INTERACTIVE AVIAN ANATOMY: FUNCTIONAL AND CLINICAL ASPECTS

(The complete interactive program with images can be accessed at: http://www.um.es/anatvet/ingles/interactive.php)

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Chapters:

INTRODUCCION

Flight is the most important characteristic of the bird, and the entire organism has evolved to aid this function. The anatomical adaptations for flight must be considered by the veterinarian in order to solve common clinical conditions in the bird. Therefore, a good anatomical knowledge is essential to make a precise diagnosis and treatment. In this chapter we will enphasize the most important anatomical characteristics of birds related to flight.

COMMON INTEGUMENT

The skin of birds is thin, dry and yellow-white in colour, with few vessels and nerve

endings; so it tears easily without apparent haemorrhage or pain. Subcutaneous injections can be administered at the level of the axillary and inguinal skin folds, or in the dorsal region of the neck. Although the epidermis is thin in all feathered areas, it is condensed and keratinised in certain places, forming structures such as the rhamphothecae of the beak, and the spur which are present in some species on the medial aspect of the tarsometatarsal region. At this level the epidermis is also modified and forms scales, similar to those in reptiles. However, without doubt the most characteristic development of the skin is the presence of feathers.

Feathers are specialised epidermal structures, without no living cells and very little keratinisation or mineralisation. Feathers have a diverse range of functions: helping to control body temperature; acting as an aerodynamic force during flight; colouring allows camouflage or communication between different individuals etc. In the adult bird there are three main types of feathers:

a) Contour feather: remiges, rectrices, coverts and tectrices.
b) Down feathers: Small feathers overlaid by the contour feathers Psittacines have a special kind of down feather; dusty down feathers.
c) Filoplume: related to proprioception.

Feathers are distributed over the body and are arranged into specific areas called pterylae, in between which there are bare areas or apteria. Recognising the pterylae and apteria is important in the case of any surgical intervention in order to avoid damage to the feather follicles. A typical feather is composed of the calamus (proximal part implanted in the follicle) and rachis (distal part). On either side of the rachis is a row of parallel barbes, which form the vane. A distal umbilicus is found on the proximal end of the calamus, the area where the papilla of the feather is enclosed by blood vessels and nerves.

Both smooth and skeletal muscles (patagial tensor muscles, tail muscles) control feather movement. Birds shed their feathers once a year, often in summer and autumn. Some species lose all their feathers at the same time, while others do it gradually. Parrots usually change their plumage throughout the year. The immune response is reduced during

shedding.

Feathers which are accidentally pulled out, with the exception if primary and secondary remiges, usually re-grow in 2-4 weeks if the follicle isn't damaged. However, cut feathers do not regrow until the next shedding. Grafting of essential feathers for flight (remiges and rectrices) is possible because of the internal structure of the rachis.

The plantar surface of the digits and metatarsophalangeal joints is covered by elevated pads (poorly vascularised adipose tissue). Comb, wattles, ricti and ear lobes are ornamental appendages. In these areas the dermis is thickened and highly vascularised, whilst the epidermis is very thin and easily damaged, which can lead to large bleeds.

The skin does not contain sebaceous or sweat glands, with the exception of those present in the external ear canal (sebaceous) and the so called uropygeal gland. This consists of a body with two lobes, situated underneath the skin, adjacent to the pygostyle. The gland secretion is a sebum rich in wax and oils which the bird smears over the feathers cleaning them and waterproofing them. Some components of the sebum are transformed into activated vitamin D3 upon exposure to sunlight, which is then ingested by the bird whilst preening. The uropygial gland is not found in all birds; it is absent in certain strains of pigeon, many parrots, emus, ostriches and woodpeckers. Subcutaneous connective tissue is scarce and this means that the accumulation of fat in certain regions (thorax and abdomen) is common.

SKELETON

The avian skeleton is much lighter than that of mammals, in fact, a large part of their bones contain air (pneumatization) instead of bone marrow. These cavities are communicated with the respiratory system and act to decrease weight, so flying is easier.

Bones which are not pneumatised include most vertebrae, and those distal to the humerus and pelvis. Avian bones are richer in inorganic substances (calcium phosphate). Long bones have a very thin cortex and the medullary cavity contains a network of trabeculae,

which increases the strength of the bone.

These factors mean that avian bones are harder, but at the same time more fragile and less elastic than those of mammals. This means that when fractured they splinter easily, but it is impossible to use plates or intramedullary screws to aid healing as they destroy the internal structure. Making external fixators is the most appropriate treatment for fractures.
Characteristic features of the avian skull include the vaulted cranium, the large bony orbits, separated by the interorbital septum, and the beak-sheaped pyramidal face. The boundaries between different bones is hard to define because of the conversion of sutures to synostosis, a few months after hatching. The upper jaw is formed by the nasal bone, maxilla and premaxilla and the lower jaw by five little bones that fuse forming the mandible.

Notable features in the avian skull include the presence of a single occipital condyle and the so named quadrate bone which connects the mandible to the skull (temporal bone). Quadrate bones are the most important component of the maxillopalatine apparatus. These enable the upper and lower jaw to move simultaneously, while the quadrate bone turns, increasing the size of the gape.
In psittacines (parrots) the craniofacial joint is synovial and the range of movement of upper and lower jaws is wider and stronger. Most of the skull bones are pneumatised. These bones communicate with the nasal and tympanic cavities, so that the weight of the head is reduced and this helps flying. The absence of teeth also contributes to this.

Skeleton of trunk (vertebrae, ribs and sternum).
The avian rachis consists of cervical (C), thoracic (T), sacral (LS) and coccygeal (Cd) vertebrae.

The vertebral formula varies between different species, and in comparison to mammals there are a larger number of cervical vertebrae. Generally the formula is: C14, T7, LS14, Cd6. The number of cervical vertebrae is variable (13 to 25). These vertebrae have got

prominent transverse processes for muscle attachment. The “S” shaped neck is needed in some species, in order to protect the encephalus from the shake produced during take off and landing.

The small ring-shaped atlas articulates with a single occipital condyle, so that the atlanto-occipital joint is very mobile, which allows the head and beak to move in different directions. The number of thoracic vertebrae is fewer than in mammals (5 to 7), and many of them fuse forming the notarium bone. The first vertebra following the notarium is the only mobile vertebra of the rachis. Trauma can cause this vertebra to move ventrally damaging the spinal cord, causing the pathology known as “kinky back”. The last two thoracic vertebrae fuse with the lumbar, sacral and first two coccygeal vertebrae, forming the synsacrum bone, which finally fuses with the ilium. The notarium and synsacrum give strength to the rachis. The first coccygeal vertebrae allows tail movement, while the last 4-6 coccygeal vertebrae fuse, forming the pygostyle.

Ribs are found on both sides of the rachis, the first two or three are “false ribs”, while the rest are “true ribs”. The bony ribs are divided into two parts, the vertebral (proximal) part, and the sternal part. The ribs in the middle of the thorax have uncinate processes which rise in a caudodorsal direction and lie against the lateral surface of the next rib. This allows the thorax to support the ventral movement of the wing while flying.

The sternum is a large bone with many processes, notches and openings.There are pneumatic openings on its dorsal surface which communicate with the clavicular air sac. The spine of the sternum on the ventral surface (keel) is where the pectoral muscles insert. This landmark is well developed in flying birds (carinates). Conversely, in birds which do not fly (ratites) the ventral surface of the sternum is flat. The subcutaneous position of the sternal keel is useful to obtain bone marrow samples in large cage kept birds, but also makes them vulnerable to deformities and injuries of the sternum when they rest on inadequate perches. The caudal extremity of the sternum is cartilagenous in young birds and ossifies with age. Therefore, its flexibility can be used as an indicator of the age of the bird.

Skeleton of the pectoral limb.

The transformation of the pectoral limbs into wings has caused important changes. There is a complete appendicular skeleton formed by three bones: coracoid, clavicle and scapula. The thoracic skeleton has fewer bones than that in mammals and the humerus is pneumatized.In the proximal thoracic skeleton the coracoid bone is well developed, and connected to the sternum by the pectoral limb. It holds the wing away from the sternum during flight, and prevents the thorax from collapsing during the downstroke of the wing. The two clavicles fuse ventrally to form the furcula; which joints the sternum and coracoid bone by the sternocoracoclavicular membrane (membrana sternocoracoclavicularis). The furcula acts as a spring holding the shoulder joint at the right distance during flight. The clavicle may not be present or may be reduced in some species of parrot. The scapula is narrow and curved, lying laterally and dorsally to the thorax, and attached to it by muscles and ligaments. Between the three proximal bones (coracoids, clavicle and scapula) a canal is formed (the triosseal canal), which is a passage for the tendon of the deep pectoral muscle.

The avian humerus is similar to mammals, but pneumatized. The pneumatic opening is situated on the proximal end, where two tubercles are seen (dorsal and ventral) for muscular insertion.

While the wing is folded, the humerus lies against the thorax and parallel to the scapula.

The ulna is more developed than the radius and both are bowed along their length, so they are protected against bending forces. The distal epyphisis of the ulna can be used for intramedullary administration of substances.

There is a great reduction in the number of carpal bones, compared to mammals. The proximal row consists of a radial carpal bone and an ulnar carpal bone, while the distal row fuses with the metacarpus forming the carpometacarpus. The three digits are the major digit, with two phalanges, the minor digit, with one phalanx and the alula digit, with two phalanges.

Attached to the skin over the carpometacarpus and the phalanges of the major and minor

digits there are the primary flight feathers. The alula digit forms the skeleton of the alula or bastard wing.

Skeleton of the pelvic limb.

The pelvic limbs are involved in locomotion, both on land and in the water. The proximal skeleton consists of three bones, as in mammals: ilium, ischium and pubis, which form the girdle. The two girdles do not fuse ventrally (and therefore the pelvic symphisis is not present), except in a very few species but ilium fuses with the synsacrum. The ischium is proportionally larger than in mammals, forming a large part of the lateral wall of the pelvis. The pubis is long and thin, palpable through the skin and its flexibility indicates the age of the bird.

The distal end of the femur slopes craniolaterally bringing a large part of the hind limb close to the centre of gravity of the body. A patella is present and fibula is reduced to a thin bone. The tibia is fused with the proximal row of the tarsal bones to form the tibiotarsus. The femur and tibiotarsus are very rich in bone marrow, unlike other long bones. The foot skeleton is formed from metatarsals II, III and IV, which fuse with the distal tarsal bones forming the tarsometatarsus. There is a small metatarsal remnant which is attached to the tarsometatarsus by ligaments. Thus in the bird there are four digits in the foot (I to IV), formed by either two, three, four or five phalanges. The most distal phalanx forms the bony core of the claw.

JOINTS AND SKELETAL MUSCLES

Avian musculature contains an increased density of muscle fibres and less connective tissue than that of mammals. Intramuscular fat is scarce and the colour of the muscle is dependent on the region of the body and the species.

In flying birds the pectoral musculature is redish in colour, indicating a large number of muscle fibres rich in myoglobin (oxidative aerobic metabolism), whereas in birds which

do not have the ability to fly, this musculature is pale due to the predominance of white glycolytic muscle fibres (anaerobic metabolism). The main muscles involved in flight are the pectoral muscles (breast). There is a *superficial pectoral muscle* and a *deep pectoral* or *supracoracoid muscle*. The superficial pectoral muscle extends from the keel of the sternum, the clavicle and the sternocoracoclavicular membrane, to the pectoral crest of the humerus. This is the main depressor of the wing. The deep pectoral muscle lifts the wing from the keel of the sternum. It develops a tendon that passes through the triosseal canal to the dorsal surface of the humerus. This tendon can be ruptured if a traumatic event occurs (flying into a window, for example) and the classic presentation is seen as the bird being unable to lift its wing. In this case repair of the tendon is required. However, by bandaging the affected wing the usual formation of a callus in the trioseum canal results in the same outcome. The pectoral musculature should always be examined as it indicates the nutritional state of the bird. It can also be used as a site for intramuscular injections. The caudal part of the superficial pectoral muscle is recommended as the cranial part has an abundant blood supply, and this increases the risk of injecting substances directly into the bloodstream.

Among the muscles of the wing, the extensor carpi radialis should be emphasized. It originates from the medial epicondyle of the humerus, extends over the cranial surface of the carpal joint and ends in the carpometacarpal extensor apophysis. Flight is also facilitated by the propatagium,a cutaneous triangular fold in the cranial part of the wing, which extends between the the shoulder and carpus.On the ventral surface of the propatagium access to the cutaneous ulnar vein is possible, making it an appropriate site for venipuncture over the site of the elbow joint.

The main function of the muscles in the pelvic limb is to maintain the body upright and in equilibrium, as well as being of use during locomotion. The pelvic muscles can be used for the administration of intramuscular injections, although due to a portal-renal venous system any drug administered here travels via the kidney before reaching the systemic circulation.

Most perch and prey birds have a reciprocal apparatus which causes the flexion of

interphalangial joints when the tarsal joint is flexed. As a result of this the digital flexor tendon passively clamps the digits around the perch when the tarsus is flexed. This mechanism should be remembered when attempting to undo the grasp of a large bird.

On the medial aspect of the tarsal joint of large birds the caudal tibial vein can be accessed for venipuncture. Also, for diagnostic purposes, for example Marek's disease, it is useful to locate the sciatic nerve at its passage through the thigh, caudal to the femur, covered by the musculature of the region.

Finally, ossification of the flexor tendons of the digits (gastrocnemius m., superficial and deep digital flexor mm.) is a sign of ageing found in some birds.

THE PERITONEAL CAVITY AND VISCERAL SYSTEMS

The birds diaphragm is different to that of mammals as it does not form a complete wall between the thoracic and abdominal cavities. Thus, all the main organs are located within a unique peritoneal cavity which can be divided into several celomic compartments; the peritoneal sacs.

The Digestive System

Starts at the beak, which has a bony base and is formed of the nasal bone, maxilla, premaxilla and the mandible. All the bones are covered by a hard keratinised sheath called the rhamphothecae. The beak's form depends on the diet of the bird and substitutes the lips, gums and teeth of mammals. Birds such as parrots use the beak to differentiate between foods.

In captive birds an overgrowth of the beak may cause problems in the normal prehension of food. A vet is usually required to remove the overgrown beak. The oral and pharyngeal cavities join into the oropharynx, which includes a long hard palate with keratinised papillae, the tongue and the laryngeal mound. Neither soft palate nor nasopharynx are present, this means that both the choana and the auditory tubes open directly into the

oropharynx through their correspondent openings.

The tongue is shaped according to the beak's shape. In web-footed birds the tongue's borders are covered by lingual bristles which together with the keratinised lamellae of the bill filter and strain the food. In parrots the tongue is hard, fleshy (formed of its own muscles) and very mobile. This allows them to make sounds and words. Salivary glands are commonly absent, except in some insectivorous birds.

The oropharynx is followed by the oesophagus. In dehydrated or injured birds the entrance to the oesophagus must be approached to re-hydrate the animal. The opening of the glottis, which lies ventrally to the oesophagus, must be avoided in this procedure. The first portion of the oesophagus is located between the trachea and the cervical muscles. However, it then moves to the right side and keeps this position further down the neck. In ducks the caudal part of the oesophagus contains an aggregation of lymphoid tissue known as the oesophageal tonsil. In almost all species a dilatation, forming the crop, is located in the mid portion of the oesophagus. The crop accumulates food but no digestion takes place. In columbiformes (pigeons), it produces a protein rich juice, the crop milk, which is regurgitated by the adults to feed to their chicks. The shape of the crop differs between species, from a simple dilatation (in aquatic birds), to a sac (birds of prey and grain eaters), to a double sac (pigeon) or an "S" shape (psittacine species). Both the oesophagus and the crop are found subcutaneously and are easily palpable and accessible surgically.

Once past the heart and the lungs the oesophagus opens into the stomach. The stomach has two parts: the proventriculus and the gizzard. The ventral aspect of the proventriculus or glandular stomach is in contact with the left lobe of the liver. The mucosa of the proventriculus produces mucous, enzymes (pepsin) and hydrochloric acid. In carnivorous birds (birds of prey) hydrochloric acid is essential for digestion of meat and bones, which form part of the diet. The gizzard or muscular stomach, is further caudal and also linked to the liver, although its main contact is the sternum and the ventral part of the left abdominal wall. Birds eat sand and grit in order to break up the coarse material on which

they feed, functioning in a similar way to teeth. The muscular wall is more powerful in grain eating birds than in carnivorous birds. The mucosa secretes a carbohydrate-protein complex forming the cuticle which protects against any damage caused by the ingested grit. In birds of prey this part of the stomach tends to retain hairs, feathers and bones that are regurgitated in the form of "pellets". The study of these pellets in an ecosystem allows an insight into the dietary preferences of the species living there.

The intestine remains in the ventral peritoneal sac, in contact with the gizzard and the reproductive organs, occupying the caudal part of the peritoneal cavity. The length and development of the intestine tract depends on the diet. It is longer in grain eating and herbivorous birds than in carnivorous and fruit eating birds. The vitelline diverticulum of the jejunum is a remnant of the yolk duct, which during the first few days of life provides nutrients to the recently hatched chick. The caeca, absent in parrots open into the transitional zone between the small and large intestine. The length of the caeca also depends on the diet, being short in grain eating birds and long in herbivorous birds. The caeca allow the digestion of cellulose, absorption of water and in certain birds, such as pigeons, also act as an immune organ due to their rich lymphoid tissue. The rectum opens into the cloaca, where the genital and urinary tracts also join. Physiologically the cloaca is divided into three compartments:

a) Coprodeum: most cranial compartment. End of the digestive system.

b) Urodeum: middle compartment into which the urogenital ducts open

c) Proctodeum: caudal compartment, which opens via the cloacal orifice. Dorsally there is the Bursa of Fabricius, a small lymphoreticular organ. Bird's excrements are frequent but small.

The liver is surrounded by four peritoneal sacs (two ventral sacs and two dorsal sacs). It has two principal lobes, right and left. The hepatopancreatic duct emerges from the left lobe, and drains bile directly to the duodenum. Two hepatocystic ducts emerge from the right lobe and carry bile to the gall bladder (absent in some parrots, pigeon and ostrich). Then the bile drains to the duodenum by the cysticoenteric duct.

The pancreas consists of three lobes (dorsal, ventral and splenic), each one of them with its own efferent pancreatic duct which drains into the duodenum.

The shape of the spleen varies depending on the species. It is located between the gizzard, proventriculus and bile duct and does not act as a reservoir for blood.

In general, due to their high rate of metabolism, birds ingest food equivalent of up to approximately 25-30% of their body weight per day. Their high energy requirements mean that small and young birds cannot survive for a long time if they are left for more than a few hours without food.

The Respiratory System.

The respiratory system is specifically adapted for flight. This activity requires a high level of muscular activity, consuming increased amounts of oxygen and this requires rapid, efficient and powerful ventilation. The nares open from the dorsal rhamphotheca of the beak, either on the keratinized plate or on the sensitive cere. The colour of the cere can be used to know if a bird is well-nourished (raptors), or to identify sex (budgerigars: blue in the cock and brown in hen and young birds). The nasal cavities are separated by the medial nasal septum, which can be incomplete rostrally (web-footed). There are three nasal conchae (rostral, middle and caudal), while the ethmoidal concha isn't developed, due to the poor development of the olfactory sense.

The infraorbital sinus is a cavity in the lateral wall of the nasal cavity, ventral and caudal to the eye. It communicates with the caudal nasal concha and nasal cavity. In many parrots the left and right infraorbital sinuses communicate with each other and have expansions (diverticula), which pneumatize extensive areas of the skull. In some species, like the Amazonian Parrot, these diverticula extend dorsolaterally on each side of the neck as far caudally as the seventh cervical vertebra.

The inspired air passes from the nasal cavities to the oropharynx via the median slit-like opening in the palate, the choana, and then into the larynx, which is formed by the cricoid and arytenoid cartilages (the epiglottis doesn't exist). Birds have no vocal cords and the

laryngeal muscles are rudimentary. This is due to the fact that the larynx, unlike in mammals, does not play a part in the production of sounds (phonation).

The trachea consists of 100 to 130 cartilaginous rings which generally ossify. These rings are also found in the main bronchi. In long necked species (swans and cranes), the trachea is massively elongated forming coils that lie in the excavation of the sternum. This hypertrophy appears to be related with an increase in the strength of the voice. The bifurcation of the trachea is modified to form the sound production organ of the bird: the syrinx or caudal larynx, which can be absent in some species (vulture, ostrich, stork). Strong syringeal muscles tense two pairs of vibrating membranes. Quality and variation of the sounds depends on the function of those muscles.

The primary bronchi enters the parenchyma of the lungs, which only represent 11% of the respiratory system, but have a great functional capacity. Both principal bronchi expand forming vestibules and continue as mesobronchus to the caudal end of the lung, where they open into the abdominal air sacs. The middle bronchi opens to the thoracic caudal air sac.

Air sacs are extrapulmonary membranous expansions, that lie between the viscera and walls of the body cavity. The main function of the air sacs is to reduce the body weight in order to allow flight and swimming, but they also help to stop the body from heating up during these two activities. Normally 9 air sacs are present: 2 cervical, 1 interclavicular, 2 cranial thoracic, 2 caudal thoracic and 2 abdominal (the left can be catheterised in the case of upper airway obstructions). The air sacs don't take part in oxygen exchange, as they facilitate a continuos air flow over the lungs. Thus, both inhaled and exhaled air passes through the respiratory system (with an absence of dead spaces) which makes the system very efficient. With each inspiration all of the air in the lungs is replaced and half of the air of the whole respiratoty system. Two respiratory cycles are needed for air to pass through the whole respiratory system, and oxygen absorbtion occurs both during inspiration and expiration.

Respiratory movements depend on the thoracic wall muscles, as birds haven't got a proper diaphragm.

The urogenital system.

The kidneys are located in the corresponding depressions on the ventral surface of the synsacrum and ilium (renal fossa). Each kidney is divided into three lobes, there is not a precise division between the cortex and the medulla, and there are lots of calyces on each lobe. The renal portal system is functional and of clinical importance. The external iliac veins and the venous trunk of the last segments of the intestines turn into capillaries as they enter the kidneys. After passing through the kidney parenchyma the capillaries converge into efferent vessels, which drain into the caudal vena cava. Administration of substances in the pelvic limb or via the chloaca is not recommended because they pass directly through the kidneys and are excretated without passing through the systemic circulation. Urine is transported by the ureters to the chloaca (urodeum) because no urinary bladder exits. Birds excrete semisolid urine (most of the water is absorbed in the urodeum) rich in uric acid.

The testicles are intra-abdominal and situated next to the cranial aspect of the kidneys. In birds without an external sexual dimorphism endoscopy is necessary to ascertain the sex. There are two possible approaches (McLelland, 1992): over the sternal notch between the penultimate and the last rib, immediately ventral to the cranial border of the sartorius muscle; or over the triangle formed by the proximal end of the femur, the last rib and the cranial border of the pubis.

The epydidimis is located on the dorsomedial border of the testis and a deferent duct drains to the urodeum. As testicles are intraabdominal organs the optimum temperature for spermatozoid production is achieved by the proximity of the air sacs which cool the testicles during forced inhalation. There are no accessory sex glands and the penis is rudimentary (penile papillae) except in some web-footed species (ducks) where it can be up to 8cm.

Only the left ovary and oviduct are developed in females. However, in some raptors, the

right ovary and oviduct are still functional. During sexual activity the ovary has a bunch like appearance, due to the numerous follicles on the surface. The oocytes contained in the follicles quickly become visible, as they are wrapped in layers of vitelline yolk (future egg yolk). The oviduct has two functions: to ensure the egg progresses towards the cloaca, and to secrete the substances which will protect it from the environment. The avian oviduct can be divided into: infundibulum, magnum, isthmus, tubular part of the uterus, uterus and vagina. The majority of the albumin is formed in the magnum and isthmus, whilst the formation of the shell membranes takes place in the ampulla and the formation of the shell in the uterus. The vagina is the last section of the oviduct in which the cuticle and specific pigment of the egg are formed: the opening into the cloaca (uroceo) is found next to the left ureter.

SENSORY ORGANS

Smell and taste are poorly developed in birds. However, touch, hearing and vision are very important senses. Sensory organs are proprioceptive and tactile corpuscles. Together with vision, tactile corpuscules are used for selecting food. These are located on the border and sides of the beak, as well as within the oral cavity. They perceive size, shape, toughness and superficial characteristics of food.

Feathers prevent the skin from perceiving painful stimulus. Thus, the skin is poorly innervated and this allows some surgical procedures to be performed without anaesthesia (castration, incision into the crop).

Hearing and balance receptors are found in the inner ear (vestibulocochlear organ), although the outer ear is not well developed in birds. The opening of the external auditory canal is round and limited by a circular fold. The canal must be kept clean and free from secretions. The possibility of aural parasites should be considered upon examination. The middle ear is formed by an elongated bone (columella) that replaces the auditory ossicles found in mammals. The inner ear is similar to mammals, but the cochlea is ten times

smaller. The sensitivity to resonance is very high, especially in nocturnal birds.

Birds have excellent vision. Eyeballs are very big and situated laterally, so their field of vision is from 280-360º. The eyeball is flattened (not spherical) and in some species (raptors) quite elongated. The retina is formed by rods and cones, and has a central fovea formed by cones. 100% of the optic nerve fibers decussate, so the consensual pupil reflex cannot be seen. The pecten is a comb-like structure located within the posterior chamber. It is a pigmented and vascularized membrane, near to the optic nerve entrance, which is floating in the vitreous humor. Its function is to provide nutrition, regulate temperature and sense changes in pressure. Internal ocular muscles are striated, which make the examination of the eye very difficult. In addition to eyelids there is large nictitate membrane (third eyelid) which is very mobile. It protects and lubricates the cornea, aided by the adjacent lacrimal gland.

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