Congenital heart defects in cattle

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SUMMARY

Congenital heart defects (CHD) are cardiac diseases present at birth and a prevalence of 0.2% to 2.7% has been reported in cattle. However, the real prevalence of bovine CHD could be underestimated because of the scarcity of surveillance programs and the low economical value of young animals, this leads the farmers to limit further diagnostic tests in calves suspected to have CHD. Moreover, many calves can have asymptomatic CHD that go undetected or die during the perinatal period before veterinary examination. The precise cause of CHD is not known in cattle and external teratogens or genetic factors can be implicated in the genesis of CHD. The use of selected sires for intensive breeding programs, especially in some of breeds with low population size, has increased the "inbreeding grade" that could be responsible for CHD. Congenital cardiac defects can be classified by various criteria and, in relation to the presence of cyanosis of the mucous membranes, they can be subdivided into cyanogenic or non-cyanogenic CHD. Ventricular septal defects, atrial septal defects and persistent ductus arteriosus are the most frequently reported non-cyanogenic CHD in cattle. Complex CHD such as conotruncal anomalies (tetralogy of Fallot, complete transposition of the great arteries and double-outlet right ventricle) are commonly described as cyanogenic CHD. Rare CHD such as malformations of atrioventricular valves, outflow tract obstructions and anomalies of vessels connected to the heart are less frequently diagnosed in the bovine species. This review aims to provide a summary of the most common CHD reported in cattle with the iconographic support from the authors' experience, offering thus an overview of which congenital anomalies should be considered during the evaluation of cattle suspected to have CHD. A precise diagnosis can be useful in cases with isolated defects, which can be associated with a favorable prognosis; likewise, it can be important an accurate and early diagnosis in cases with severe and complex malformations, often associated with a poor prognosis for long-term productivity and survival. This is of primary importance in order to avoid unnecessary treatments or animal suffering.

KEY WORDS

Calf; congenital disease; echocardiography; heart.

INTRODUCTION

The term congenital heart defects (CHD) refers to heart diseases present at birth. This condition can arise from abnormal development of the heart and vessels or from unsuccessful adaptation of the cardiovascular system to the physiological changes during the calving and perinatal period. CHD should be considered a "progressive" condition as their hemodynamic characteristics can change during extrauterine life: indeed, the cardiovascular system in animals affected by CHD is characterized by "continuous" changes which can remain asymptomatic for months or lead to early death. Rarely, some of CHD can resolve spontaneously after the birth (e.g., spontaneous closure of perimembranous ventricular septal defects in humans and horses)[1,2]. Therefore, an early diagnosis of CHD becomes crucial in order to assess their clinical relevance and prognosis. Echocardiographic examination is the most useful diagnostic tool to confirm or rule out the presence of CHD in cattle[3-5]. The availability of portable ultrasound equipment allows easily to perform an echocardiographic exam in veterinary hospitals as well as in farms.

The prevalence of CHD in cattle is less well-defined than in other species and historical studies suggest a prevalence of 0.2% to 2.7%[6-9]. However, the real prevalence of bovine CHD could be underestimated: it is possible that many calves with CHD die during the perinatal period before veterinary examination; moreover, other calves can have asymptomatic CHD that go undetected. Unfortunately, the scarcity of surveillance programs and the low economical value of young animals leads the farmers to limit further diagnostic tests *in vivo* or *post-mortem* in animals with clinical signs of CHD.

The precise cause of CHD is not known in cattle as well as in all veterinary species. In humans, teratogens (drugs, toxin, biologic agents) or chromosomal abnormalities/mutations can be implicated in the genesis of CHD[10]. In cattle, familial risk has been suspected only for ventricular septal defects in Limousine, Jersey, and Hereford breeds[11-14]. The use of selected sires for intensive breeding programs, especially in some of breeds with low population size, has increased the "inbreeding grade". This could lead to a high frequency of some allelic variants carrying genetic anomalies that could be responsible for congenital diseases as CHD. Genetic causes include also "*de novo*" mutations that can occur in the germ cells

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of the parents or in the fertilized egg itself during embryogenesis[15]. It is likely that multiple genetic and environmental factors can be implicated in the development, with a close link between genetic predisposition and epigenetic factors. Therefore, the focus of future studies will be that of determining which specific genes and external factors can lead to CHD in cattle.

This review aims to provide a summary of the most common CHD reported in cattle with the iconographic support from the authors' experience, offering thus an overview of which congenital anomalies should be considered during the evaluation of cattle suspected to have CHD.

CLASSIFICATION

CHD can be classified by embryologic, anatomical, clinical, or pathophysiologic criteria. In this review, CHD have been clinically subdivided into cyanogenic and non-cyanogenic heart diseases, depending on the presence or absence of cyanosis of the mucous membranes (blue-colored *versus* pink-colored mucous membranes). Among the non-cyanogenic CHD, the most common anomalies characterized by left-to-right shunting (ventricular septal defects, atrial septal defects, and persistent ductus arteriosus) will be described. Conversely, among cyanogenic heart diseases, complex CHD such as conotruncal anomalies (tetralogy of Fallot, complete transposition of the great arteries, and double-outlet right ventricle) will be considered. Finally, CHD less frequently reported in the bovine species will be briefly presented.

NON-CYANOGENIC CONGENITAL HEART DEFECTS

Ventricular septal defects

Ventricular septal defects (VSD) are characterized by abnormal communications between the left and right ventricle, which occur either isolated or as part of a complex cardiac anomaly. These defects represent the most frequently observed CHD in the bovine species[4,16]. VSD are classified according to the anatomical location into perimembranous defects (adjacent to the base of the aortic valve and the septal leaflet of the tricuspid valve), doubly committed defects (immediately below the aorta and pulmonary artery) o muscular defects (within the muscular part of the septum, in apical or mid-ventricular position)[4,5,11,12].

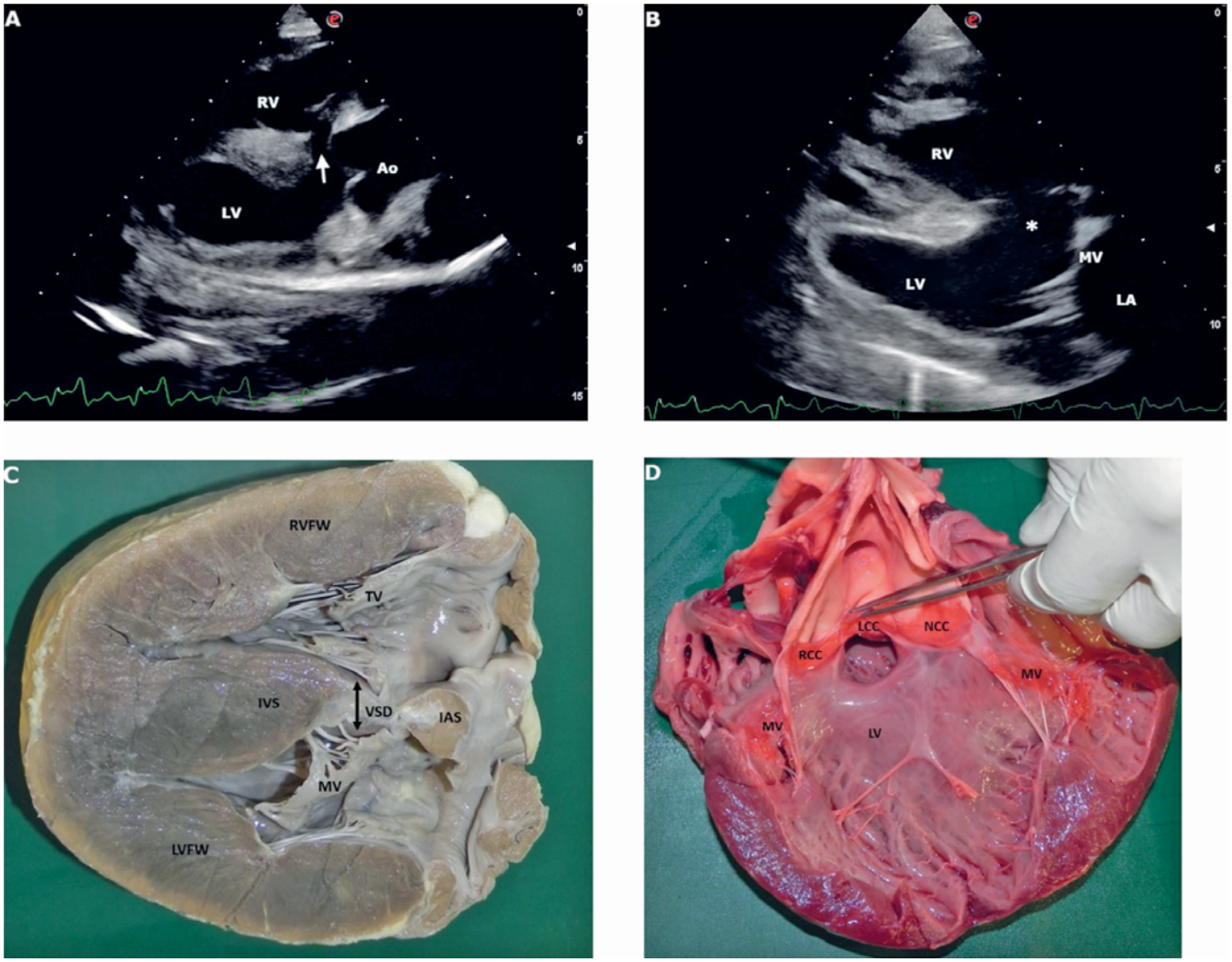

Figure 1 - Echocardiographic and gross findings in calves affected by ventricular septal defect. (A) Right parasternal long axis view of the left ventricular outflow tract showing a perimembranous ventricular septal defect (arrow); (B) right parasternal long axis four chamber view showing a large ventricular septal defect (*), enlarged right ventricle (RV) and thickened right ventricular free wall; (C) four chamber cut of a formalin-fixed heart showing a perimembranous interventricular septal defect (VSD); (D) left ventricular (LV) view of a large perimembranous ventricular septal defect just below left coronary aortic cusp (LCC). LV, left ventricle; LA, left atrium; Ao, aorta; RVFW, right ventricular free wall; LVFW, left ventricular free wall; IVS, interventricular septum; IAS, interatrial septum; RCC, right coronary cusp; NCC, non-coronary cusp; MV, mitral valve.

The presence of VSD results in a shunt from the left to the right ventricle, the magnitude of which depends on the size of the defect and the pressure gradient between the two ventricles: in small defects, the amount of blood flowing is limited and causes only mild volume overload (commonly termed "restrictive" defects)[5]; on the other hand, a large defect offers no resistance to blood flow, which consequently causes significant volume overload to the pulmonary circulation and venous return to the left heart (commonly termed "nonrestrictive" defects)[5]. Chronic and high-volume left-to-right shunt can result in pressure overload in the pulmonary circulation, pulmonary vascular remodeling, increased pulmonary vascular resistance, right ventricle hypertrophy and consequently right-to-left shunt flow if pulmonary vascular resistance exceeds systemic vascular resistance (termed Eisenmenger's syndrome)[4, 11, 18]. This latter condition results in deoxygenated blood entering in the left ventricle and systemic arterial circulation, causing cyanosis[4, 11, 18].

The magnitude of the shunt also influences the clinical signs[4, 5]. Calves with small defects are frequently asymptomatic and a holosystolic or pansystolic, plateau shaped, heart murmur with its point of maximal intensity (PMI) cranially and below the tricuspid valve area, can be heard, whose intensity is not predictive of the severity of VSD[4, 14, 18]. Thrill can be palpable on the right hemithorax. A slightly less intense ejection murmur due to volume overload of the right heart and increase of pulmonary blood flow can be heard over the left heart base (termed "relative pulmonary stenosis"). Respiratory distress and clinical signs of right-sided congestive heart failure have been reported in calves affected by moderate to large VSD[4]. The heart murmur intensity could gradually decrease until disappearance in animals with Eisenmenger's syndrome. In this case, a systolic murmur due to tricuspid regurgitation, central cyanosis, erythrocytosis, severe intolerance to movement and poor weight gain can be observed[4]. Pulmonary infection can be a complication in calves with VSD: impairment of mucociliary clearance has been suspected in asymptomatic cattle affected by VSD[4, 17, 18].

Echocardiographic examination allows to identify and localize the VSD (Figure 1), as well as to quantify of the volume overload. A VSD is defined as small if the size of the defect is ≤ 1/3 of the aortic annulus, whereas it is considered a large defect if this ratio exceeds 2/3 [5]. The Doppler studies allow the identification/localization of a very small VSD and the evaluation of shunt direction through the defect[4]. Flow velocity through the defect can be measured by continuous wave Doppler and the pressure gradient between the ventricles can be estimated: a peak velocity of 4.5-5 m/sec (pressure gradient > 80 mmHg) confirms a restrictive defect[5].

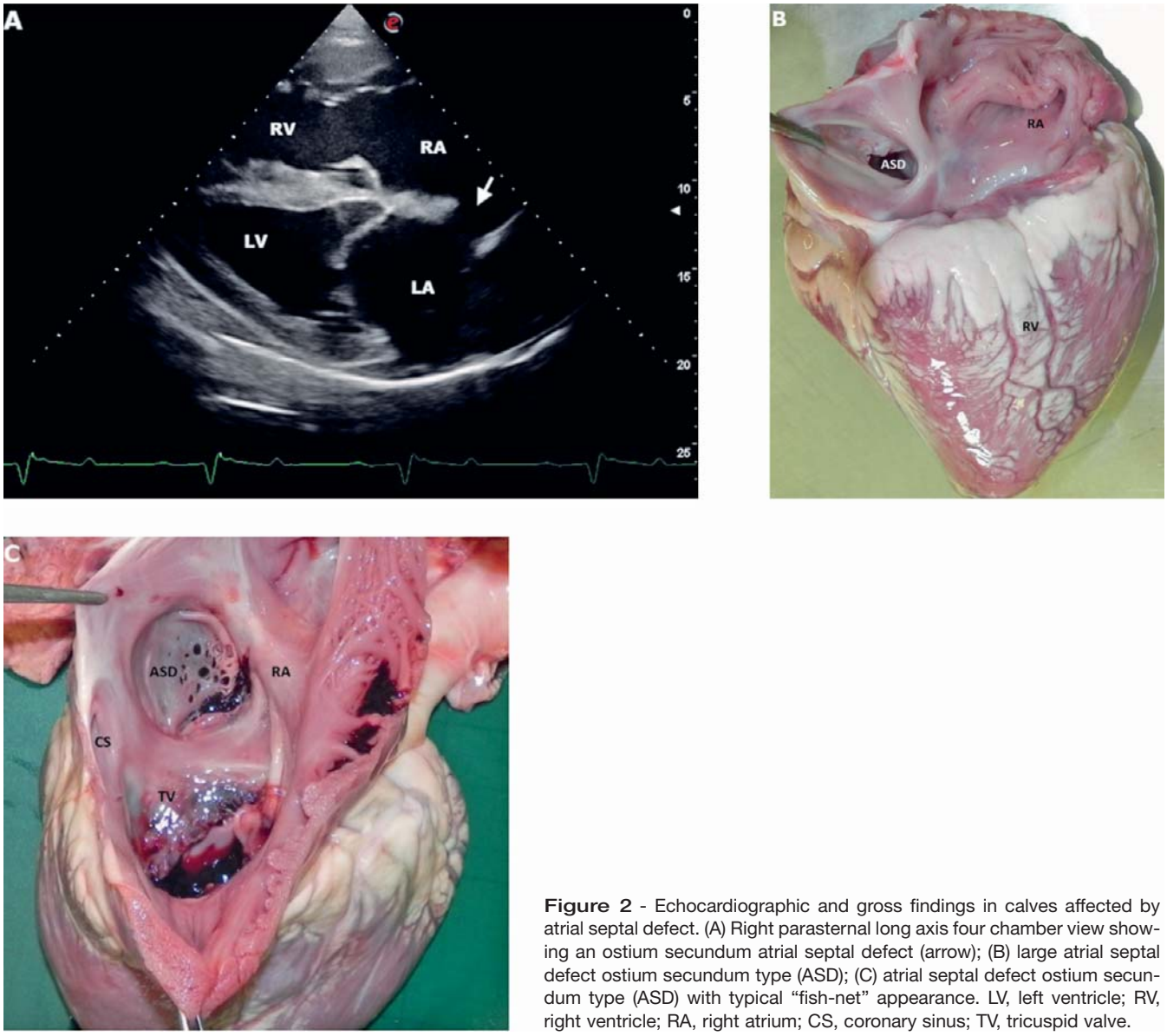

Figure 2 - Echocardiographic and gross findings in calves affected by atrial septal defect. (A) Right parasternal long axis four chamber view showing an ostium secundum atrial septal defect (arrow); (B) large atrial septal defect ostium secundum type (ASD); (C) atrial septal defect ostium secundum type (ASD) with typical "fish-net" appearance. LV, left ventricle; RV, right ventricle; RA, right atrium; CS, coronary sinus; TV, tricuspid valve.

Prospective studies are lacking in the literature to evaluate the prognosis in calves with VSD. No prognostic factors have been identified to determine the outcome of calves affected by VSD: Buczinski *et al.* reported a poor prognosis in many affected animals in their retrospective study but failed to define prognostic factors useful in assessing the evolution of the disease[4]. It should be underlined that even if adult cattle with small defects have normal reproductive and productive performances, they can be predisposed to complications, such as bacterial endocarditis[19,20]. Finally, owing to the likely genetic implications in the development of CHD[3], the potential disadvantages of breeding cattle with CHD should always be discussed with the farmer.

Atrial septal defects

Atrial septal defects (ASD) are persistent communications between the left and right atrium. These congenital anomalies are rarely observed as single defect, whereas they are most commonly detected as part of complex CHD[6,8,13,16]. ASD can be classified into *ostium primum* ASD (located in the ventral interatrial septum above the tricuspid valve), *ostium secundum* ASD (located in the area of the f*ossa ovalis*) and sinus venosus ASD (located near the cranial and caudal vena caval inflow)[6,8,13,16]. Patent *foramen ovale* (PFO) is characterized by unfused flap of tissue covering the *foramen ovale* and it is not considered as a real ASD. *Ostium secundum* defects can have a typical "fish-net" appearance, characterized by the presence of multiple coalescing small defects associated or not to a larger one (Figure 2).

ASD cause left-to-right shunt predominantly during the end-systole, when pressure gradient between the atria is higher, increasing pulmonary blood flow. In moderate to large ASD, volume overload of the right heart results in the right atrial and ventricular enlargement, and pulmonary overcirculation[13,16].

Clinical signs in small and isolated ASD can be irrelevant (no clinical signs, no murmur). Large ASD can lead to right-sided volume overload and pulmonary overcirculation with potentially clinical signs of left-sided congestive heart failure[13,16]. Volume overload of the right heart and increase of pulmonary blood flow can generate a "relative pulmonary stenosis" murmur at the left heart base. Concurrent cause of high right atrial pressures (e.g., pulmonary outflow obstruction or pulmonary hypertension) can result in right-to-left shunt with clinical symptoms, such as intolerance to movement and central cyanosis[13,16].

Echocardiographic examination allows the visualization of the abnormal communication and evaluation of the flow through the defect (Figure 2). Small ASD cannot be easily detect by Doppler studies because of overlapping physiological flows from pulmonary or caval veins[5]. Saline contrast study (microbubbles obtained by mixing saline solution and air) can provide additional information and confirm the shunt[5].

Calves with small and isolated ASD can have a favorable prognosis; this anomaly can be detected incidentally at necroscopy, although prospective studies are not available in the literature. On the other hand, the prognosis for large defects or ASD associated with complex CHD should be considered guarded.

Patent ductus arteriosus

Patent ductus arteriosus (PDA) is a congenital anomaly that is mostly associated with other and more complex CHD in calves. The ductus arteriosus is an arterial connection between main pulmonary artery and descending aorta that permits shunting of blood in the fetus[21]. This ductus closes at birth or in the first days after the delivery[5,21]. When this communication fails to close, a left-to-right shunt from the aorta to the pulmonary artery occurs, resulting in volume overload of the pulmonary circulation and left heart chambers[22-27]. The clinical signs depend on the magnitude of the shunt, which in turn is dependent on the size of the PDA and the pressure gradient between the aorta and pulmonary artery[22-27]. In very large PDA, volume and pressure overload can result in pulmonary hypertension with right-to-left shunt flow if pulmonary vascular resistance exceeds systemic vascular resistance (Eisenmenger's syndrome).

Physical examination findings include a continuous "machinery" heart murmur and thrill, usually loudest at the left base of the heart (craniodorsally to the aortic valve area - left axillary area)[22-27]. Moreover, it is possible to detect "bounding" arterial pulses characterized by rapid increase of the systolic pressure (due to volume overload) and rapid decrease of diastolic pressure (due to shunting through the PDA). Signs of congestive heart failure and poor weight gain have also been reported[22-27]. Volume overload can also lead to left congestive heart failure (tachypnea/dyspnea for pul-

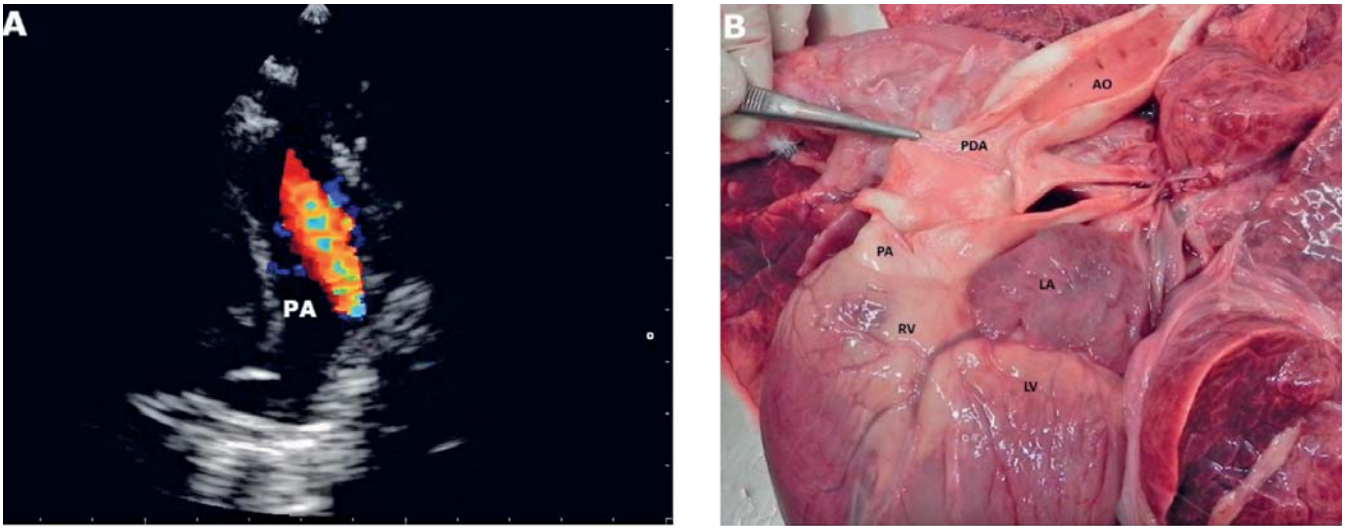

Figure 3 - Echocardiographic and gross findings in two calves affected by patent ductus arteriosus. (A) Color Doppler image recorded from a modified left cranial parasternal view, showing left-to-right turbulent flow within the pulmonary artery (PA); (B) gross appearance of an opened patent ductus arteriosus (PDA). PA, pulmonary artery; AO, aorta; RV, right ventricle; LV, left ventricle; LA, left atrial auricle.

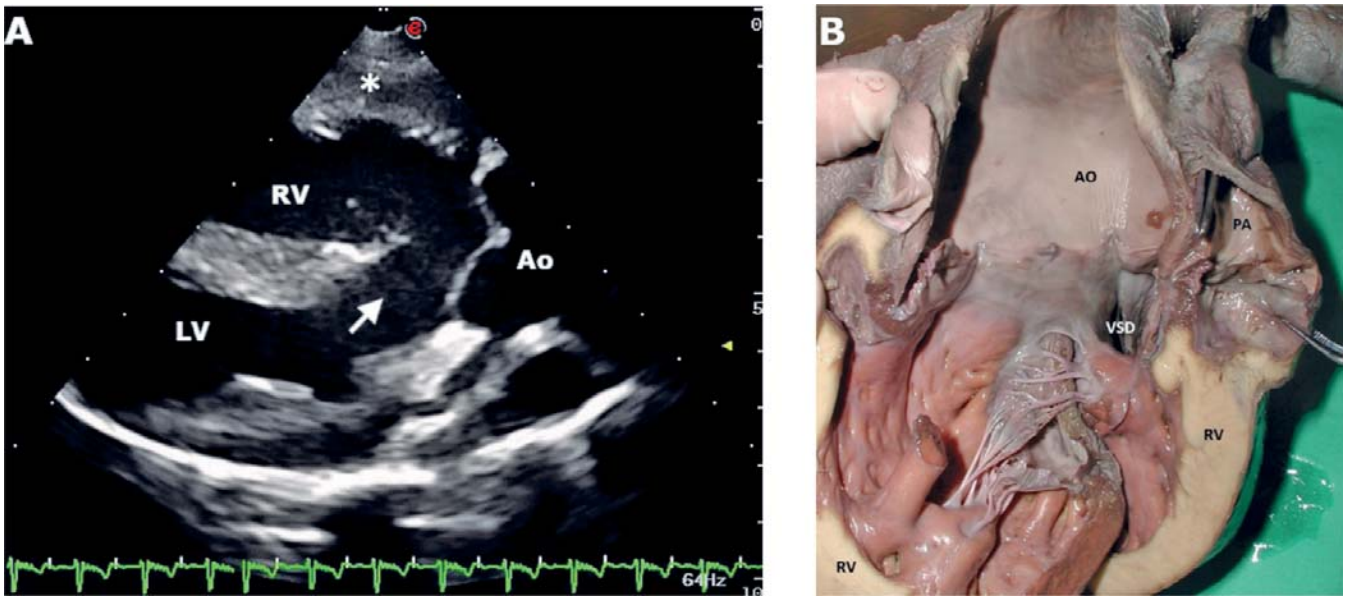

Figure 4 - Echocardiographic and gross findings in a calf affected by tetralogy of Fallot. (A) Right parasternal long axis view of the left ventricular outflow tract showing large ventricular septal defect, dextrally located aorta (Ao), enlarged right ventricle (RV) and thickened right ventricular free wall (*); (B) right ventricular view with enlarged aorta (AO) overriding a large interventricular septal defect (VSD), smaller pulmonary ostium and artery (PA) and thickened right ventricular free wall (RV).

monary edema)[22-27]. When right-to-left shunt flow occurs, heart murmur disappears and differential cyanosis could be evident (genital mucous membranes are cyanotic, whereas head mucous membranes are normal). Some of affected calves could show hind limb weakness, especially after exercise. Rarely, aneurysm of the PDA can occur with clinical, radiological and ultrasonographic findings suggestive of a mass in the cranioventral mediastinum[27]. Echocardiography allows the visualization of the PDA and the estimation of left ventricular volume overload using various echocardiographic indices[5]. The Doppler studies allow to visualize the flow through the PDA into the pulmonary artery (Figure 3) and measure its velocity[5]. A low velocity (< 4.5-5 m/sec) can be considered prognostically unfavorable because it is due to an increase of the pulmonary pressures or reduce of the systemic pressure secondary to severe left ventricular systolic dysfunction.
Prospective studies are not available in the literature for calves affected by PDA; however, prognosis is guarded to poor in several case reports[22-27]. Thromboembolic arteritis caused by a chronic thromboarteritis of PDA has been reported in an adult cow with normal reproductive and productive performances[26].

CYANOGENIC CONGENITAL HEART DEFECTS

Abnormal ventriculoarterial connections are complex CHD reported in humans and domestic animals[28-37]. In cattle, these anomalies can present a wide spectrum of anatomic abnormalities including malposition or malformation of great vessels that can arise from the wrong ventricle. Some of these complex CHD are tetralogy of Fallot, transposition of the great vessels, double-outlet right ventricle. Less frequent malformations are those in which the great arteries emerge from the base of the heart as a common trunk (single common arterial trunk), or pulmonary artery is absent and only the aorta is identified (solitary arterial trunk)[38-40].

Tetralogy of Fallot

Tetralogy of Fallot (ToF) is a complex CHD characterized by VSD, overriding (dextroposition) of the aorta and right ventricular outflow tract obstruction (usually hypoplasia of the valvular annulus and main pulmonary artery) inducing adaptive right ventricular hypertrophy. If ToF is combined with ASD or PDA, these abnormalities is named pentalogy of Fallot. ToF is a well-documented complex CHD responsible for right-to-left shunting, arterial desaturation, and cyanosis in calves [41-46].
Right-to-left shunt through VSD is due to the high right intraventricular pressure secondary to pulmonary stenosis. The degree of cyanosis and severity of clinical signs depend on the volume of blood traversing the lungs. ToF with severe right ventricular outflow tract obstruction is characterized by high pressures in the right ventricle, large amount of blood flow through the aorta and VSD, and central cyanosis. Mild right ventricular outflow tract obstruction associated with a small VSD characterize forms of tetralogy of Fallot without cyanosis or with cyanosis that only appears after exercise (termed «pink» tetralogy of Fallot).
Calves affected by more severe forms show poor weight gain/failure to thrive, lethargy, central cyanosis, dyspnea and intolerance to movement[41, 42, 45, 46]. Erythrocytosis, metabolic acidosis (poor tissue oxygenation) and dehydration can also be detected. A loud systolic ejection murmur over the pulmonic valve area due to pulmonic stenosis can be heard[41, 42, 45, 46]. Echocardiographic examination reveals the typical abnormalities of ToF: hypertrophy of the right ventricular free wall, VSD, dextroposition of the aorta, and hypoplasia of the pulmonary valve and main pulmonary artery[41, 42, 45, 46] (Figure 4). The Doppler studies allow to detect the shunt through VSD and high-velocity flow through the pulmonary valve[41, 42, 45, 46].

The prognosis in calves with ToF is guarded to poor, as described in the literature[41-43]. It is possible for affected calves to live for months or years[43-46].

Complete transposition of great arteries

Complete transposition of the great arteries (TGA) is a complex cardiac anomaly characterized by atrioventricular concordance and ventriculoarterial discordance: the atria are normally connected

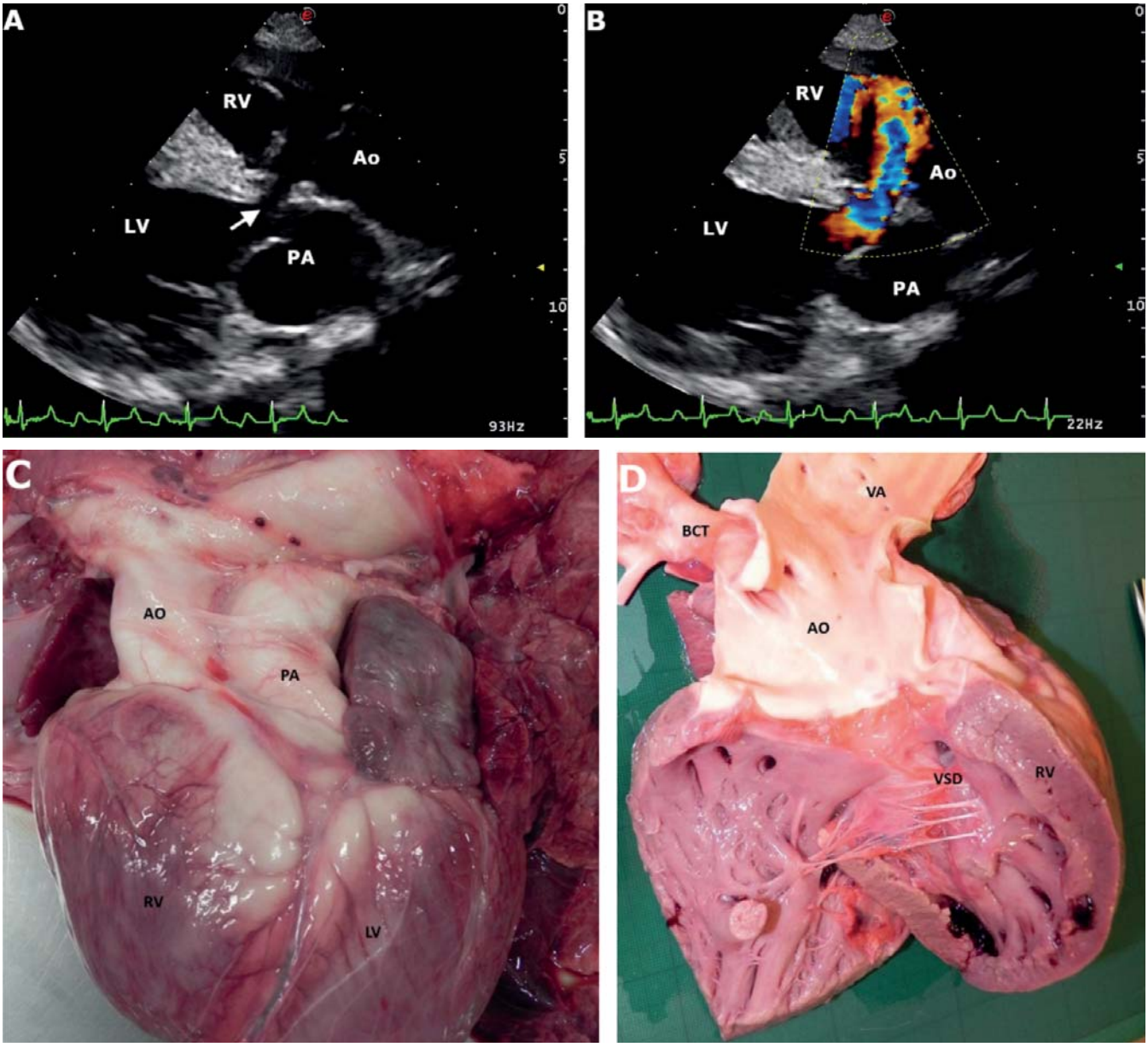

Figure 5 - Echocardiographic and gross findings in a calf affected by complete transposition of the great arteries. (A) Right parasternal long axis view of the left ventricular outflow tract displaying a ventricular septal defect (arrow) and the great vessels (Ao - aorta and PA - pulmonary artery) arising from ventricles in parallel alignment (anomaly of the right ventricular outlet position); (B) colour flow mapping indicates turbulent flow across the defect; (C) external view with aorta (AO) arising from right ventricle (RV) whereas pulmonary artery (PA) overrides left ventricle (LV); (D) right ventricular (RV) view with aorta (AO) overriding a ventricular septal defect (VSD). BCT, brachiocephalic trunk; VA, vertebral arteries.

with their respective ventricles, whereas the pulmonary artery arises from the left ventricle and the aorta from the right ventricle. This occurs due to absence of the normal 180° rotation of the great arteries during embryonic development[47]. Consequently, as the pulmonary and systemic circulation are independent and parallel, oxygenated blood from the lungs cannot reach the systemic circulation. Therefore, this abnormality should be incompatible with life without associated communications between the pulmonary and systemic circulation that allow mixing of oxygenated and non-oxygenated blood (e.g., VSD, ASD or PDA)[48, 49]. Clinical signs are characterized by poor weight gain/failure to thrive, exercise intolerance, central cyanosis (especially after exercise) and tachypnea/dyspnea, as a consequence of reduced amount of oxygenated blood reaching the tissues and its mixing with non-oxygenated blood[48, 49]. A typical heart murmur due to VSD or PDA can be heard in the affected calves[48, 49].

Echocardiographic examination can detect the abnormal communication (VSD, ASD or PDA), as well as identify the pulmonary artery and its branches that arise from the left ventricle whereas the aorta leaves the right ventricle[48, 49] (Figure 5). The Doppler studies can confirm the presence and the direction of shunting through the abnormal communication (typically bidirectional)[48, 49].

The prognosis in calves is poor for this type of CHD[48-51]. Calves with small communication between the pulmonary and systemic circulation die soon after birth[50].

Double-outlet right ventricle

Double-outlet right ventricle (DORV) is a complex CHD characterized by ventriculoarterial discordance, as already seen for TGA. Unlike the latter, both the aorta and the pulmonary artery arise from the right ventricle. This cardiac abnormality has been de-

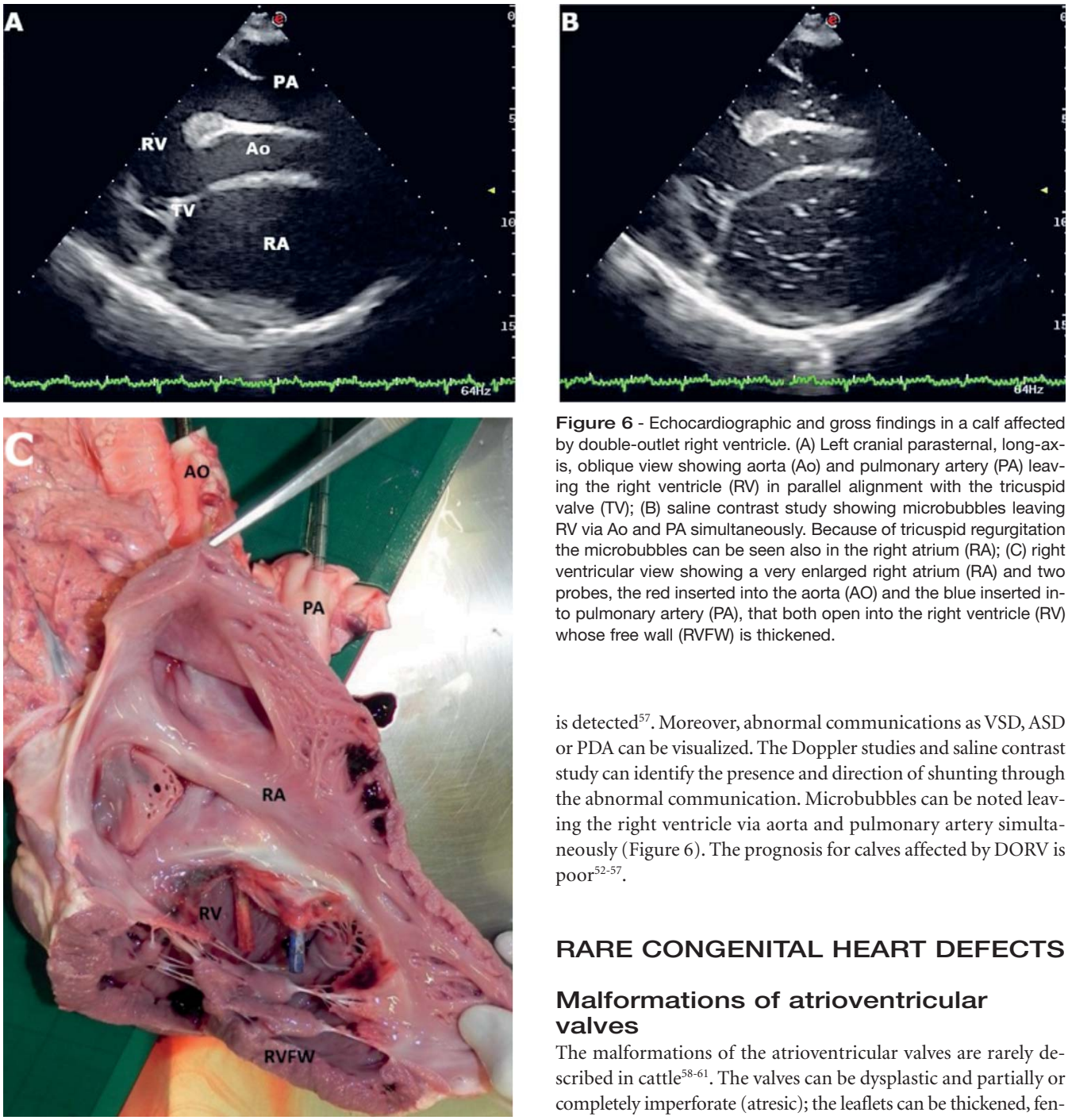

Figure 6 - Echocardiographic and gross findings in a calf affected by double-outlet right ventricle. (A) Left cranial parasternal, long-axis, oblique view showing aorta (Ao) and pulmonary artery (PA) leaving the right ventricle (RV) in parallel alignment with the tricuspid valve (TV); (B) saline contrast study showing microbubbles leaving RV via Ao and PA simultaneously. Because of tricuspid regurgitation the microbubbles can be seen also in the right atrium (RA); (C) right ventricular view showing a very enlarged right atrium (RA) and two probes, the red inserted into the aorta (AO) and the blue inserted into pulmonary artery (PA), that both open into the right ventricle (RV) whose free wall (RVFW) is thickened.

scribed in Chianina, Angus, Brangus, Herford and Friesian calves[52-57].

As for TGA, this abnormality is incompatible with life without associated communications between the pulmonary and systemic circulation that allow mixing of oxygenated and non-oxygenated blood (e.g., VSD, ASD or PDA). Clinical signs are characterized by failure to thrive, intolerance to movement, central cyanosis (especially after exercise) and tachypnea/dyspnea[53, 55-57]. A systolic, plateau shaped, heart murmur with PMI over the tricuspid area (valvular insufficiency secondary to dilation of the right ventricle) and/or a murmur due to VSD or PDA, can be heard[53, 55-57]. Echocardiographic examination allows identification of both great arteries originating from the right ventricle in anomalous parallel alignment with the tricuspid valve; usually, severe dilation of the right-sided cardiac chambers with a hypoplastic left ventricle is detected[57]. Moreover, abnormal communications as VSD, ASD or PDA can be visualized. The Doppler studies and saline contrast study can identify the presence and direction of shunting through the abnormal communication. Microbubbles can be noted leaving the right ventricle via aorta and pulmonary artery simultaneously (Figure 6). The prognosis for calves affected by DORV is poor[52-57].

RARE CONGENITAL HEART DEFECTS

Malformations of atrioventricular valves

The malformations of the atrioventricular valves are rarely described in cattle[58-61]. The valves can be dysplastic and partially or completely imperforate (atresic); the leaflets can be thickened, fenestrated, fused or cystic; the chordae tendineae can be altered in size, length, position or orientation[21, 58-61]. These anomalies are frequently detected as part of complex CHD.

A severe form of malformation of the atrioventricular valves is the atrioventricular septal defect (also known as endocardial cushion defect). It is a complex CHD due to maldevelopment of the atrioventricular junction and valves (atrioventricular septum), originating from the endocardial cushions. In humans, the atrioventricular septal defect can be complete, partial, intermediate and transitional, according to the location of ASD/VSD and the morphology of atrioventricular valves (number of orifices and site of insertion of chordae tendineae)[62]. The complete or partial form of this CHD has been more frequently described in veterinary medicine[63-65]: the complete form shows an abnormal communication between all four cardiac chambers (*ostium prim*um ASD, large VSD and common atrioventricular valve with single orifice); the partial form is characterized by only *ostium primum* ASD or only VSD with discrete orifices of the atrioventricular valve *annuli*. In both

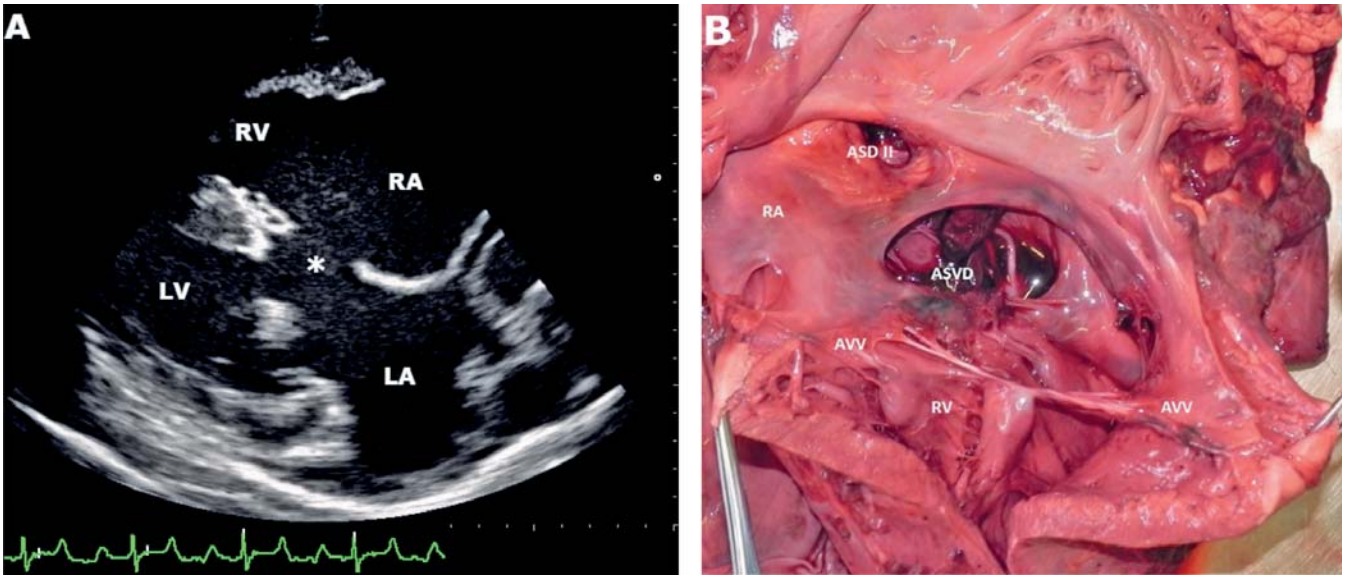

Figure 7 - Echocardiographic and gross findings in a calf affected by atrioventricular septal defect. (A) Right parasternal long axis four chamber view with opened atrioventricular valves showing an evident anomaly (*) occurring at the site of the atrioventricular septum; (B) right ventricular (RV) view showing large atrioventricular septal defect (AVSD) with enlarged right atrium (RA) and a common atrioventricular valve (AVV). LV, left ventricle; LA, left atrium; ASD II, atrial septal defect.

forms, the anomalous morphology of the atrioventricular valves can result in variable degrees of regurgitation. The atrioventricular septal defect has been rarely described in cattle[21, 49].

Clinical signs can be variable as a consequence of the size of ASD/VSD and the amount of shunting. Calves with atrioventricular septal defect will be hemodynamically similar to one with a large VSD. Affected calves show tachypnea/dyspnea due to pulmonary volume overload and systolic heart murmurs (VSD and relative pulmonary stenosis)[49].

Echocardiographic examination allows the visualization of the ASD adjacent to the atrioventricular

valves and VSD below the atrioventricular valves as well as abnormal morphology of the atrioventricular valves (abnormalities of the atrioventricular septum)[49] (Figure 7). Doppler studies can identify the presence and direction of shunting through the abnormal communications[49]. Prognosis reported in calves affected by atrioventricular septal defect is poor[21, 49].

Outflow tract obstructions

The right or left outflow tract obstructions can be located in the subvalvular, valvular, or supravalvular regions[66-68]: subvalvular forms can result from shelves of fibromuscolar tissue; valvular forms can occur for hypoplasia/dysplasia of the valves (fusion, tethering or thickening of the leaflets); supravalvular forms can result from hypoplasia/restriction of the pulmonary artery or aorta. Severe forms of these congenital anomalies are represented by the atresia of the semilunar valves[66-68].

Outflow tract obstructions result in concentric hypertrophy of the respective ventricle, dynamic obstruction of the outflow tract, and subsequent eccentric dilation with atrioventricular valve regurgitation due to dilation of the right ventricle. To the authors' knowledge, isolated left or right outflow tract obstructions have not been reported in calves but can be detected in combination with other complex CHD, such as tetralogy of Fallot[41-43, 45, 46].

A systolic ejection heart murmur is usually evident over the left base. Other clinical signs depend on the type of associated complex CHD[41-43, 45, 46].

Echocardiographic examination allows the evaluation of the ventricular outflow tracts, valvular morphology and motion, associated ventricular changes (hypertrophy or dilation)[5]. The Doppler studies can identify blood flow turbulence (Figure 8) and measure the velocity of the blood flow to estimate the stenosis (flow velocity > 2 m/sec can indicate stenosis)[5]. Color Doppler studies can also detect regurgitation of the atrioventricular valves[5].

Prognosis in calves affected by outflow tract obstruction is related to the associated complex CHD.

Anomalies of great arterial and venous vessels connected to the heart

Congenital defects affecting the aortic arch (hypoplasia), caval veins (persistent left cranial vena cava), pulmonary venous vessels or coronary arteries have rarely been described in cattle[21,49]. These abnormalities have mainly been observed during postmortem examinations[21,49].

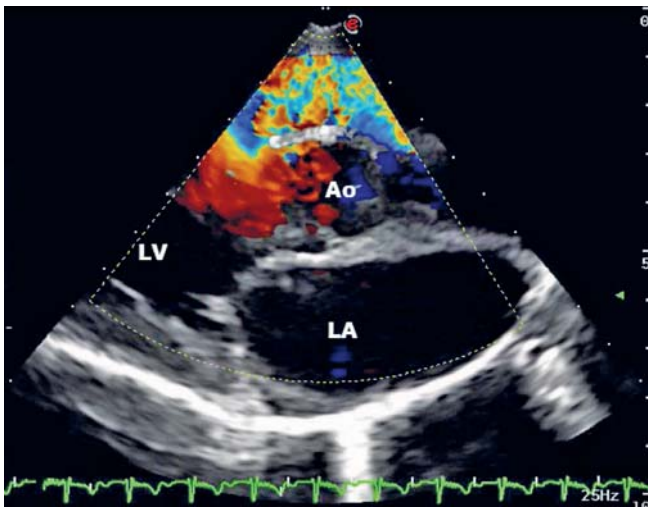

Figure 8 - Echocardiographic findings in a calf affected by pentalogy of Fallot. (A) Right parasternal long axis view optimized to visualize aorta (Ao) and pulmonary artery showing turbulent flow in the hypoplastic pulmonary artery. LV, left ventricle; LA, left atrium.

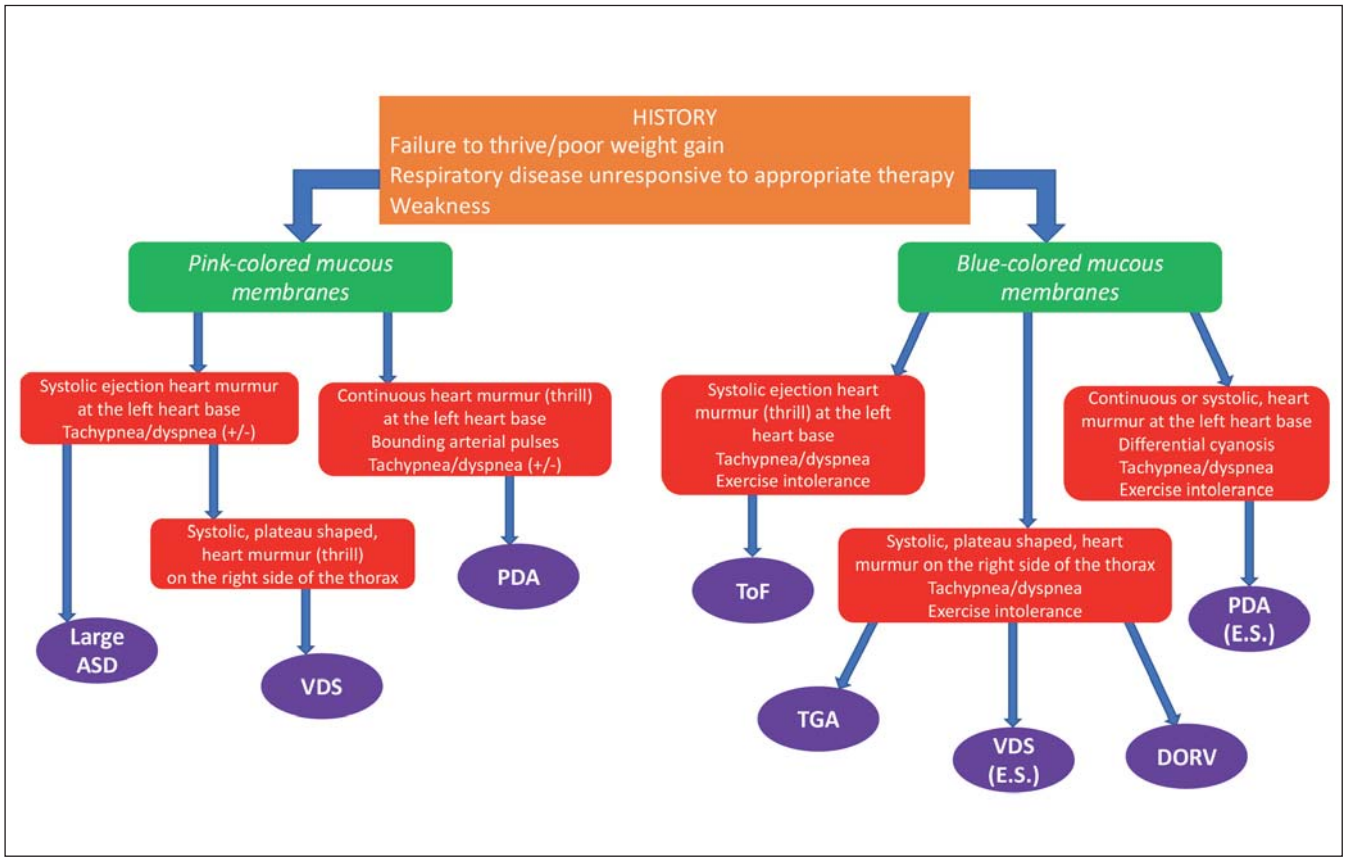

Figure 9 - Algorithm showing the history and clinical signs in the most common congenital heart defects. +/-, with or without; ASD, atrial septal defect; VSD, ventricular septal defect; PDA, patent ductus arteriosus; ToF, tetralogy of Fallot; TGA, complete transposition of great arteries; E.S., Eisenmenger's syndrome; DORV, double-outlet right ventricle.

CONCLUSIONS

CHD represent a small part of congenital diseases in cattle; however, these defects can occur with a wide spectrum and complexity. History and physical examination can be useful to suspect the presence of CHD: failure to thrive, poor weight gain, respiratory disease unresponsive to appropriate therapy, weakness, cyanotic mucous membranes, intolerance to movement and heart murmur are reported in calves affected by CHD (Figure 9). The echocardiography represents the most sensitive and specific diagnostic test to obtain a definite diagnosis. Moreover, this diagnostic tool is readily available and can be performed in veterinary hospitals as well as in farms. Because of complexity of some CHD, evaluation of affected cattle should be performed in consultation with a specialist in veterinary cardiology. A precise diagnosis can be useful in cases with isolated defects, which can be associated with a favorable prognosis; likewise, it can be important an accurate and early diagnosis in cases with severe and complex malformations, often associated with a poor prognosis for long-term productivity and survival. This is of primary importance in order to avoid unnecessary treatments or animal suffering.

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Conflict of Interest

The authors declare that there were no conflicts of interest.

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