm NATO bullet fired into gelatin. From Farjo and Miclau (1997).**

The differences in birds compared to human injuries in response to gunshot injury have not been well studied. From the material above, some differences might be expected in avian patients. Firstly, it may be supposed that birds are more likely to suffer serious injury with low energy weapons because the reduced body size will result in a greater relative effect of the permanent and temporary cavitation. The reduced size of the coelomic cavity will also increase the severity of damage from wounds to the body. Penetration or devitalisation of the intestinal tract in birds is likely to result in mortality. The brittle nature of avian bones with their high calcium carbonate content may make fractures more likely. Aspergillosis is more likely to result in birds with intra-coelomic injury. In contrast, birds are relatively resistant to blood loss and hypovolaemic shock and the lack of a separate thoracic cavity with a negative pleural pressure may reduce the morbidity associated with wounds of the chest and lungs.

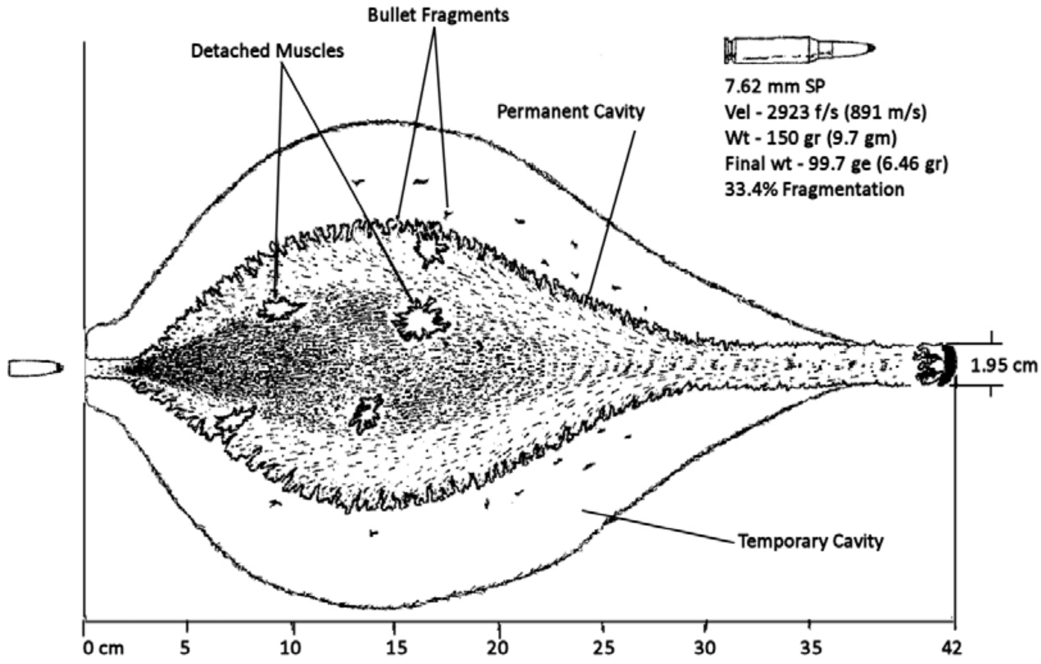

Figure 3. The wound profile for an unjacketed 7.62mm NATO jacketed bullet fired into gelatin. From Farjo and Miclau (1997). The wound shows a much larger permanent cavitation which is closer to the entrance wound.

DIAGNOSIS AND PROGNOSIS

The initial challenge with many avian patients is recognising that the wounds are caused by a gunshot injury. With low energy weapons such as airguns, the only indication may be the small entry wound (Campbell-Hewson et al., 1997). Radiographic evaluation of all suspected gunshot injuries (in both clinical and post mortem cases) is recommended (Volgas et al., 2005) and the precise determination of the path of the bullet under general anaesthesia by endoscopy or simple probing. Computed tomography may allow more accurate localisation of bullet fragments and the permanent cavitation path, but it is unlikely to aid in delineating the extent of temporary cavitation (Adesanya et al., 2000). Blind surgical exploration of the bullet path will only rarely be justified.

The expected prognosis for gunshot injuries in people is summarised in Table 1 taken from a review by Volgas et al. (2005). People with abdominal gunshot wounds tend to die of complicating infections. Poor prognostic factors for survival in people with abdominal gunshot wounds include the presence of shock on admission, presence of penetrating colon injury, more than two intra-abdominal organs injured, and prolonged surgical times. Prolonged injury to surgery time was a significant predictor of post-operative infectious complications and mortality (Adesanya et al., 2000).

Table 1. The prognosis for people with gunshot injuries taken from a review by Volgas et al. (2004).

Determination of High- vs. Low-risk Wounds		
	Low risk	**High risk**
Location of wounding	City street	Battlefield/farmyard
Time to treatment	Less than 1 h	Greater than 6 h
Weapon used	Handgun	Military rifle, hunting rifle, shotgun
Path of projectile	Straight through, entrance and exit wounds at same level	Entrance and exit wounds at different levels, ± no exit wound
Size of exit wound	Small	Large
Organ involvement	Skin, muscle only	Solid organs, spine, CNS, vascular injury
Bone involvement	Intact, little comminution	Much comminution
Bullet fragmentation	Little	Much
Number of projectiles	One	Several

These prognostic factors have altered over time in human medicine due to development of efficient ambulance services, blood banks and improved regional trauma care (Adesanya et al., 2000). Prior to this the primary cause of death in people following gunshot injury was exsanguinating haemorrhage, and this is still likely to be the primary cause of avian mortality following gunshot wounds. The prognostic factors affecting avian survival following gunshot injury have not been determined, However, similar to human casualties, time to treatment of avian gunshot injuries is likely to be a significant factor in survival and incidence of complications.

TREATMENT

The basic principles of gunshot wound treatment include treatment of the soft tissue wounds, fracture stabilisation and antibiotic treatment.

In high calibre wounds, exploration and debridement or excision of tissues devitalised in the permanent cavity should be attempted (Volgas et al., 2005). All retained bullet fragments should be removed during this initial operative exploration (Rhee and Martin, 1997). However, due to the variable effects of temporary cavitation on tissue, many authors suggest that the surgeon remove only tissues which are clearly non-viable in the first instance and perform a re-exploration of the wound at a later date, when the degree of tissue effects are more obvious (Miclau and Farjo, 1997).

In contrast, current best practice in human medicine for low energy gunshot wounds is to manage the wounds with local wound care, with or without excision of the permanent cavity and entry/exit wounds (DuBose et al., 2007). Bullets retained in soft tissues, muscle or bone can be left in place and electively removed if causing problems at a later date (Rhee and Martin, 1997). These bullets are contained by fibrous avascular scar tissue and are thus inert. However, all intra-articular and intrabursal bullets should be removed to prevent lead arthopathy and systemic lead toxicosis. Metallic lead is soluble in joint fluid. Lead arthropathy is a destructive arthritis caused by a combination of inflammation and mechanical abrasion. In human cases where this occurs synectomy is the recommended treatment (Ganocy Ii and Lindsey, 1998).

Bullets present in weight bearing surfaces should also be removed. Copious wound irrigation and minimal debridement is recommended. It is recommended that close range shotgun wounds be treated aggressively similar to high energy wounds. This is due to the massive soft tissue damage and the introduction of wadding into the wounds. Wadding is difficult to find as it is radiolucent and can act as a nidus for infection and continuing inflammation (Volgas et al., 2005).

Stabilisation of fractures associated with gunshot injury should follow general principles of fracture repair, with through debridement and irrigation of the fracture site and removal of devitalised bone fragments. Bone grafting is often necessary in people but is generally delayed until after the soft tissue injuries are resolved. Fractures associated with high energy wounds should be treated as open wounds (Volgas et al., 2005).

Gunshot wounds should be considered as primarily contaminated wounds and infection is promoted by the penetration and introduction of foreign material and debris into wounds (clothes in people, feathers in birds), devitalisation of tissues caused by kinetic energy transfer, disruption of vasculature and systemic effects on the host such as blood loss and shock. In addition, bullets are not sterilised by the firing process and can carry bacteria on their surface. In human medicine, post traumatic osteomyelitis is a common complication of gunshot treatment. Antibiotic treatment is therefore recommended for all gunshot wounds (Miclau and Farjo, 1997).

The current best practice for treatment of high energy wounds in people is for operative debridement of devitalised tissues and lavage to reduce bacterial numbers, open wound management, the use of tetanus toxoid and broad spectrum antibiotics including parenteral cephalosprins, aminoglycosides and penicillin. This combination is administered intravenously from presentation for up to 72 hours post-operatively. In field situations, where treatment will be delayed, intramuscular benzylpenicillin given in the first hour after wounding will effectively reduce infection rates, but is ineffective if given six hours or more after injury (Miclau and Farjo, 1997).

The antibiotic treatment of low energy wounds in people is controversial as in human medicine these patients tend to have much lower rates of complicating infections. While not yet conclusive, the evidence in human medicine tends to suggest that there is no increase in infection rates by treating low velocity wounds with local wound care with either oral antibiotics or no antibiotics compared to the more intensive protocols outlined above for high energy wounds (Miclau and Farjo, 1997).

In one of the few papers on the management of gunshot trauma in birds, Jekl et al. (2006) reported the endoscopic removal of an airgun bullet from the coelom of a peregrine falcon where it was adjacent to the heart. It is assumed that the bullet was removed because of its proximity to the myocardium but this was not discussed in the paper. The soft tissue wounds were treated with debridement, lavage and delayed closure. The bird was treated with oral antibiotics and made a delayed but ultimately successful recovery (Jekl et al., 2006).

FORENSIC INVESTIGATION OF BULLET WOUNDS

Post mortem diagnosis of gunshot injury begins with recognising the possibility of a gunshot wound. Small entry wounds may be overlooked if a careful physical examination is neglected. Radiography should be carried out prior to the post mortem examination in all cases where gunshot injury is suspected (Saukko and Knight, 2004). Radiographs can aid in the identification of small bullet fragments left behind in the permanent cavity caused by the bullet path, the location of single bullets to aid in retrieval and to assess the extent of dispersal of shot in shogun injuries. Close examination of the skin and any wounds is useful in identifying entry and exit wounds (Table 2), and giving an estimation of the range of firing (Cooper and Cooper, 2007).

Table 2. Characteristics used to identify entry and exit wounds. Modified from Cooper and Cooper (2007) and Saukko and Knight (2004).

Entry	Exit
Well circumscribed, round or oval wound	Ragged everted edges, irregular shape
A collar of abrasion and discharge residue (close	Collar and discharge are rarely evident
Same size or smaller than the bullet	Variable sized, often larger than entry
Foreign material drawn into the bullet's path	No foreign material in the immediate wound

The identification of ammunition and weapon type is best left to forensic ballistic experts. However, veterinarians may be called upon in veterinary forensic cases to retrieve ammunition for analysis. Plastic forceps should be used to remove ammunition to minimise damage to the striation patterns used for weapon identification and create difficulties in the ballistic investigation. Careful documentation of the site of ammunition collected and the associated wounds is important as many animals will carry bullets and shot from previous woundings (Cooper and Cooper, 2007).

The following material is a summary of forensic protocols from the Institute of Environmental Science and Research (ESR) laboratories, courtesy of Kevan Walsh (personal communication 22nd August, 2011). The ESR is a Government-owned New Zealand Crown Research Institute, and is the only provider of forensic laboratory services in New Zealand.

SUMMARY OF RELEVANT ESR PROTOCOLS

View X-rays or CAT scans to determine the number and location of projectiles, the path of projectiles and to help distinguish the entry holes from the exit holes. Estimate the number of pellets if dealing with a shotgun wound.

Prior to washing the wound, look for the presence of projectile particles and partially burnt propellant particles. Collect any that are observed.

Examine the skin around the wound for the presence of embedded propellant particles (tattooing marks), projectile particles and sooting. Draw and make appropriate measurements of the hole, sooting and particles.

Consider the symmetry of the wound to determine the possibility that the shot was angled or that the projectile was tumbling when the target was struck. If buckshot was used, look for and collect any buffer material.

Examine the hole and surrounding skin for signs of tearing that may indicate a contact or near-contact shot. Draw relevant details and note the presence of underlying bone which may affect the conclusion.

Examine the hole for the presence of propellant particles, projectile particles and sooting in the wound path.

Observe the wound path to the projectile. Photograph, sketch or obtain copies of the X-rays. Draw a diagram of the path relative to the body.

Make appropriate conclusions, and ensure that notes are made regarding:
the presence of sooting, propellant and other particles around and in the wound path; the angle and path of the shot; the entry and exit holes; relevant measurements; and the symmetry of the hole.

Assist with collection of the projectile. Ensure that the projectile is not removed with metal tools if possible. If the projectile is embedded in bone, either cut out the bone for retrieval of the projectile later in the laboratory, or ensure appropriate cuts are made to aid removal without damaging the projectile. If dealing with a shotgun wound, collect a number of the pellets.

Collect the wad(s) if appropriate.

OTHER FORENSIC COMMENTS

The three main differences in projectiles may be important. These can be summarised as falling into two groups - multiple projectiles (pellets) from shotguns and single projectiles from rifles and handguns. Within the latter group, a distinction could be made between lead projectiles and jacketed projectiles. A shotgun typically fires a plastic wad which contains from eight large lead pellets (00-buckshot) to many hundreds of lead (or steel) pellets. (The exception being a shotshell that is loaded with a single projectile called a "slug".) The wad may only be present in a wound where the shot was from a very close range (less than about two metres). From a viewpoint of obtaining evidence to link to a firearm, a shot from a shotgun is the least useful as the pellets are not marked in a way to enable comparison back to the barrel of the shotgun. Occasionally a wad may be marked, enabling a comparison to be made.

Single projectiles (bullets) have the potential to be linked back to the firearm from a comparison of the surface features of the bullet with those of bullets test-fired in the questioned firearm. If a lead bullet is involved (typical for the common .22 Long Rifle calibre), retrieval of this with minimal disruption to the surface detail may enable a comparison to a questioned firearm.

If a jacketed bullet is involved (eg. .22 Magnum, .17 HMR, .22 Remington, .303 British, 7.62x39mm, etc) it is possible that the bullet will break up with the outer jacket material separating from the inner core of lead (or steel). The jacket material has the surface detail that can be compared to test-fired bullets. The jacket will be the less dense material seen on an x-ray, and may also be present in a wound where the lead core has exited the body.

In cases where there is too much damage and a microscopic comparison of surface features isn't possible, it is important to gather as much of the projectile or pellets (and wad) as possible to enable a calibre determination and comparison with ammunition.

REFERENCES

Adesanya, AA, da Rocha-Afodu, JT. et al. 2000. Factors affecting mortality and morbidity in patients with abdominal gunshot wounds. Injury 31, 397-404.

Campbell-Hewson, G., Egleston, CV. et al. 1997. The use of air weapons in attempted suicide. Injury 28, 153-158.

Cooper, JE. and Cooper ME. 2007. Introduction to Veterinary and Comparative Forensic Medicine. Oxford, Blackwell Publishing.

Desmarchelier, M., Santamaria-Bouvier, A. et al. 2010. Mortality and morbidity associated with gunshot in raptorial birds from the province of Quebec: 1986 to 2007. Canadian Veterinary Journal - Revue Veterinaire Canadienne 51, 70-74.

DuBose, J., Inaba, K. et al. 2007. Selective non-operative management of solid organ injury following abdominal gunshot wounds. Injury 38, 1084-1090.

Farjo, LA. and Miclau, T. 1997. Ballistics and mechanisms of tissue wounding. Injury 28, Suppl 3, C12-C17.

Ganocy Ii, K. and Lindsey, RW. 1998. The management of civilian intra-articular gunshot wounds: Treatment considerations and proposal of a classification system. Injury 29, Suppl 1, S1-S6.

Jekl, V., Tukac, V. et al. 2006. Endoscopic removal of a bullet from the cranial thoracic air sac of a peregrine falcon (Falco peregrinus). Journal of Avian Medicine and Surgery 20, 242-246.

Maiden, N. 2009. Ballistics reviews: mechanisms of bullet wound trauma. Forensic Science Medicine and Pathology 5, 204-209.

Miclau, T. and Farjo, LA. 1997. The antibiotic treatment of gunshot wounds. Injury 28 Suppl 3, C1-C5.

Rhee, JM and Martin R. 1997. The management of retained bullets in the limbs. Injury 28 Suppl 3, C23-C28.

Saukko, P. and Knight, B. 2004. Gunshot and explosion deaths. Knight's Forensic Pathology. London, Arnold: pp 245-280.

Volgas, DA, Stannard, JP et al. 2005. Ballistics: a primer for the surgeon. Injury 36, 373-379.

Volgas, DA, Stannard, JP et al. 2005. Current orthopaedic treatment of ballistic injuries. Injury 36, 380-386.