Praca oryginalna ***Original paper***

Postmortem diagnosis of gunshot injuries in great black cormorants (*Phalacrocorax carbo*) for forensic veterinary medicine

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Summary

Veterinarians rarely have the opportunity to examine shot animals. This inexperience makes it difficult to assess such cases. Based on the example of postmortem examinations of shot cormorants (*Phalacrocorax carbo*), the authors indicated the elements necessary for the proper diagnosis of gunshot wounds in birds. The study used mixed diagnostic techniques, including imaging diagnostics. Postmortem examinations of the corpses of 80 black cormorants obtained as a result of shooting with lead shot ammunition have been carried out. Autopsies and imaging examinations were performed. The results of the research were presented in the context of the needs of forensic veterinary medicine. Attention was paid to the characteristic anatomical changes caused by shotgun shells in the bodies of the birds. In addition, possible mistakes made during postmortem assessment of bird corpses were indicated. The method of using imaging techniques (X-ray and CT) in the diagnosis of gunshot wounds was presented. The possibility of using other imaging techniques, in doubtful cases that do not confirm gunshot wounds, was also indicated.

Keywords: gunshot wounds, birds, veterinary diagnostics, medical imaging, hunting, black cormorant

Bird hunting is common, and hundreds of thousands of birds are killed in Poland (millions in Europe) every year (10, 11, 24, 30). Nevertheless, veterinarians are rarely able to perform a post mortem examination on shot birds, and the number of birds that are treated for shot wounds is marginal. This is because of the legality of bird hunting. In general, veterinarians examine animals that have been shot illegally (23). These often only represent single cases. This group includes protected birds, mostly birds of prey (9). In such cases, law enforcement agencies (the police, the prosecutor's office, the State Hunting Guard) commission veterinarians to conduct post mortem examinations that may help to identify the perpetrators of such acts (8, 9, 27).

The previously mentioned lack of experience of veterinarians in the post mortem assessment of shot animals makes it difficult to properly perform the examination. Thus, it is difficult to conclude accurate findings. Moreover, the corpses of animals are usually placed on the autopsy table without additional information and are often in a state of decomposition, which can significantly hinder an in-depth assessment.

The aim of this study was to indicate the practical possibilities of using various diagnostic techniques to assess anatomopathological changes in birds as a result of shot ammunition.

Material and methods

This study was conducted on 80 corpses of common cormorants (*Phalacrocorax carbo*) that were obtained as a result of reduction hunting in fish ponds in the summer and autumn of 2019. Cormorants are partially legally protected in Poland (2). These birds are not protected in fish farming ponds (3). However, permission is required from state authorities to hunt these birds in such areas (2). Moreover, only hunters (members of the Polish Hunting Association) (the Act on Hunting) can engage in reduction shooting.

Hunting must be carried out in accordance with Polish law (1). That is why it is known that double-barrelled shotguns (top) and lead shot ammunition No. 4 (pellet diameter 3 mm) were to used to hunt the birds being examined in the present study. Polish law allows birds to be shot while in flight; therefore, the authors assume that the birds were hit while in the air.

The shot birds were frozen and delivered to the Anatomy Department of the Institute of Veterinary Medicine, Nicolaus Copernicus University in Toruń. All of birds underwent a complete necropsy. Before the post mortem examination, 20 randomly selected cases underwent a radiographic examination, and 6 of them underwent an additional computed tomography (CT) scan. The authors did not have the funds to perform these studies in all of the birds.

X-rays were taken in two orthogonal projections: ventral-dorsal and lateral. The radiographs were created with the Futura Max Pro (Intech) device. The scintillator that was used was cesium iodide (Csl), and images were taken at a 148 µm pixel resolution and in a working area of 425 × 425 mm. This examination allowed the pellets and their fragments as well as the location of these pellets and fragments in the bird's bodies. In addition, the radiographs revealed fractures and fragmentations of the skeletal bones. In-depth imaging diagnostics were performed using cone-beam CT (CBCT) and a FIDEX scanner (Animage, www.animage.com) with a 16 cm field of view and a plate thickness of 0.29 mm. Advanced filters were used during the 2D reconstruction process to enable the selected structures to be imaged precisely. The images were diagnosed by a veterinarian (specializing in veterinary radiology) who had been working in his own veterinary clinic for over 20 years.

The images that were obtained by means of CT allowed for the precise determination of the position of individual lead shots, which were characterized by high densities, in specific parts of the cormorant bodies. The applied tomographic technique with 3D reconstruction also enabled the shape of the projectiles and their fragments as well as the cormorant bone fractures to be visualized.

The bodies of all of the cormorants were subjected to a full autopsy. During the examination the lead shots and their fragments were retrieved. After the autopsy, the bones and their fragments were dissected from the bodies of twelve birds for the purposes of gunshot damage analysis.

The authors consciously refrained from statistical comparisons due to the multiplicity of factors influencing the effects of gunshots (12, 13). This assumption would require each gunshot to be treated as an individual and unique phenomenon (12, 13).

Results and discussion

The preliminary examination of the birds' corpses did not allow for the assumption of small arms shooting in all cases (Fig. 1). This was similar in the case of the ascertainment of fractures of the limb and neck bones.

The X-ray images show the presence of bullets as highly shaded round and irregularly shaped elements (Fig. 2). The examined animals were obtained from lead shot ammunition shooting, which explains the characteristic radiograph image. The combination of radiographs in the sagittal and lateral projections allowed for a more precise location of the shots. The analysis of the radiographs enabled the assessment of the damage to the skeletal system of the dead birds (Fig. 2). In some individual cases, bone lesions were found without the presence of highly contrasting elements (shots) (Fig. 2).

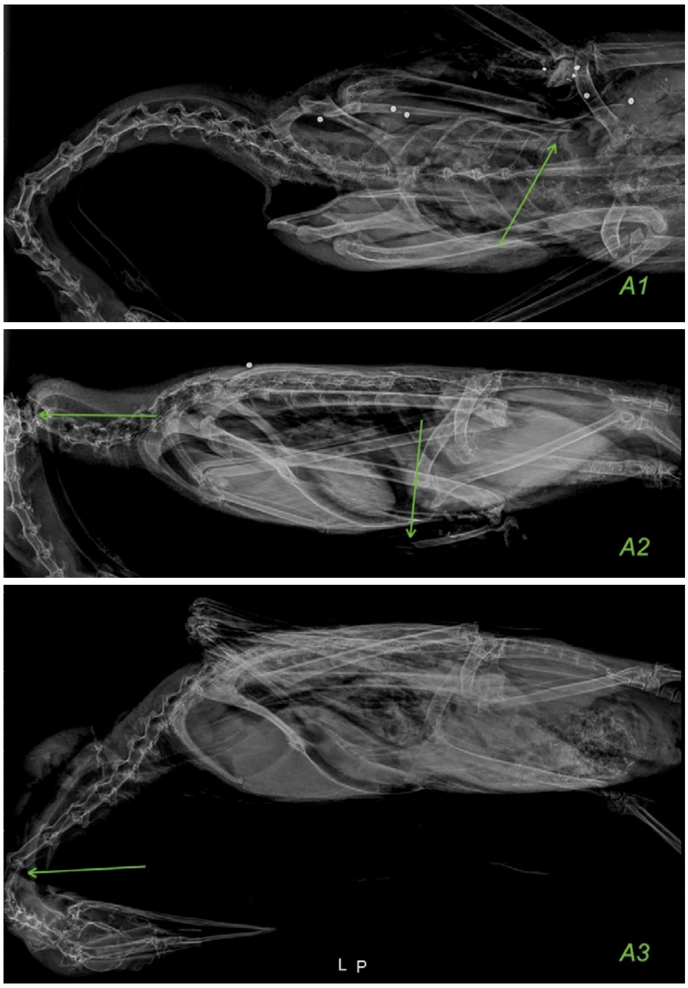

Fig. 1. Radiographs of three cormorants. Green arrows indicate bone damage. Mineral density white circles represent individual shot pellets. A1 visible projectiles of various sizes (defragmentation) and a humerus fracture. A2 one shot and two fractures visible. A 3 no projectile is visible, damage to the cervical vertebrae is visible, but may go undetected

Performing computed tomography enabled a more accurate, three-dimensional imaging of bone damage and the location of individual shots and their fragments (Fig. 3).

During the preliminary examination (before removing the plumage), not all birds showed feather damage and pathological changes to the skin suggesting gunshots wounds. After removing the feathers, the bird's skin displayed changes characteristic of gunshot wounds (Fig. 4). In a few cases, the changes were too unspecific to establish their cause solely on the basis of external examination. Most of the skin wounds were not covered with blood clots, but there was always a characteristic redness (hyperemia and extravasation) around the wound inlet (Fig. 4). After removal of the

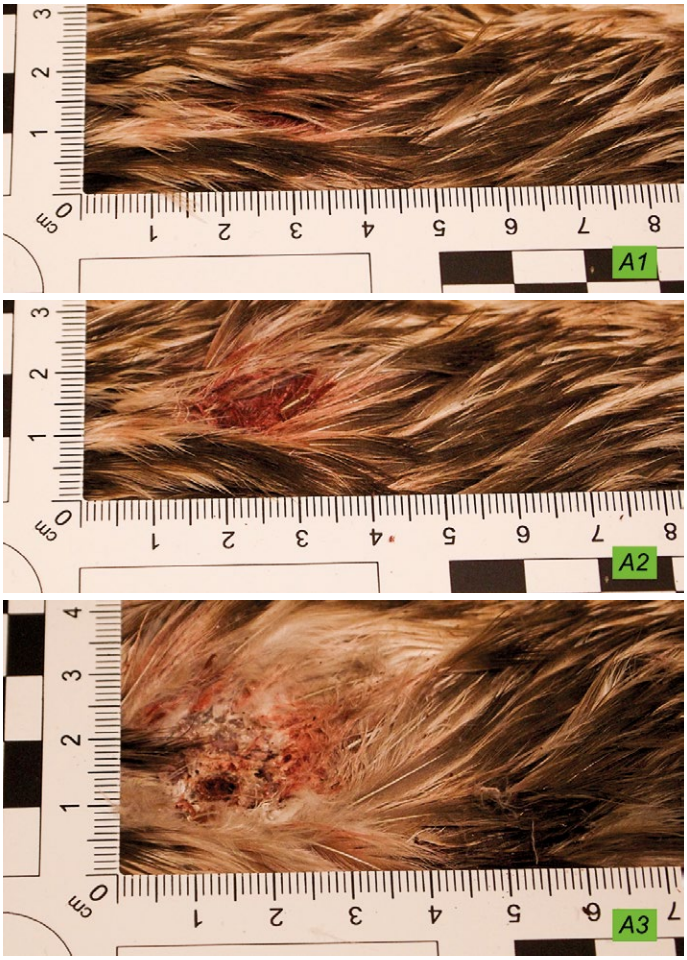

Fig. 2. The figures show changes indicating the possibility of a gunshot wound. A1, small areas of clotted blood are visible on the cover feathers. A2, after removing a few feathers the blood clots are clearly visible. A3, after removing more feathers the gunshot entry wounds can be seen

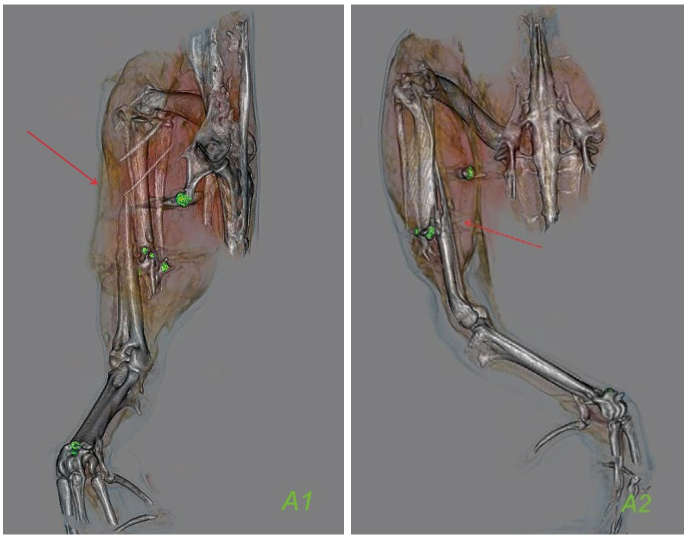

Fig. 3. Computed tomography (CT) images with filters showing bone tissue and shots (green elements). The images show bone fractures (red arrows) and the location of the pellets and their fragments. The images show the right limb and pelvis of the bird. Images A1 and A2 indicate the possibility of observations in any plane. The technique used allows for the examination of bones and pellets in different planes (from different sides)

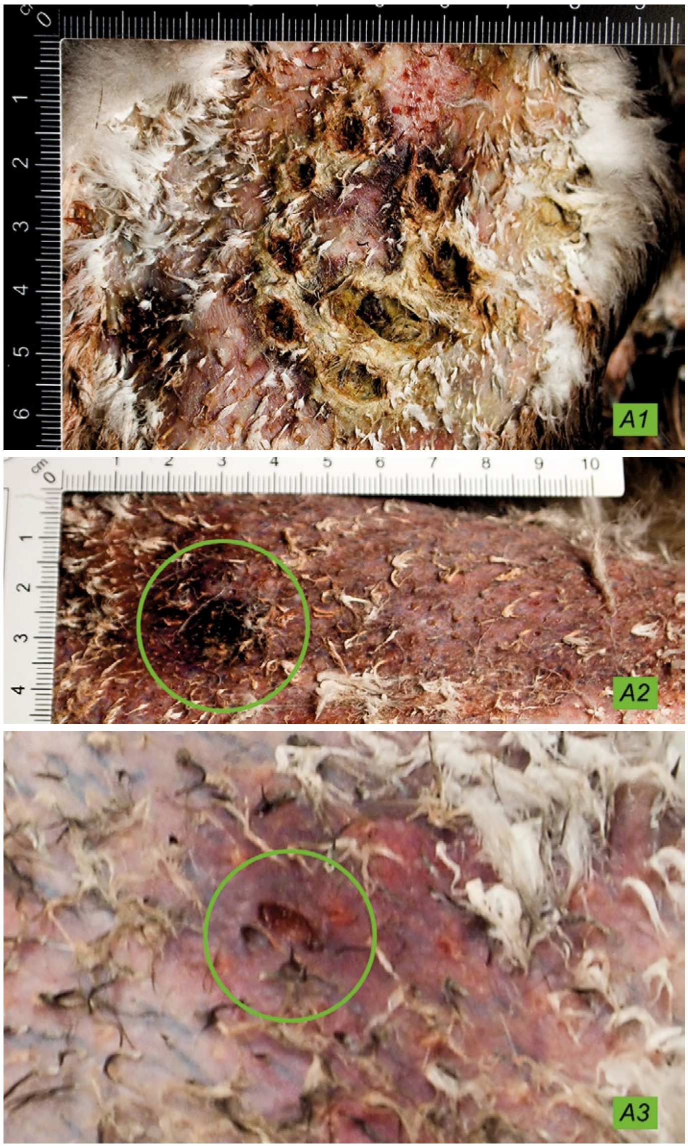

Fig. 4. Photos of bird skin after plumage removal. A1, characteristic for gunshot shots with shells, numerous skin lesions (gunshot entry wound) circular in shape with characteristic hyperemia around the edge. A2, single gunshot entry wound with characteristic hyperemia around it. A3, gunshot entry wounds inlet with no blood clots and with slight hyperemia around the edge. Image characteristic of projectiles with low kinetic energy. Such birdshots are usually situated just under the skin

skin, in the vast majority of cormorants the wounds visible in the muscles and tissues (located directly under the skin) were so characteristic (shape, blood clots, congestion around the wound) that they could be recognized as gunshot wounds (Fig. 5).

Round and oval lesions of the muscle tissue (about 3 mm in diameter) with slightly irregular edges were visible on the surface of the muscles (in particular the thoracic) (Fig. 5). These lesions most often appeared throughout the thickness of individual muscles, creating an irregular canal. There were areas of redness around the canal suggesting circulatory disturbances (extravasation and hyperemia) (Fig. 5). A characteristic feature of gunshot wounds in birds (shot with pellets) is the presence of feathers and their fragments in the

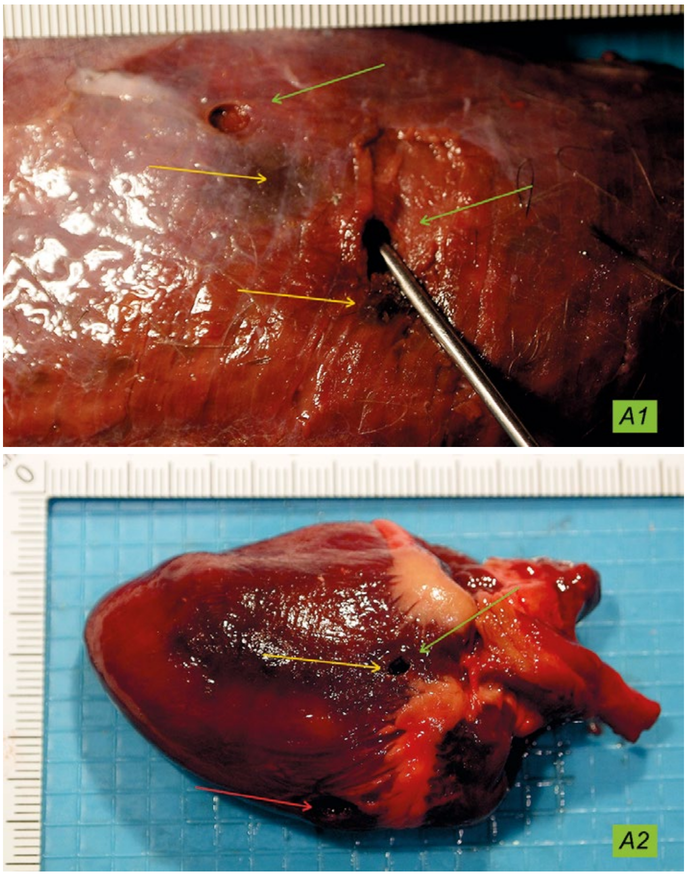

Fig. 5. Gunshot entry wound in the pectoral and cardiac muscles (green arrows) and gunshot exit wound (orange arrows) in the myocardium. Areas of hyperemia around gunshot wounds in muscles (yellow arrows). A1 characteristic for damage caused by pellets, oval entry in the external pectoral muscle and asymmetrical congestion in the areas around the wound (effect of the TC action). The rigid metal probe is placed in one of the wound channels, which enables the examination of the wound (distinguishing between penetrating and perforating wounds). A2 entry and exit wound in the walls of the heart muscle. The hyperemia, around the entry wound, is also asymmetrical (effect of the TC action). The gunshot exit wound is larger than the entry wound (characteristic for pellets)

wound canal, in particular in the pectoral muscles and the sternum (Fig. 6). The changes observed in the internal organs were varied. In birds shot in the heart, hemorrhages always occurred into the pericardial cavity. In the heart muscle itself, the bullet caused damage similar to that described above in the skeletal muscle (Fig. 5). Lungs damaged by the bullets displayed extensive pathological changes, and there were always profuse extravasations (blood clots) around them. There were areas of circulatory disturbance around the points of penetration, covering all or significant parts of the lobes. Intestines damaged caused by shots displayed discontinuities in the form of round and oval cavities in their walls (Fig. 7). In a few cases, these cavities were spindle-shaped or occupied a larger area of the intestine. The anatomical changes in the cavity of the bird's body were always accompanied by clots of various sizes or the presence of blood-colored fluid (Fig. 7).

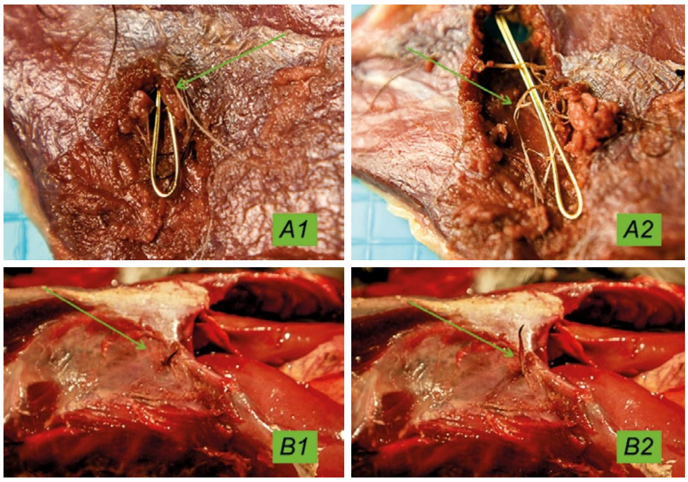

Fig. 6. The figures illustrate the presence of feathers and their fragments in the gunshot wound canal (green arrows), typical of shots with this type of ammunition. A1 fragments of cover feathers in the wound canal in the external pectoral muscle. And A2 more feather fragments were observed after cutting open the wound canal. B1 tip of a feather flag protruding out of a hole in the bird's sternum. B2 the same feather pulled out from the hole in the sternum for better visibility. A flexible probe (with a loop) is preferable to a rigid probe for examining a gunshot wound canal in birds (small animals, small organs). It allows penetration of the wound without damaging the walls of the wound canal. In addition, the loop allows the extraction of elements stuck in the wound canal. Feathers and their fragments are carried to the wound canal by pellets, and therefore allow the direction of the projectile to be determined

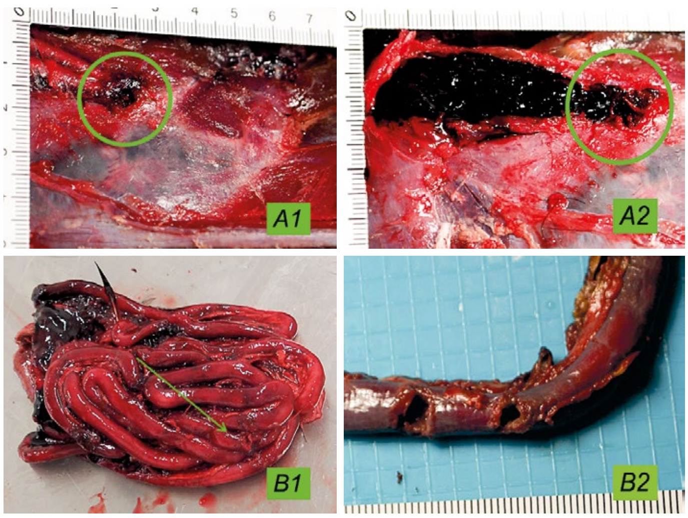

Fig. 7. The figures show damage to blood vessels and intestines as a result of shots. A1 gunshot entry wound on the border of the sternum and ribs (green circle) with characteristic hyperemia and a blood clot. A2 extensive blood clot under the ribs a result of damage to the blood vessels (the green circle was placed in the same place as in the previous photo). B1 intestinal wound characteristic of projectile damage shots. B2 projectile injury in the intestinal wall characteristic of pellets impact

Circular lesions penetrate the walls of the muscular stomach. There was congestion and extravasation around the wound canal. In the case of the goiter, the gunshot damage to the wall of this organ was difficult to notice in the autopsy due to the lack of congestion.

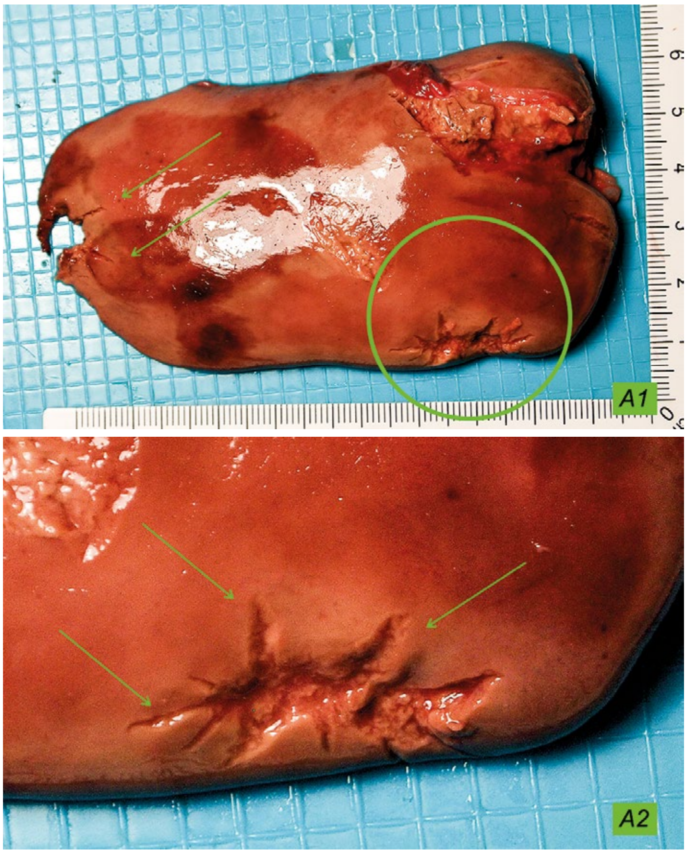

Fig. 8. The figures show liver damage resulting from shots. The characteristic ruptures of this organ (green arrows) arise as a result of the action of the TC (projectile energy transfer to the outside of the wound canal in the damaged organ). A1 whole liver with shot-projectile tears and concentric cracks. A2 Closer view of the area marked by the green circle

Characteristic changes in the liver are noteworthy. This inflexible and fragile organ is subject to the action of a temporary cavity (TC) which tears the lobes perpendicular to the axis of the wound canal. This manifests itself in characteristic concentric (star-shaped) cracks on the surface of the liver (Fig. 8).

Long bone fractures found during autopsy were not always characteristic enough to be attributed to small arms shots. However, multi-fragment fractures with numerous small fragments of damaged bone around the point of the alleged shot should be considered characteristic of gunshots. Some of the fractures were multi-fragmented with numerous pieces of small bone (Fig. 9). In some birds, these fractures were observed simultaneously with skin breakage (open fractures). Fractures of the forearm and lower leg bones (arranged in parallel) in most cases showed multi-fragment fractures in one of the bones, while the other displayed transverse fractures. In multi-fragment open fractures, part of the bone fragments was outside the body of the birds (Fig. 9). The sternum lesions appear as round and oval holes with a diameter comparable to the diameter of shots in the body of the cormorants. In other flat bones and in the cervical vertebrae, shots cause characteristic damage. If the projectile does not penetrate a bone, the entry wound has a diameter smaller than

Fig. 9. Highly comminuted fracture of the long bone characteristic of a gunshot. A1 dissected bone fragments. A2 reconstruction (gluing the available fragments) of bones from dissected elements. A3 close-up of a bone fragment with some visible missing fragments. A4 the same close-up from another side with visible splinters

the diameter of the projectile and the bullet remains in such a hole or in its immediate vicinity. In the case of bone penetration, the hole is only slightly larger than the diameter of the shot. In both cases, on the surface of the bone on the other side of the shot, characteristic conical extensions of the diameter of the hole formed by the projectile can be observed (Fig. 10). Flat bird bones, in particular the sternum, are more flexible (fibrous) than long bones, therefore on the other side of the shot flat bone there are often characteristic visible bends of the bone's fragments (Fig. 10). As a result of shots hitting the external bone damage in the form of chipping off the external fragments can be observed. This is clearly seen in skull bones damaged by pellets (Fig. 11).

In Poland, a No. 4 lead shot (ball diameter 3 mm) is usually used for hunting birds (such as ducks, pheasants, or cormorants), while lead shot No. 3 (ball diameter 3.25 mm) is used less often. Such small birdshots do not always damage the feathers. Wounds that are obtained from these types of shots do not always bleed profusely enough for the blood to stain the feathers. This type of ammunition (pellet) does not always deal

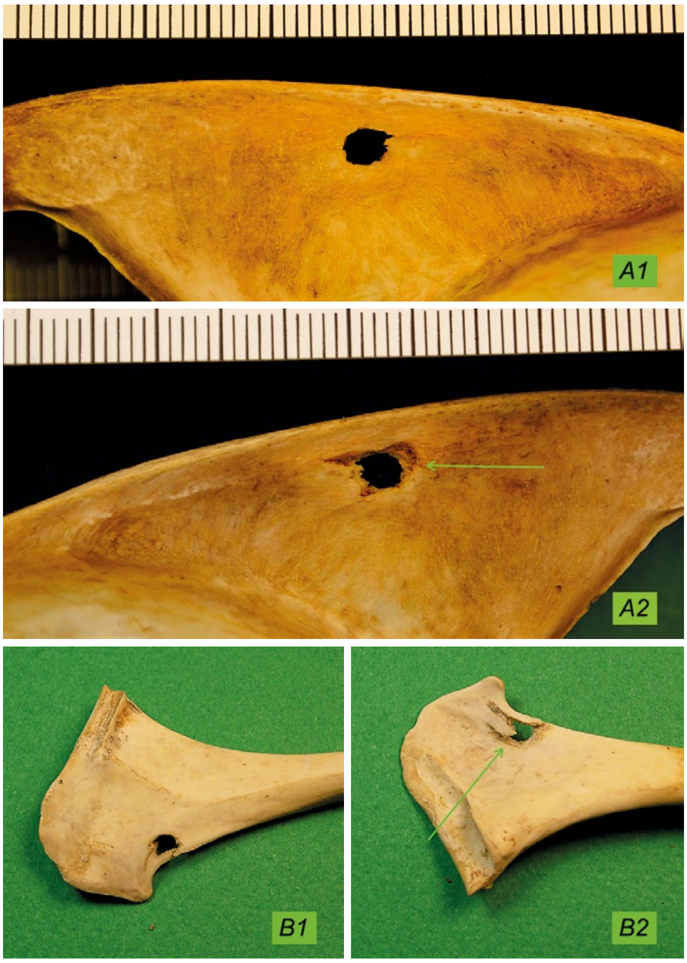

Fig. 10. Images showing characteristic shot damage in the flat bones. A1 sternum crest with a shot hole. A2 characteristic splinters of the sternum bone on the other side of the bone (green arrow). A1 and A2 – the damage was caused by a shot fired from the side of a cormorant. B1 damage to a fragment of the coracoid bone caused by a shotgun projectile. B2 characteristic splits and bends of the bone on its other side (green arrow)

Fig. 11. Skull bone injuries characteristic of gunshot. A1 external fragment of the frontal bone damaged by a shot (green arrow). A2 bone splitting characteristic of shots

the same amount of damage as gunshot wounds. Thus, a cursory external examination does not always allow for the detection of (suspicious) gunshot wounds. If an animal's body was delivered in a package (foil bag, plastic container), then the first radiograph should be taken together with the transport package (without opening it). This is to show projectiles or their fragments in the feathers or hair and any extensive wounds that have been caused by those fragments or pellets (33). These items may remain in the container/package or may fall out of the container. Because of this, it is possible to lose elements that may be important for diagnosis. For this reason, animal carcasses should be handled very carefully (33).

The best way for veterinarians to reveal gunshot shells that are present in the bodies of birds is to perform digital radiography imaging, preferably in the ventral dorsal and lateral views. In the vast majority of cases this type of evaluation us able to detect the presence of even the smallest amounts of high-density elements (lead, iron, tungsten) in the animal's body. In terms of the forensic veterinary examinations that were examined here, it is important to note that not all of the birds showed changes (signs) that were indicative of gunshot injuries during the initial examination. However, in cases where it is possible that a bird has been shot, an X-ray should be taken. Because commonly used ammunition is made of high-density materials, it is always visible in X-ray examinations. In addition to the person who is assessing these X-rays having adequate experience, the technical quality of these images is also important for a correct diagnosis to be determined (15, 16, 33). Some of the photos that had been commissioned by the authors were taken incorrectly. Cormorants have a long neck; therefore, when taking X-rays in the sagittal/lateral and torso-abdominal/frontal projection, the birds' necks and heads should be very carefully positioned. Digital radiography should be the standard procedure for a veterinarian when diagnosing the cause of death in birds, especially for forensic veterinary purposes (7, 9, 14-16, 19, 23, 25, 29-33). Moreover, digital radiography images reveal fractures and other bone damage (7, 9, 15, 16, 32). These injuries should always be considered as a consequence of gunshots, even if no pellets are found in the birds' bodies. It is important to remember radiographic examination when conducting these investigations (16). This is particularly the case when examining animals with long necks.

If there are suspicions that an animal has been injured due to a gunshot wound, a CT examination should be performed whenever possible (4, 9, 15-17, 33). When assessing the images that are obtained from a CT examination, it is worth using an appropriate software that allows for 3D reconstruction and filters that allow the birdshots and bone tissue to be visualized in different colours. This allows for the pellets and any pellet fragments to be easily and precisely located (4, 7, 16). Moreover, these reconstruction and filter abilities make it possible for bone damage to be ideally illustrated (4, 7, 15, 16, 33). In the present research, the authors only used basic CT capabilities. CT is very useful in forensic veterinary medicine (not only for gunshot wounds), and the device should always be used properly. It is worth entrusting this examination to a veterinarian who is a specialist in radiology. Care should also be taken to properly position the animal's carcass during the examination (14-16, 33). Each case (specific animal) should be approached individually. Not all tomographs have the same technical parameters (14, 16), but the modern ones allow high-quality images to be obtained. A detailed description of the parameters that are necessary to obtain CT images that are useful in forensics (e.g., contrast, spatial resolution, artifacts, acquisition parameters, extended computer tomography scale) is available in scientific reports (14, 15, 33).

It is worth mentioning that lead projectiles are not used in many countries. In addition, shots may be fired from unusual weapons, or unusual types of ammunition may be used (wooden, plastic, rubber, and the like). The density of these materials requires the CT device to be properly scaled and set (15, 33). Note that the use of lead shots for bird hunting has been prohibited in many countries, such as in the USA, since the 1990s. Various metal alloys (e.g., iron and tungsten), polymers, and ceramics are used in the production of shotgun shells. Therefore, the use of such ammunition can cause the x-ray images to be affected and requires the use of different/special diagnostic imaging techniques (16, 33).

Although the authors did not have access to magnetic resonance imaging (MRI), this diagnostic technique is worth mentioning. Many publications have indicated the usefulness of this technique in other studies that have focused on imaging gunshot wounds, especially in those that occur to soft tissues. MRI allows the pathological changes that are caused in these tissues by pellets to be observed and even enables traces of projectiles in soft tissues (e.g., comet tail effect) to be observed (15, 26, 33). It should be remembered that ammunition manufactured from materials other than lead is increasingly being used. MRI for such materials may not be of much use. In the post-mortem examination, this method does not take into account the threats to the health and life of live animals. Imaging diagnostics are not always available. Therefore, a full autopsy should always be performed. Post mortem examination allows for projectiles and their fragments to be recovered from the animal's body, which may be helpful for investigators (police) (9, 18).

The autopsies that were conducted without prior X-rays likely did not reveal all of the pellets in the birds. Radiographic examination, CT scans in particular, were very helpful for finding metallic fragments during the autopsies. However, even with the results of radiography and computed tomography, it was sometimes difficult to localize the pellets (9). There were two reasons for this. The first is the presence of lead shots in the lumen of the digestive tract or in the body cavity (7). Due to their high specific gravity, such projectiles migrate when the animal is transferred and when sections are performed. The second reason (especially in the case of projectile fragments) is the movement of projectiles within significantly disrupted areas. Birdshots damaging long bones (limbs and wings) turn them into secondary projectiles, increasing the extent of their damage. These fragments are not permanently embedded. They are able to move freely; therefore, in the present study, they were found in other places than those that were indicated by radiographs and CT examinations (9, 33). Some pellets were found while dissecting damaged bones.

Cavities that were characteristic of gunshot wounds were observed on the birds' skin at the points where the projectiles hit. Slight hyperemia and extravasation were found in most cases around round and elliptical skin defects. It was clear that these skin defects were caused by impact with elements that were moving at high speeds (several dozen or several hundred meters per second). The edges of such wounds cannot be brought together by restoring the original shape of the skin. Contrary to gunshot wounds, wounds resulting from the impact of slower moving objects on the skin (stab wounds and bites) do not show cavities; thus, their edges can be easily brought together, thus restoring the original state of the flesh (20). Shot shells lose their speed after they leave the barrel, thus hitting the bodies of birds at different speeds. Hits from a greater distance can damage the bird's skin as well as other parts of the bird's anatomy. In this case, they most often remained just under the skin (9). In some cases, their energy is so low that they do not pierce the skin, leaving traces in the form of a circle-shaped hyperemia, where the intensity of the hyperemia is clearly greater in the central part.

In the birds' muscles, especially in the pectoral muscles, the birdshots cause damaged in the form of round-edged canals with pronounced, although irregular, hyperemia around them (8, 9, 12). Blood clots were present in these wounds. Similar changes can be caused by other ball or circle-tipped objects that move much slower than shots do (slower than a few meters per second) (12, 20). However, in such cases, circulatory disturbances around the wound canal in the form of hyperemia and extravasation that are characteristic of the TC cannot be observed (12, 20). The distinguishing feature of gunshot wounds in birds is the presence of feathers or their fragments. These elements were present in the vast majority of cases and were found in the wound channels in the muscles.

Soft tissue penetrating bullets can damage them larger than their own diameter (due to TC generation). This is especially true for organs and tissues with low elasticity. This feature makes it possible to distinguish gunshot wounds from wounds that are caused by the action of other objects (12, 20).

When gunshots hit a bird's lungs, they usually cause extensive damage. Even if the projectile does not damage the pulmonary lobe (elastic organ), it always damages blood vessels (effect of TC), which manifests itself in extensive circulation disturbances (bleeding, congestion, blood clots). Similar circulatory disturbances, in the form of pericardial extravasation (with time, clots), were observed with gunshots to the heart. However, in this case similar pathological changes could also be observed as a result of other factors. The heart muscle, an elastic and stretchy organ, is resistant to the destructive effects of the TC; therefore, the changes that occur in this organ are not very characteristic (especially for an inexperienced pathologist). Birdshots that hit the heart must make their way through the bird's body, the skin and deeper tissues, and sometimes the sternum. Thus, when these shots hit the heart, their energy is relatively low. As a result, pellets or their fragments were the most often found in the heart muscle or in its immediate vicinity. Gunshots to the crop, especially in birds with extensive organs (cormorants), manifest themselves in the form of circular lesions in their wall. Due to the small vascular network in the wall of this organ, hyperemia is rarely observed around the canal. Thus, gunshot wounds may be confused with injuries that have been inflicted by other circular objects (20). When suspecting gunshots to the crop, it is important to note that the pellets may be contained with the bird's stomach contents (e.g., fish in cormorants). The wounds in the walls of the muscular stomach were more characteristic. In this case, they were round, and their diameter was greater than the diameter of the birdshot (greater than 3 mm). This is due to post mortem relaxation of the stomach wall after the bird dies. On the external wall of the organ, around the wound caused by a shotgun projectile, slight hyperemia is visible, something that is absent in wounds of a similar shape that are caused by other factors (12, 20). Shotgun damage to the intestine can take many forms (from circular to spindle-shaped), and large fragments of the intestine can also be damaged by these types of shots. The intestines of the birds were rarely deprived of food contents and thus demonstrated relatively high inertia. Fast-moving birdshots destroy intestinal fragments in a similar way to how they destroy the skin (permanent cavities). Contrary to wounds that are caused by other objects (travelling at a much slower speed), the edges of intestines that have been damaged by pellets cannot be fit back together (12, 20). It should be emphasized that the presence of lead shots in the gastrointestinal tracts of birds, especially in the initial section (up to the muscle stomach), does not have to be a consequence of gunshots. Herbivorous birds swallow lead shots, as they tend to mistake them for small pebbles (gastroliths), which stay in the muscular stomach for a longer period of time. On the other hand, birds of prey can swallow pellets that are stuck in the bodies of animals that they hunt (30).

The liver demonstrated the most characteristic changes caused by birdshots. These changes cannot be confused with those resulting from other causes. The liver is a fragile solid organ that is prone to fractures from concussive force. When a shotgun projectile penetrates this organ, especially when it has been deformed, it generates an extensive TC in the liver (12). This phenomenon causes the organ to break concentrically around the gunshot wound canal. The effects of this TC were clearly visible in the form of radial ruptures of the liver lobes.

As gunshot projectiles move at high speeds, they leave a great deal of characteristic bone damage. This is most clearly seen in flat bones, particularly in the sternum. The sternum is made of thin and flexible bone plates, so when pellets hit this bone, the pellet punches out of it, producing circular or ovoid defects with regular edges. Those with less energy remain in the bone, causing the characteristic bending of the bone plates on the opposite side. Those with more energy produce a punch/cut hole that is comparable in size to the diameter of the pellet making the hole. Similar damage is caused to other thin flat bones. In bones that are thicker than the sternum and that have a denser structure, lead shots chip off bone fragments (12, 27). A characteristic feature of this type of damage is its conical expansion, which is compatible with the projectile velocity vector (18). Long bones with a denser structure were subjected to multiple fractures as a result of the gunshots (7, 9, 17). Characteristics of gunshot wounds directly to the ulna or tibia were the simultaneous fracture (without fragments) of the corresponding radius and fibula.

The conical widening of the holes in the long bones, something that is characteristic of flat bone injuries, cannot be observed due to their fragmentation. However, in most cases this type of damage can be observed on the bone fragments that have been in direct contact with the birdshots. Long bone fragmentation is a characteristic of shotgun wounds (7, 9). Due to the high speed of the projectiles, the energy of the pellets is transferred to the bone fragments, which act as secondary projectiles, tearing the skin apart and exiting the body (8). With open multi-fragment fractures, the norm/regularity is the absence of bone fragments in the bird's body. Due to the diagnostic value, especially in the case of failure to reveal shots in imaging tests or the inability to perform such tests, it is worth retracting damaged long bones along with their fragments and trying to reconstruct them. Such a procedure enables injuries that are characteristic of gunshots (e.g., conical holes or splinters) to be observed as well as the absence of individual fragments in open fractures to be ascertained. The characteristic bone changes that are caused by projectiles were very persistent and can be observed despite the decomposition of soft tissue and even this tissue has been burned (5, 6). Other bone lesions caused by other factors were also characteristic and different from the changes observed after gunshots (7, 9, 20).

The shots at birds in flight were most often fired from below; hence, the shots mainly hit the pectoral muscles of the bird, damaging the sternum and coracoid bones. In most cases, the direction from which the shot hit the animal can be determined by analyzing the flat bones that have been damaged by the projectiles (9, 11). In the case of birds shot on land or water, the pattern of soft tissue and bone damage most often allows for similar findings. When assessing both an X-ray image (also CT) and during post mortem examination, it is important to remember that the bird may have been shot while in motion (e.g., it was flying or moving on water or on land). In this case, the mutual arrangement of the individual body parts at the time of the shot could differ significantly from the position of these elements during the autopsy (also during imaging tests) (9, 33). This is of particular importance in the post mortem assessment, as the damage to individual tissues and organs caused by the pellet in the body of the bird delivered for examination most often does not line up – the original wound trajectory may lose its continuity after making impact with the animal. The authors repeatedly noticed a shift in skin lesions in relation to muscle lesions. Similar "mismatches" could also be seen in the anatomical elements that make up the wings. The hind limbs, neck and head seem to be the least susceptible to this type of displacement.

In the case of birds that eat fish and swallow them while foraging, the possibility of the lead shot penetrating the crop and entering the body of the swallowed fish should be taken into account. In the case of cormorants, it is impossible to swallow pellets, as these birds only eat fish. However, for other bird species (e.g., ducks, swans, or pheasants), this possibility should be considered. Many birds do not distinguish shot ammunition from pebbles and therefore swallow and retain them in the muscular stomach (11). Some birds that are shot with this type of ammunition survive the gunshot and live, even with a few pellets in their tissues. Such projectiles can be easily identified given that enough time has passed from the shot and given that the body has had time to complete the healing processes (9). In the case of shots occurring one after another in a short period of time (several days), it is indistinguishable. This is also the case when a body is being examined a long time after being shot. In such cases, it is helpful to evaluate and compare the pellets that have been recovered from the body of the animals or to evaluate them on an X-ray. If the undeformed projectiles differ in diameter (different caliber), then the assumption that the bird was shot multiple times can be made (9).

In the differential diagnosis, especially in game birds, the occurrence of bite wounds caused by hunting dogs should be taken into account. Similar wounds may occur in flightless birds (birds with damaged wings, during feather replacement, or young birds) that are caught and bitten by dogs. Skin wounds caused by teeth are at first glance very similar to gunshot wounds.

If a gunshot is suspected, especially if there were no strong shading elements on the X-ray or CT scan, defects near or between skin lesions that are suggestive a gunshot wound should be sought (9, 15, 16, 33). Other existing imaging techniques (e.g., PET, SEM-EDX, or ICM-MS) that are applicable in the diagnosis of post mortem wounds in forensic veterinary medicine were not taken into account due to their costs and limited availability (21, 22, 28, 34).

Veterinarians are rarely able to perform an autopsy on birds that have died as a result of gunshots. These are usually isolated cases where a bird has been killed or injured illegally. This group includes protected birds, mainly of prey. Since many veterinarians are inexperienced in evaluating autopsies of shot animals, it becomes difficult to perform the examination properly. Due to the increasing frequency of court cases involving the shooting of animals, knowledge of the characteristics of gunshot wounds seems essential for modern veterinarians. At the initial stage of the investigation, it is often necessary to find out if the animal was shot (killed) with small arms. This knowledge is also necessary for veterinarians, radiology specialists who perform diagnostic imaging examinations. The knowledge and application of various diagnostic techniques facilitates the proper assessment of gunshot wounds in birds.

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