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Case Report

Cardiovascular Anatomy of the Huemul Deer (Hippocamelus bisulus)

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Abstract

Hearts from a neonatal death case, from another young fawn and an adult male resulted in a first description of the cardiac anatomy in huemul deer (Hippocamelus bisulcus). Dextrocardia, a patent ductus arteriosus, and a congenital atrial septal defect were confirmed in the neonate. In this species, the anterior descending coronary artery (anterior interventricular artery) is entirely intramyocardial: defense or parietal stress under certain conditions can lead to severe ventricular arrhythmia and 'sudden death'. The cardiac conduction system follows the general pattern found in mammals, particularly ungulates. The mitral valve presented striated cardiac muscle within its leaflets - a feature found in some species but never as prominently as in the huemul. The heart of the neonate had a structural congenital heart disease (non-lethal), but it died right after birth due to intestinal volvulus caused by congenital jejunoileal junction stenosis. Both issues add to the already known harm caused by inbreeding. These significant findings underscore the need to intensify efforts to prevent such occurrences likely stemming from inbreeding.

Keywords: Cervid; huemul; cardiac anatomy; pathology; congenital; genetics; inbreeding

Introduction

The huemul (Hippocamelus bisulcus) is one of the most threatened deer species on the planet [1]. Although it was persecuted rather than studied for much of the 20th century, the study and preservation of this species have gained significant prominence in the latter part of that century and in the present one. Accordingly, recent studies confirmed that the artificial all-year permanence in summer ranges explains the high prevalence of pathologies and concomitant very short live spans [2-7]. Initiated in 2012, the project "Huemul in danger: adaptive management proposal" was approved to Flueck and Smith-Flueck, and together with the Fundacion Shoonem resulted in the establishment of the Breeding Station Shoonem. By 2022, and in collaboration with the Fundacion Temaiken, the first huemul were captured and translocated to the Breeding Station, which has been operating since then.

Within this framework of individual protection and monitoring, a huemul fawn died shortly after birth; a necropsy was subsequently

performed, along with a detailed analysis of the cause of death and tissue histology, in accordance with established protocols. In the present article, we describe the cardiac anatomy of this neonatal fawn and of additional huemul cases. One case stem from a specimen that was one or two weeks old, while the third case stems from an adult male. Based on our literature review, these are the first such descriptions made available. We present a study of the heart from a specimen that was a few days old and exhibited dextrocardia, a patent ductus arteriosus (also called the ductus Botalli), and an atrial septal defect. Additionally, the coronary anatomy of the huemul and the atrioventricular cardiac conduction system (bundle of His and its branches) are also described here for the first time.

Case Presentation

The heart of a huemul that died as a neonate due to intestinal volvulus caused by congenital jejunoileal junction stenosis was dissected. The necropsy was performed at the Pasteur Institute in Buenos Aires (Argentina), supervised by the head of Anatomic Pathology and the facility's medical director, with the participation of members from the University of Buenos Aires (UBA), and the Temaikén Foundation. 29 Regarding the heart inspection: a supersaturated sodium solution and 1% formalin were used for preservation, after which the coronary tree was injected with prevulcanized latex following the laboratory's standard technique.

The dissection was initially performed using the naked-eye technique, subsequently supplemented by magnification. A Newton® microscope with 6x to 10x magnification was used for the detailed dissection. Cardiovascular surgical forceps and scissors were used to dissect the delicate structures. It is important to specify the use of these particular instruments, as standard tools for general surgery, necropsy, or routine dissection are unsuitable. The method used to inject the coronary tree is also significant, given that the coronary vessels of the newborn huemul barely exceeded one millimeter in diameter.

Results

The results are rather surprising. Although inbreeding leads to an increased incidence of congenital defects, we did not expect to find three structural congenital heart anomalies, namely:

a) dextrocardia: isolated, with "situs solitus" and atrioventricular concordance, concordant venous return, and L-aortic arch.

b) patent ductus arteriosus: Ostium secundum-type interatrial connection. It should be noted that this finding is unequivocal; it is not a simple patent oval foramen, but a clear atrial septal defect, as highlighted in the photographs (Figure 1).

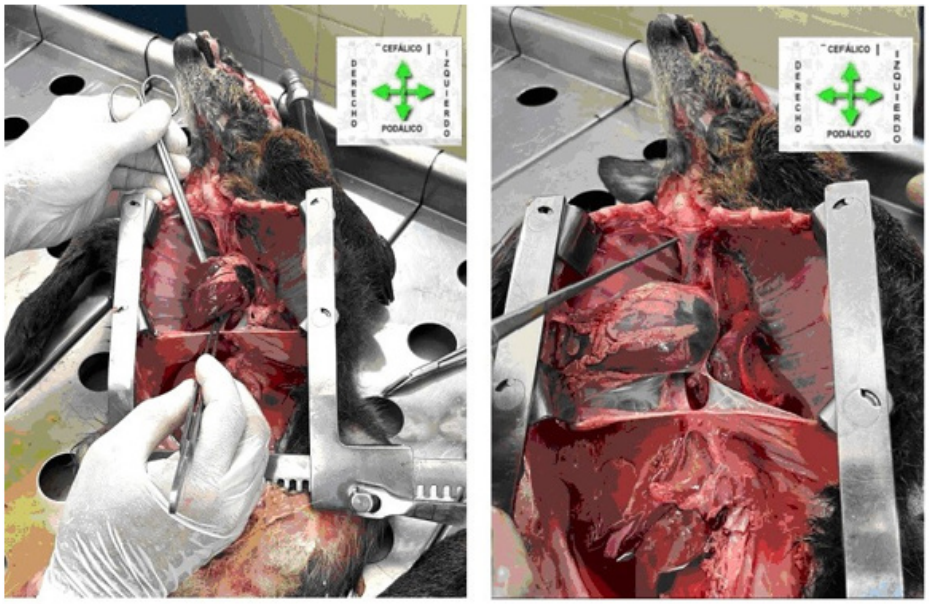

Figure 1: Thorax of a huemul fawn opened via median sternotomy. Dextrocardia is evident. The pericardial ligaments lie toward the right. A highly revealing photograph.

General External Configuration

In this case, a dilated right heart chamber was remarkable. This prompted consideration of right-sided hyperflow conditions, leading to the discovery of an atrial septal defect and a patent ductus arteriosus (Figure 2,3).

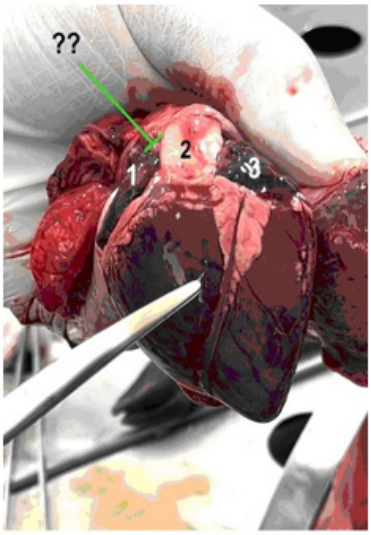

Figure 2: External configuration: the right ventricle, indicated by the Metzenbaum scissors, is dilated. The pulmonary artery (2) is clearly dilated and anterior to the aorta, marked only by a question mark. (1) and (3): the right and left atria.

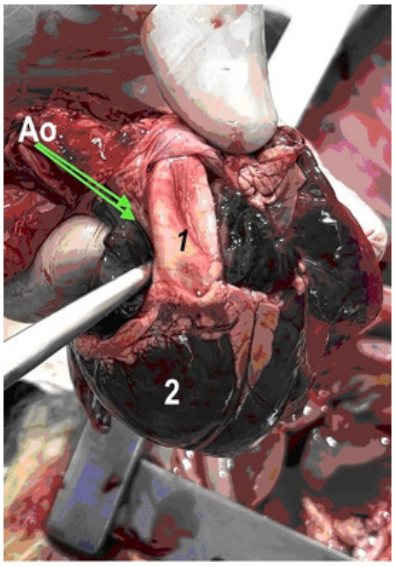

Figure 3: External configuration: the four chambers are visible. Arrows indicate the slender ascending aorta, obscured by the moderate dilation of (1) the pulmonary artery a clear clinical sign of right-sided chamber volume overload. (2) Right ventricle.

Ductus Arteriosus

We have found a patent ductus in two huemul hearts: one from an adult and the fawn case detailed here. In the adult, the patent tract had a negligible lumen, though its diameter was not insignificant. In the fawn case at hand, however, the ductus was clearly patent and of considerable size. Figure 4 shows an adult heart (right) alongside the heart from the fawn. Ligatures were applied to the great vessels of the heart from the fawn in order to inject prevulcanized latex into the coronary arteries - and only the coronary arteries (Figure 4).

Coronary Arteries

The coronary arteries in the huemul (based on two fully dissected specimens: an adult and the fawn of this report) follow the general mammalian pattern. There are two coronary arteries designated right and left along with their branches. It is worth noting that we observed a configuration in the huemul that is uncommon in mammals (though found in marsupials and some rodents). Specifically, the anterior descending artery (anterior interventricular artery) is entirely intramyocardial. The anterior descending artery is intramyocardial in both the adult and fawn specimens of this report. In the commentary, we will discuss the significance of this finding in relation to sudden death (Figure 5-7).

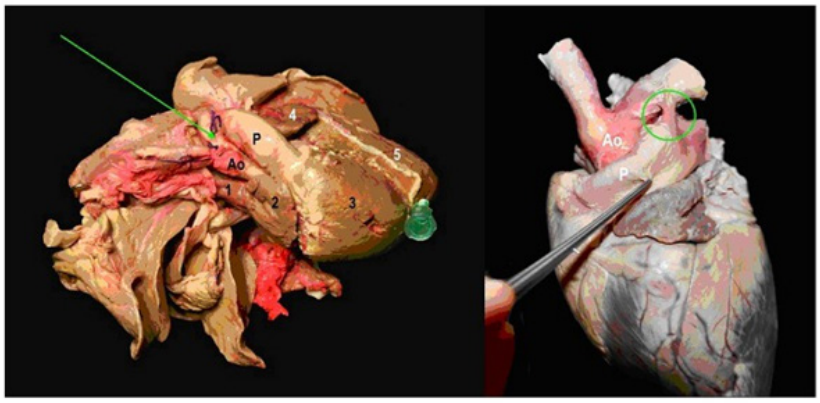

Figure 4: (Left): The aorta (Ao) is smaller than the pulmonary artery (P). Following the blood flow: the superior vena cava (1), the right atrium (2), and the right ventricle. (4) and (5) indicate the left atrium and left ventricle, respectively. (Right): The ductus, circled.

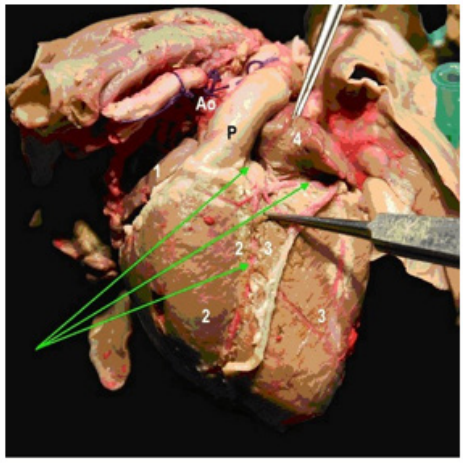

Figure 5: The heart is rotated to the left to allow visualization of 11 both ventricular chambers. Left main coronary artery, anterior interventricular artery, and circumflex artery. The left atrial appendage and the pulmonary artery have been retracted to reveal the origin of the left coronary artery (upper arrow). Note the detail showing how the anterior descending artery is covered by myocardium; the overlying layer must be removed to expose it. The potential role of this unique anatomical feature during isometric exertion or stress will be discussed later. (1) Right atrium, (2) Right ventricle, (3) Left ventricle, (4) Left atrial appendage. (P) Pulmonary artery. The arrows indicate, from top to bottom: the left main coronary artery, the circumflex artery, and the anterior interventricular artery (covered by myocardium, which has been lifted back for visualization).

Figure 6: Dorsal view of the heart: The right coronary artery is visible between the green lines, and on the opposite side, the lateral and poster ventricular branch of the circumflex artery also intramyocardial can be seen, though certainly not the termination of the anterior interventricular artery (Figure 5). (1) Right ventricle. (2) Left ventricle. (VC) Dorsal vena cava.

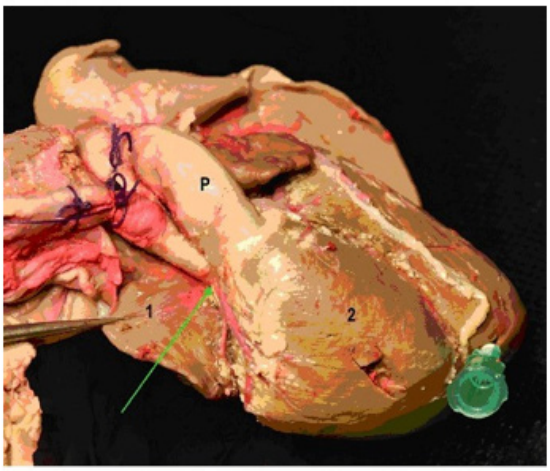

Figure 7: Right coronary artery: The right atrial appendage (1) has been strongly retracted laterally to expose the atrioventricular groove and its contents the right coronary artery which, in this case, is not intramyocardial. The arrow points to the vessel's origin from the ascending aorta. (2) Right ventricle (P) Pulmonary artery.

Cardiac Conduction System

The cardiac excitation-conduction system-or the Tawara-His-Purkinje system, discovered over three decades of human effort to understand how the orderly cardiac impulse is transmitted–is composed of myocardial cells (not nerves) isolated within collagen. One of the authors has dissected specimens from more than 40 animal species (including whales), successfully demonstrating the atrioventricular node (Tawara), the atrioventricular bundle, and its branches in the huemul. This is the first description featuring photographs of this system, which follows the general structural plan found in mammals, particularly ungulates (Figure 8,9).

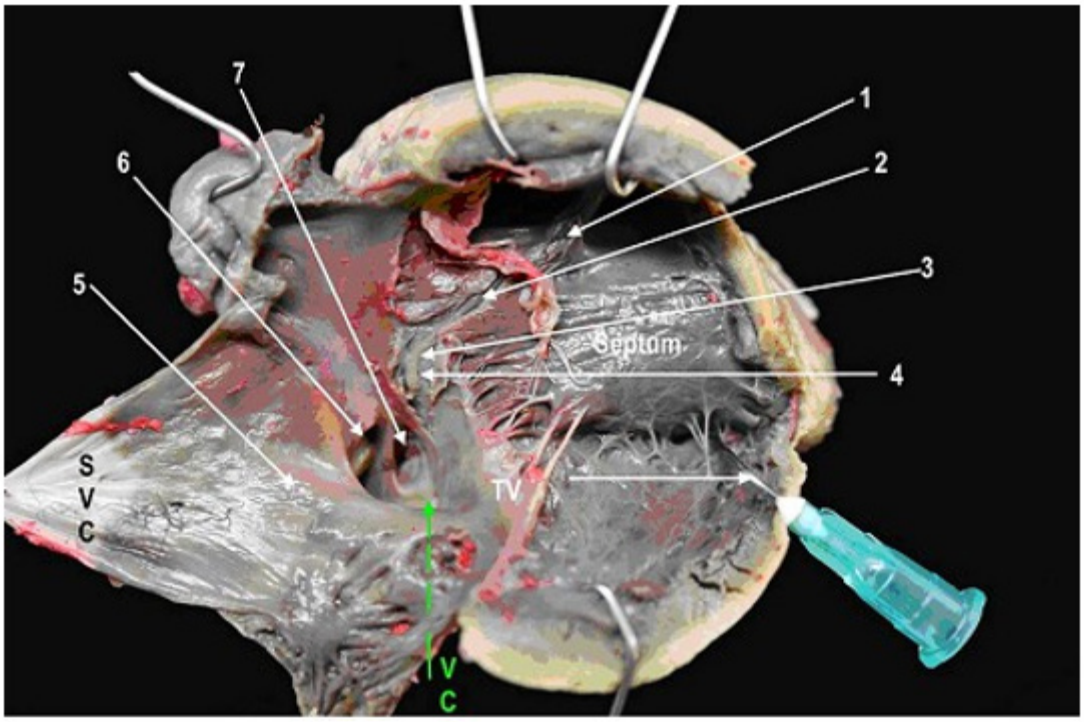

Figure 8: First description with a complete photograph of the conduction system of the 11 huemul (Hippocamelus bisulcus). It continues with the right branch of the bundle of His (2), crossing the tricuspid valve toward the atrioventricular fascicle (bundle of His 3) until reaching the atrioventricular node (4). The right atrium (5) with its anatomical features. (6) Pathological interatrial communications found in the huemul in question. (7) Opening of the coronary sinus. The dorsal vena cava is visible, with its angle directed toward the limbus of the fossa ovalis. Both the right atrium and the right ventricle have been opened. The structure with chordae is the tricuspid valve with its papillary muscles (TV). The moderator band (1).

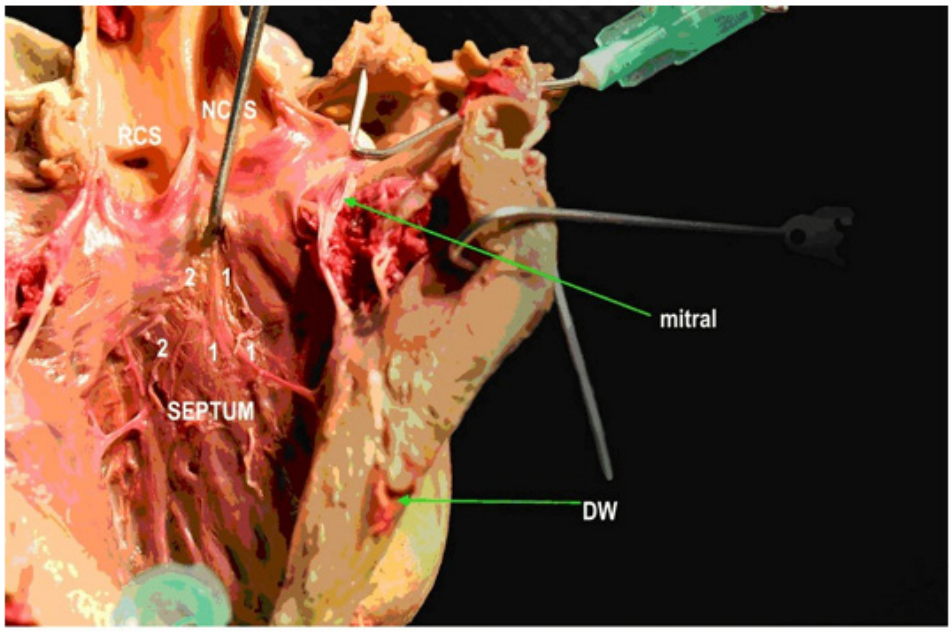

Figure 9: Left branch of the Bundle of His (atrioventricular bundle) in the huemul. First complete morphological description of the conduction system. The aortic valve and its sinuses (RCS and NCS) are visible, as is the mitral valve with its anterior leaflet sectioned to allow observation of the interventricular septum and the left branch of the Bundle of His. As in all ungulates, the left branch consists of two well-defined branches - unlike in humans. In the huemul, this branching pattern is even more pronounced. (1) and (2) indicate the anterior and posterior divisions of the left branch. Note in detail how both rapidly subdivide; these contrasts sharply with the right side. This difference will be explained later.

Associated Congenital Heart Disease

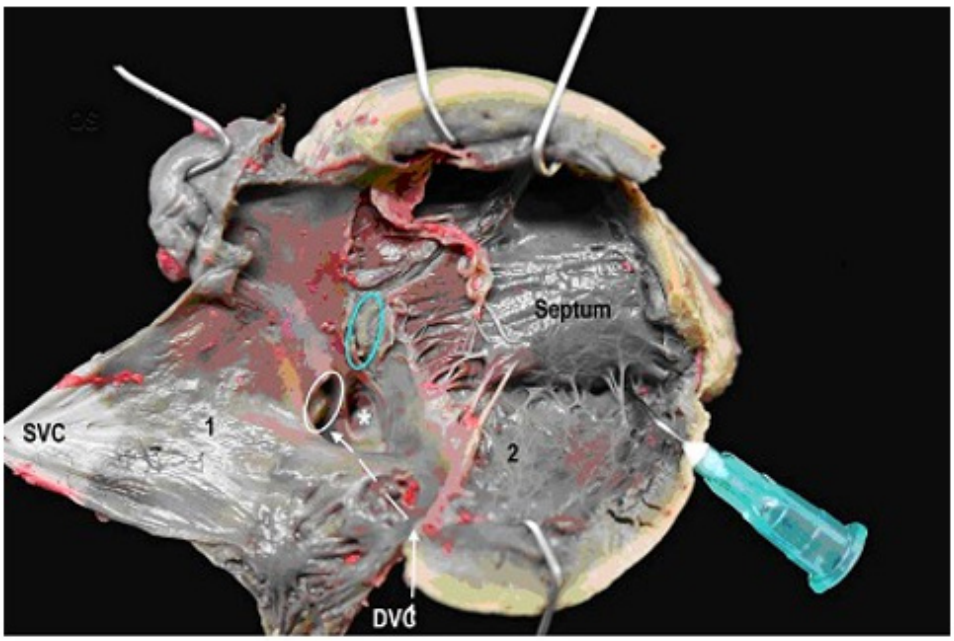

Figure 10: Ostium secundum-type atrial septal defect in a huemul. The white oval indicates the atrial septal defect, while the turquoise ellipse marks the atrioventricular node. The coronary sinus (*) frames the area. View showing the opened right chambers: the right atrium (1) and the right 12 ventricle (2).

Ostium secundum atrial septal defect and patent ductus arteriosus were confirmed. As illustrated in Figures 4 and 8, this specimen presented a patent ductus arteriosus and an atrial septal defect. The atrial septal defect is described in further detail (Figure 10,11).

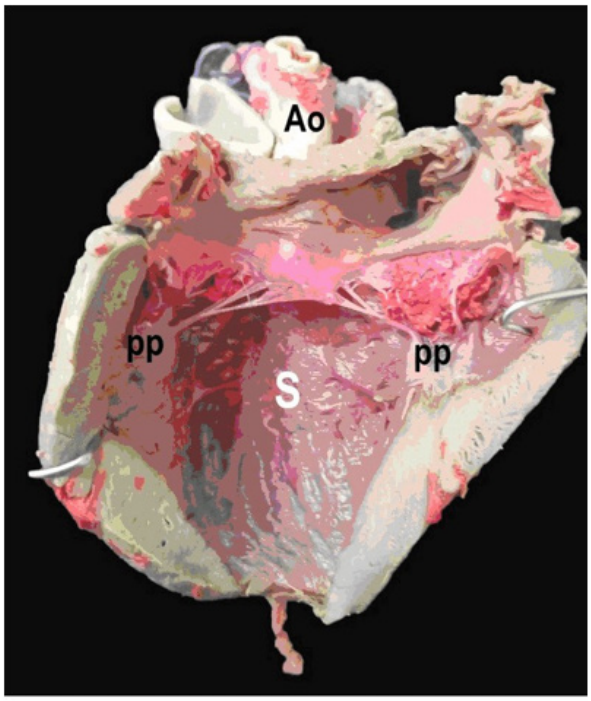

Figure 11: (pp) papillary muscles. (S) septum. The aortic valve, hidden by the anterior leaflet of the mitral valve - that pale pink structure.

Figure 12 reveals the muscle within the veils an anatomical feature rarely visualized with such clarity. Although the photograph shows the adult specimen, the fawn mentioned in this publication also possesses this trait; the image is included solely to provide further visual evidence (Figure 12).

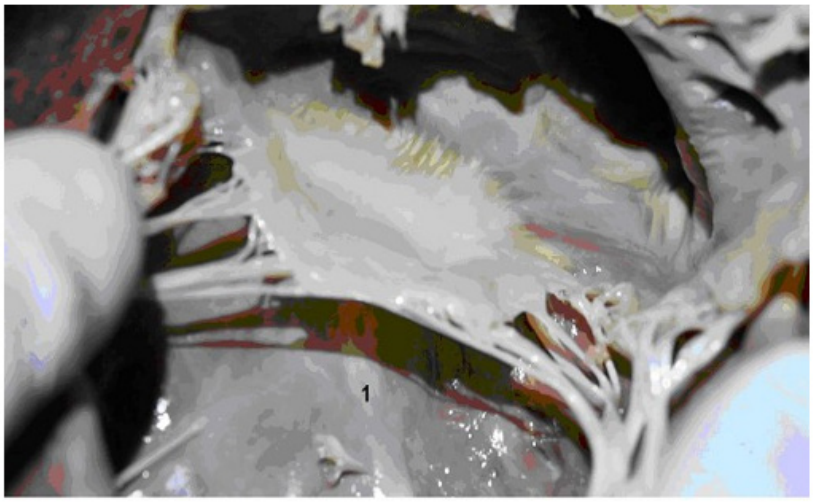

Figure 12: Anterior mitral valve with surrounding myocardium, adult huemul heart. (1) Left branch of the bundle of His. The myocardium can be clearly seen - resembling a comb draping over the anterior mitral valve.

Discussion

Sudden Death

South American camelids - and the huemul in particular were studied only anecdotally until recent decades, when genuine efforts to protect the species began to be undertaken. This is one such effort: gaining an understanding of the huemul species. Herbivores in general, and ungulates in particular, tend to exhibit a poorly understood phenomenon when threatened: sudden deaths. Theories have been proposed that lack any physiological or morphological basis. It is reasonable to hypothesize a vagal reaction - or any other mechanism one might choose – such that the Divine Providence, in the face of imminent death, spares the animal by bringing about a painless, premature end. While we may poetically subscribe to that elegant intellectual explanation, the findings in two huemul hearts with identical structures draw our attention to a specific fact: the anterior interventricular artery is completely intramyocardial.

Although this finding is observable in rodents, humans, marsupials, and cetaceans, in this instance, the vessel in question – which supplies blood to 55% of the left ventricle and the septum - is entirely covered by a layer of myocardium. In this morphological study, we document this clearly, proposing that rather than a vagal reflex or some other event that is difficult to verify, it is an isometric effort (such as a struggle or parietal stress caused by arterial hypertension resulting from a catecholamine surge) which triggers a contraction across the ENTIRE left ventricular wall AND the myocardial bridge. Under certain conditions, this can lead to severe ventricular arrhythmia and SUDDEN DEATH. We would certainly not contradict Sir William Harvey, who as early as 1617 began to say that "until every aspect of morphology is clarified, no one should speak of physiology." Indeed, more than 400 years later, we remain aligned with his views. It is also our duty to report this morphological finding as another step forward in our understanding, and to at least hypothesize about its function.

Structural Congenital Heart Disease and Digestive Tract Disease

The finding of a structural congenital heart disease (non-lethal), along with congenital jejunoileal junction stenosis in the huemul (lethal in this case), adds to the already known harm caused by inbreeding. These morphological findings reinforce the concept of crossbreeding huemul from different areas - with an appropriate program - to mitigate inbreeding.

Conduction System

This is the first detailed (and generic) description of the atrioventricular bundle in this cervid. It is worth noting its differences from that of humans and other species. The structure of the conduction system has already been dissected in another adult huemul with identical findings.

The Mitral Valve Is Supported by The Usual Collagen System and By Striated Muscle

This finding, which is not exclusive to the huemul deer as it is also found in humans and other mammals, is very prominent in the huemul. It is so prominent that it can be seen with the naked eye, something that is not so clearly visible in other mammals. The increase in intracavitary pressure during isometric exertion, as well as the unknown connections of these myocardial fibers, may be a source of arrhythmogenic activity.

Conclusions

The cardiac anatomy of the huemul has been delineated in great detail, covering its external and internal configuration, coronary vessels, and cardiac conduction system; the descriptions of the latter two represent first case descriptions in the international literature. A non-immediately lethal congenital structural heart defect was identified in this fawn, as well as an intestinal malformation (the cause of death), both possibly linked to the inbreeding affecting the species. This significant finding underscores the need to intensify efforts to prevent such occurrences. The presence of intramyocardial vessels suggests a potential cause of sudden death in these animals.

Declarations

Acknowledgments

The research was done as part of the project "Huemul in danger: adaptive management proposal" approved by the authorities of the Province of Chubut, and the corresponding transit permits.

Conflict of Interests

The authors declare no conflict of interest.

Ethics Approval

This does not apply in the current article.

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