MORPHOLOGY OF THE PULMONARY VALVE
(VALVA TRUNCI PULMONALI)
IN CHOSEN SPECIES OF DOMESTIC
AND WILD BIRDS USING IMAGING METHODS

BARTŁOMIEJ J. BARTYZEL

Department of Morphological Sciences, Faculty of Veterinary Medicine,
Warsaw University of Life Sciences, 02-776 Warsaw, Poland
bartlomiej_bartyzel@sggw.pl

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Abstract

The morphological types of the pulmonary valve and its adjacent structures were determined. The research was conducted on the heart of 498 domestic and wild birds of five orders. The organ underwent imaging with the use of an X-ray apparatus, a 16-slice computed tomography scanner, and an ultrasonograph. The structures examined are characterised by a great changeability as far as particular taxonomic individuals are concerned. This is connected with the ways and living conditions of particular taxonomic and ecological groups of birds. New terms to characterise the pulmonary valve were suggested. Research of this type will allow us to link such basic sorts of study with cardiac surgery in the future.

Key words: birds, heart, pulmonary valve, morphology, imaging methods.

The analysis and the determining of types of the valvular system structure of birds’ and mammals’ heart are essential when talking about imaging and cardiosurgical procedure. The majority of such research has been conducted on human heart (4). In veterinary medicine such studies have only been conducted for the last few years, taking into account the types of particular anatomical structures of the heart in connection with the possibilities of the newest imaging techniques (8, 9, 14, 18).

The blood flow through the opening of the pulmonary trunk and the opening of the aorta, shown by using a Doppler apparatus, tells us about the efficiency of the valves present there, and enables us to estimate the degree of their stenosis or incompetence. It is strictly connected with their macroscopic and microscopic structures. Polish and foreign textbooks on birds’ anatomy are limited to the description of some of the anatomical structures of the valvular system, without concentrating on the types and variations characteristic of a particular species (3). The majority of such a research has been conducted on embryos and adult chicken (15, 17, 25).

The lack of proper anatomical writings concerning the pulmonary valve and other structures makes it impossible to take advantage of the present diagnostic possibilities. It also creates a big gap between the technical possibilities and the basic knowledge in the area. Therefore, it is important to work out the morphological structures for various species of birds (both domestic and wild), which will allow us to estimate the results of imaging in a proper way in the future. The huge gap, which has appeared in this branch of science, should be filled as soon as possible. It will improve the comfort and lifespan of domestic birds, as well as wild ones living both in the wild and in zoos.

Material and Methods

The research was conducted on the heart of 498 domestic and wild adult birds of four orders (Table 1). The initial examination showed a lack of any significant differences in their macroscopic structure as far as sexual dimorphism was concerned. Therefore, the males and females are not described separately in this article. The research material is part of a collection for exhibits from the Department.

The material was kept in 10% formalin and 5% ethanol. An image study was made of the chosen hearts before they underwent morphological analysis (Table 1). Each heart was irrigated in running water and washed using a surface-active substance (OT24). Then, they were dried inside and outside using filtering paper and a mechanical aspirator. The prepared heart was cut at the basis of the opening of the left and right pulmonary arteries through the outer wall of the pulmonary trunk, the pulmonary valve, where the left semilunar cusp meets the right semilunar cusp.
Table 1

<table>
<thead>
<tr>
<th>Kind of research material</th>
<th>Total number of hearts (type of research number of hearts)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Domestic birds</strong></td>
<td></td>
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<tr>
<td>Order Galliformes</td>
<td></td>
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<tr>
<td>Domestic chicken, <em>Gallus gallus f. domestica</em></td>
<td>75 (M 75; RTG 9; CT 8, USG 7)</td>
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<tr>
<td>Domestic turkey, <em>Meleagris gallopavo f. domestica</em></td>
<td>72 (M 72; RTG 7; CT 8, USG 7)</td>
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<tr>
<td>Order, Anseriformes</td>
<td></td>
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<tr>
<td>Domestic goose, <em>Anser anser f. domestica</em></td>
<td>55 (M 55; RTG 6; CT 8)</td>
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<tr>
<td>Domestic duck, <em>Anas platyrhynchos f. domestica</em></td>
<td>42 (M 42; RTG 11; CT 5, USG 8)</td>
</tr>
<tr>
<td><strong>Wild birds</strong></td>
<td></td>
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<tr>
<td>Order, Anseriformes</td>
<td></td>
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<tr>
<td>Bean goose, <em>Anser fabalis</em> (Latham, 1787)</td>
<td>41 (M 41; RTG 12; CT 8)</td>
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<tr>
<td>White-fronted goose, <em>Anser albifrons</em> (Scopoli, 1769)</td>
<td>30 (M 30; RTG 11; CT 8)</td>
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<tr>
<td>Greylag goose, <em>Anser anser</em> (Linnaeus, 1758)</td>
<td>9 (M 9; RTG 5; CT 6)</td>
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<tr>
<td>Mallard, <em>Anas platyrhynchos</em> Linnaeus, 1758</td>
<td>29 (M 29; RTG 12; CT 5;USG 6)</td>
</tr>
<tr>
<td>Long-tailed duck, <em>Clangula hyemalis</em> Linnaeus, 1758</td>
<td>30 (M 30; RTG 8; CT 7; USG 4)</td>
</tr>
<tr>
<td>Black scoter, <em>Melanitta nigra</em> (Linnaeus, 1758)</td>
<td>21 (M 21; CT 4)</td>
</tr>
<tr>
<td>Velvet scoter, <em>Melanitta fusca</em> (Linnaeus, 1758)</td>
<td>29 (M 29)</td>
</tr>
<tr>
<td>Greater scap, <em>Aythya marila</em> (Linnaeus, 1761)</td>
<td>22 (M 22)</td>
</tr>
<tr>
<td>Tuffed duck, <em>Aythya fuligula</em> (Linnaeus, 1758)</td>
<td>28 (M 28)</td>
</tr>
<tr>
<td>Order, Podicipediformes</td>
<td></td>
</tr>
<tr>
<td>Red-necked grebe, <em>Podiceps grisegena</em> (Boddaert, 1783)</td>
<td>8 (M 8; RTG 7; CT 5; USG 4)</td>
</tr>
<tr>
<td>Great Crested grebe, <em>Podiceps cristatus</em> (Linnaeus, 1758)</td>
<td>7 (M 7; RTG 3; CT 8; USG 3)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>498</td>
</tr>
</tbody>
</table>

Type of study: M - morphological, RTG - an X-ray apparatus, CT - Computed Tomography scanner, USG - an ultrasonograph.

Then, the cut ran in the direction of the apex of the heart through the outer wall of the conus arteriosus and the anterior wall of the right ventricle. In some cases, before opening the cavity of the right ventricle, the right and left atria were cut off at the level of the coronary groove. This allowed us to estimate the shape of the conus arteriosus and the location of the valve cusps of the pulmonary trunk in relation to each other and to other heart structures.

Some of the heart cavities were injected through the right brachiocephalic trunk and the right pulmonary artery with the radiological contrast agent Visipaque 320™ dissolved in 0.9% saline solution, used while conducting the Computed Tomography (CT), as well as barium sulfate diluted in purified water. The imaging was conducted with the use of a GE prestige II X-ray apparatus and GE LightSpeed® PRO16 CT scanner (KVP - 120.0 kv; exposure - 5 mAs; farm size - 411x411; slice thick - 0.63 mm; bit depih - 16) as well as a Honda ultrasonograph using a linear probe. All the imaging techniques were performed in Ap projection in long and short axis (transverse) of the heart and in a lateral projection. The USG and RTG research was conducted at Faculty of Veterinary Medicine, Warsaw University of Life Sciences, whereas CT study took place at the Medical University of Warsaw (the image research was carried out in a digital format).

The material to be subjected to morphological analysis was described using a surgical microscope (PZO:OpM-1) and a stereoscopic microscope (PZO:MsT-130). The photographic documentation was taken with a computer linked camera (MikroOkular 3.0MP).

Results

The pulmonary trunk of domestic and wild-living birds starts at the extension of the right conus arteriosus, *conus arteriosus dexter* (a suggested term), of the right heart cavity. The inside of the preparations examined was almost completely smooth and had a triangular shape. The pulmonary trunk runs on the left of the ascending part of the aorta, slanting upwards, downwards and to the left. Below the left brachiocephalic trunk it divides into the right pulmonary artery and the left pulmonary artery.

The pulmonary valve, except for that of the turkey, consists of three cusps. Each of the elements was restricted by incisures, lying by the fibrous ring. In all of the preparations cusps made an anastomosis between the apex and the interlobar incisure. It was suggested to name them: the commissures of the semilunar cusps, *commissurae valvularum semilunarium*. The valves studied contained three commissures and they were as follows: the right commissure, *commissura dextra*, between the dorsal semilunar cusp and the right semilunar cusp, the left commissure, *commissura sinistra* between the dorsal semilunar cusp and the left semilunar cusp, and the anterior commissure, *commissura anterior*, between the right semilunar cusp and the left semilunar cusp. The left commissure is a bifurcation of the pulmonary trunk into the right pulmonary artery and the left pulmonary artery. (Figs 1, 2, 3).
Considering the exceptional structure of the pulmonary valve of turkeys, it was suggested to differentiate the two types of the structure; type I being a valve consisting of three cusps, and type II being a valve consisting of four cusps (four cases). The structure described is situated between the dorsal semilunar cusp and the right semilunar cusp. The author suggests that two terms to name this structure should be introduced: for the commissure an additional commissure, *commissura accessorius*, and for the cusp an additional semilunar cusp, *valvula semilunaris accessoria* (Fig. 4).

Each cusp of the valve corresponds with prominences in the anterior and posterior wall of the pulmonary trunk forming the sinuses of the pulmonary trunk, *sinus trunci pulmonalis* (3). The shape of the sinuses took two forms: I - a “scaphoid, boat-like” form, and II - an “open-bracket” form. Both forms appeared in both the domestic and wild birds. The only difference was the thickness of the free cusp of the valve. Domestic birds had delicate and thin-walled cusps, whereas the wild birds’ structures were thick-walled (Figs 5 and 6).

Fig. 1. The basis of the heart. I- red-necked grebe (lateral view). II - great crested grebe (cut and half-open pulmonary trunk), III - domestic chicken (top view, after removing the pulmonary trunk): 1- aortic arch; 2 - right brachiocephalic trunk; 3 - left brachiocephalic trunk; 4 - pulmonary trunk; 5- pulmonary valve; 6 - right commissure; 7 - left commissure; 8 - anterior commissure; 9 - aortic valve; 10 - left atrioventricular valve; 11 - right atrioventricular valve.

Fig. 2. The commissures of the semilunar cusps (cut and half-open pulmonary valve). I - domestic turkey; II - great crested grebe; III - bean goose; IV - tufted duck (for other denotations see Fig. 1).

Fig. 3. An X-ray image of the heart (digital picture). I - domestic turkey (anterio-posterior); II - domestic duck (lateral view); III - Mallard (lateral view); IV - greylag goose (anterio-posterior); 12 - right ventricle; 13 - left ventricle (for other denotations see Fig. 1).
Fig. 4. The pulmonary valve of the domestic turkey (cut and half-open – anterior view). I, II, III: 14 - additional commissure; 15 - additional semilunar cusp (for other denotations see Fig. 1).

Fig. 5. Computed tomography of the heart (digital image). I - domestic turkey; II - domestic chicken; III - mallard; 16 - right semilunar cusp; 17 - left semilunar cusp; 18 - dorsal semilunar cusp; 19 - right pulmonary artery; 20 - left pulmonary artery (for other denotations see Figs 1 and 3).

Fig. 6. Ultrasonography of the heart of the domestic turkey (short-axis projection). I, II (double enlargement- 2x); 21 - right sinus of pulmonary trunk; 22 - left sinus of pulmonary trunk; 23 - dorsal sinus of pulmonary trunk.

Fig. 7. The pulmonary valve (cut and half-open - anterior and top view): I - domestic chicken; II - greater scaup; III - velvet scoter; 24 - dorsal lunule of the semilunar cusp; 25 - dorsal basilar part.
Along the free margin of the cusp of all prepa rated valves, between the commissures of the semilunar cusps, there is an exceptionally thin cord, which was called a lunule of the semilunar cusp, luna valvulae semilunaris. It clearly divides the free part of the semilunar cusp of the valve into two zones: zone I, which is the lunule of the semilunar cusp (the suggested name), the form, which appeared in domestic birds, and zone II, which is the basilar one, pars basalis (in wild birds there are two zones). Considering the future research, the following terms were suggested: the right, left, and dorsal lunules of the semilunar cusp to be called luna valvulae semilunaris dexter, sinister et dorsalis; and the right, left, and dorsal basial part to be called pars basalis dextra, sinistra et dorsalis (Fig. 7).

Discussion

In the anatomical nomenclature of birds and mammals concerning the heart there are big gaps (3, 20). Therefore, it was suggested that some terms already existing in human anatomy (7, 12, 19) should be used to describe the structures present in the pulmonary valve of birds, or new ones to name new structures should be created. The pulmonary trunk starts at the extension of the right conus arteriosus as far as all species of birds, mammals, and humans are concerned. It runs along the left side of the ascending aorta, slanting upwards. In the preparations analysed it divides below the brachiocephalic trunk into the pulmonary arteries, contrary to mammals in which it divides directly below the arch of the aorta (1, 2). The parent vessel of the pulmonary arteries of birds and mammals is the pulmonary trunk, which is connected to the pulmonary valve. Most frequently, it consists of three cusps (19). However, there are also cases of quadricuspid or even bicuspid valves in humans (11, 16, 24). In the material collected only the domestic turkey had a quadricuspid valve. Most frequently, it consists of three cusps (19). In the valves studied, the nodule of the semilunar cusp was not observed in the central part of the free margin. The nodules of the semilunar cusps are present, for example, in mammals (1). However, all the birds had two zones, one of which was called a lunule of the semilunar cusp. In birds, which dive very well, e.g. the greater scoup, long-tailed duck, velvet scoter, common scoter, and grebe, the lunule occupied only a small part (a quarter of a free cusp). It may be suggested that the structure and shape of the pulmonary valve play a big role in these birds' abilities to dive in deep waters. Such research has been conducted concerning penguins; however, it was very limited because the authors only provided linear measurements of the heart and mass of the ventricles compared to the mass of the whole organ (10). They did not include any morphological details concerning the structure of the valvular system and the adjacent structures, which have a very great influence on the birds' adaptation to various environments and lifestyles, for example, diving.

The morphological evaluation of the pulmonary trunk and the adjacent structures, as well as of the aorta valve, is a standard element of imaging, for example echocardiographic imaging. The examination is a standard one as used on humans and dogs as far as parasternal short projection is concerned, and it enables us to see the pulmonary trunk and the pulmonary valve. The pulmonary trunk and both arteries are visible in subcostal short projection in humans, and in vascular short-axis projection from the right in dogs. The Doppler test in abdominal long projection is performed in birds (22). The research conducted showed the pulmonary valve in the short projection. This type of examination allowed us to evaluate the pulmonary valve with great accuracy. Other image examinations with the use of a RTG apparatus and CT scanner were very useful when evaluating the valves of the vessel. On the basis of the CT examination, it was possible to estimate the quantity and size of the structures studied within the pulmonary valve and other parts of the heart (Fig. 3). The knowledge of the topography and types of the pulmonary valve, and its adjacent structures allows us to perform Balloon Sinuplasty. Such procedures are already being carried out in dogs (5, 23).

The above thoughts are a kind of a preliminary, as there is not much information concerning imaging in birds so far (6, 13). Further research within this sphere, as well as morphological research with the use of imaging techniques, will make it possible in the future to reveal more differences in the various ecological adaptations of birds. They will also allow us to use the newest imaging techniques to treat domestic and wild-living birds.

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References