Fetal Anatomy: The Pulmonary Valve in Fetal Pulmonary Valve Disease

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9.1 Introduction

Prenatal diagnosis has changed the understanding of the development of congenital heart defects during the gestational period. Some defects remain unchanged throughout pregnancy since the early period, while others evolve from mid to late fetal life. During gestation the pulmonary valve and trunk are slightly larger than the aortic valve and the aorta, and this difference persists until birth. The semilunar pulmonary valve is formed before the right atrioventricular valve is completed, and the cusps appear thicker early during gestation and progressively became thinner until birth. The nodules of Morgagni, identified at the line of apposition and free edge, can be identified also during fetal life. The structure of the cusp is composed by the fibrosa covered by the ventricularis and the arterialis and by the spongiosa located on the ventricular side between the fibrosa and the ventricularis.

9.2 Morphological Features

Pulmonary valve atresia and critical valve stenosis with intact ventricular septum usually develop in the setting of a hypoplastic right ventricle outflow, supporting the blood flow theory for the progressive onset of pulmonary valve stenosis and atresia and right ventricle hypoplasia during pregnancy and the development of intrauterine cardiac intervention therapeutic approach [4, 7, 8, 13, 17].

Pulmonary atresia with intact ventricular septum is a heterogeneous lesion morphologically characterized by the absence of communication between the right ventricular outflow tract and the pulmonary trunk [1, 19]. The size of the right ventricle

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can vary considerably from normal size right cavity and pulmonary valve atresia at the level of the cusps with imperforate valve to severe right ventricle hypoplasia, lack of outflow tract, and pulmonary valve and abnormal right ventricle coronary artery communication. In these last settings, the hypoplasia of the right ventricle could be often ascribed to massive hypertrophy of the right wall due to the outflow tract obstruction [11, 14–16]. The associated anomalies will influence the outcome and management of these patients [3–5]. The tricuspid valve can be dysplastic or of diminutive size, and usually tricuspid valve dimension is directly proportional to the size of the right ventricular cavity [12, 18]. The presence of severe dysplastic valve cusps with severe incompetence can be a favorable parameter providing a potential right ventricle growth secondary to right ventricle overload. However massive tricuspid regurgitation can produce right ventricle negative remodeling with thinning of the parietal wall and dilatation [7]. The presence of the three components of the morphologically right ventricle, namely, the inlet, the trabecular, and the outlet portions, does not necessarily ensure an adequate size of the cavity due to the secondary hypertrophy [9]. Pulmonary arteries are usually of normal size retrogradely supplied via the ductus arteriosus. The presence of a restricted foramen ovale can reduce the right-to-left shunt and favor tricuspid and right ventricle growth. Fistulae are associated with pulmonary atresia and intact septum in one third of the fetal cases [2, 6, 8, 10, 15].

Focusing on the pulmonary valve morphology, three types of valves can be identified in pulmonary valve atresia/critical valve stenosis with intact ventricular septum:

- **Type a**: pulmonary valve atresia, due to imperforate valve, with a dome-shaped valve and two to four raphes (Fig. 9.1). Usually there is potential continuity between the right ventricle and the pulmonary trunk. Only seldom there is a muscular pulmonary atresia with no continuity between the outflow and the pulmonary trunk.
- **Type b**: critical pulmonary valve stenosis, with three dysplastic leaflets (10–20 % of patients with critical pulmonary valve stenosis) with a pinhole central jet of flow (Figs. 9.2 and 9.3).
- **Type c**: critical pulmonary valve stenosis, with the bicuspid or unicuspid valve with hypoplasia of the annulus (Fig. 9.4).

Type a is characterized by different morphologic features starting from pulmonary atresia with intact ventricular septum in the setting of imperforate valve but still with identifiable three cusps and well-formed commissures, as if the three cusps had fused after being well formed and differentiated during development. The right ventricle is variable in size but is usually small in around 50 % of the cases, moderately hypoplastic in 25 %, and normal in only 10–15 %. The right infundibulum is also hypoplastic with a hypertrophic parietal wall with an underdeveloped tricuspid dysplastic valve, small tricuspid annulus, and short chordae. The pulmonary arteries are usually normal in size and only in about 10 % of the cases can be smaller. Sinusoidal communications between the right ventricle and the coronary arteries

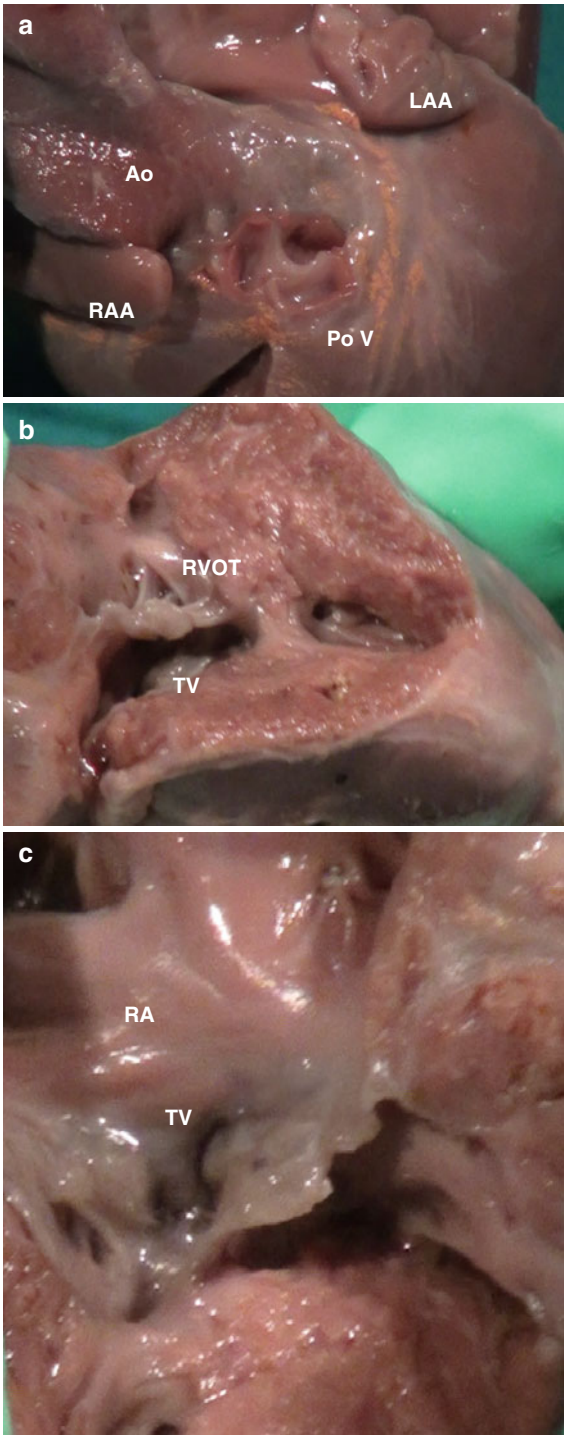

Fig. 9.1 Pulmonary valve atresia with imperforate valve. (**a**) View of the imperforate valve, after removal of the pulmonary trunk. Three cusps and well-formed commissures are still identifiable, as if the three cusps had fused after being well formed and differentiated. (**b**) The right ventricle has been opened from the apex toward the infundibulum. Note the severe hypoplasia of the right ventricle, with hypertrophic free wall. (**c**) The tricuspid valve has been opened along the acute margin of the right ventricle. Note that the tricuspid valve is also severely dysplastic. (type a). *Ao* aorta, *LAA* left atrial appendage, *PoV* pulmonary valve, *RA* right atrium, *RAA* right atrial appendage, *RVOT* right ventricular outflow tract, *TV* tricuspid valve

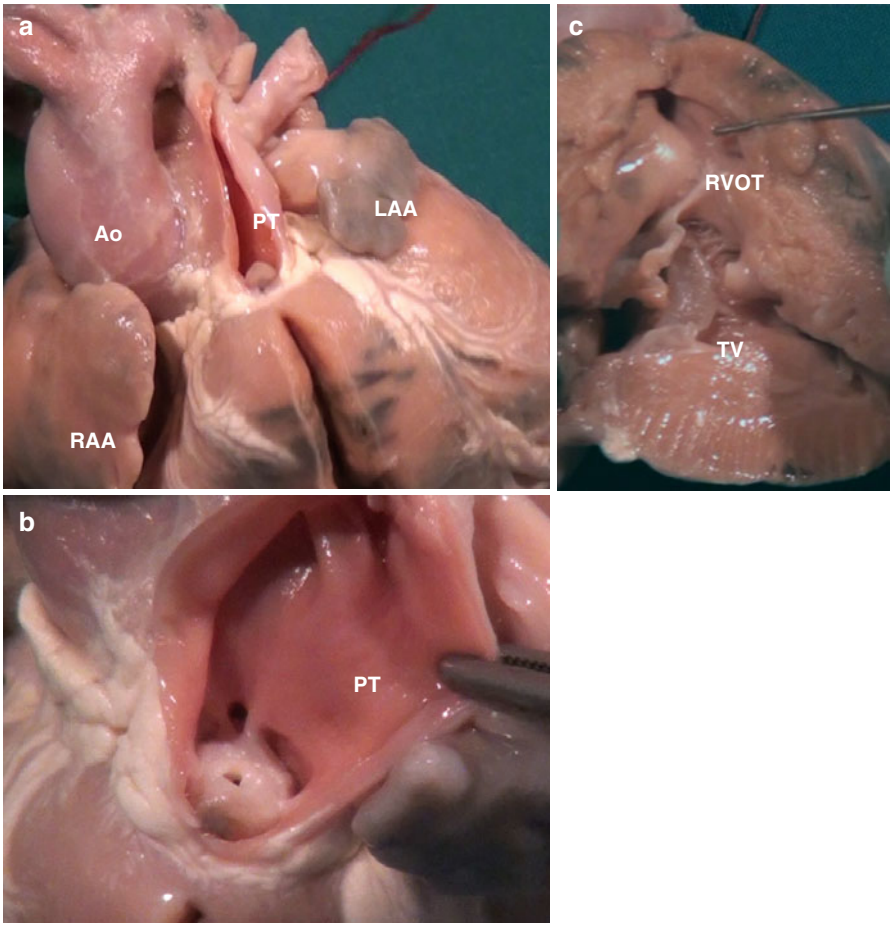

Fig. 9.2 Dome-shaped critical pulmonary stenosis. (**a**) Anterior view of the heart with hypoplasia of the pulmonary trunk and normal size aorta. (**b**) A dome-shaped pulmonary valve with a pinpoint central orifice and dysplasia of the free cusps (type b). (**c**) A dysplastic and hypoplastic tricuspid valve is also present. *Ao* aorta, *LAA* left atrial appendage, *PT* pulmonary trunk, *RAA* right atrial appendage, *RVOT* right ventricular outflow tract, *TV* tricuspid valve

may develop as a mechanism of decompression of the blood from the right ventricle [6, 8, 15]. In some cases endocardial fibroelastosis can be detected in the right ventricle [8]. The right atrium is usually enlarged and hypertrophied, and the foramen ovale usually patent.

Type b is characterized by cusps with a dome-shaped pattern without clear separation in cusps, the appearance being of a thick curtain, with two to four raphes, and a pinpoint central hole allowing some blood flowing through the valve. In these cases the central hole can vary in dimension, but what seems constant is the hypoplasia of the pulmonary annulus and the dilatation of the pulmonary trunk and

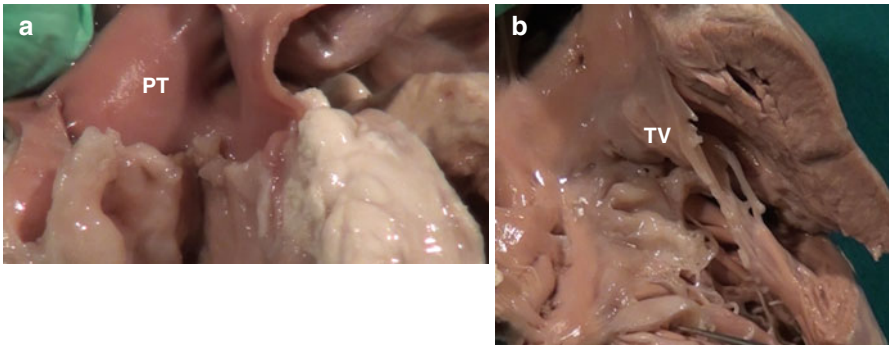

Fig. 9.3 Critical pulmonary valve stenosis and dysplastic tricuspid valve. (**a**) Note the three cusps with severe dysplastic thickening and identifiable commissures. (**b**) The tricuspid valve has been opened along the acute margin to show the severe dysplasia (type b). *PT* pulmonary trunk, *TV* tricuspid valve

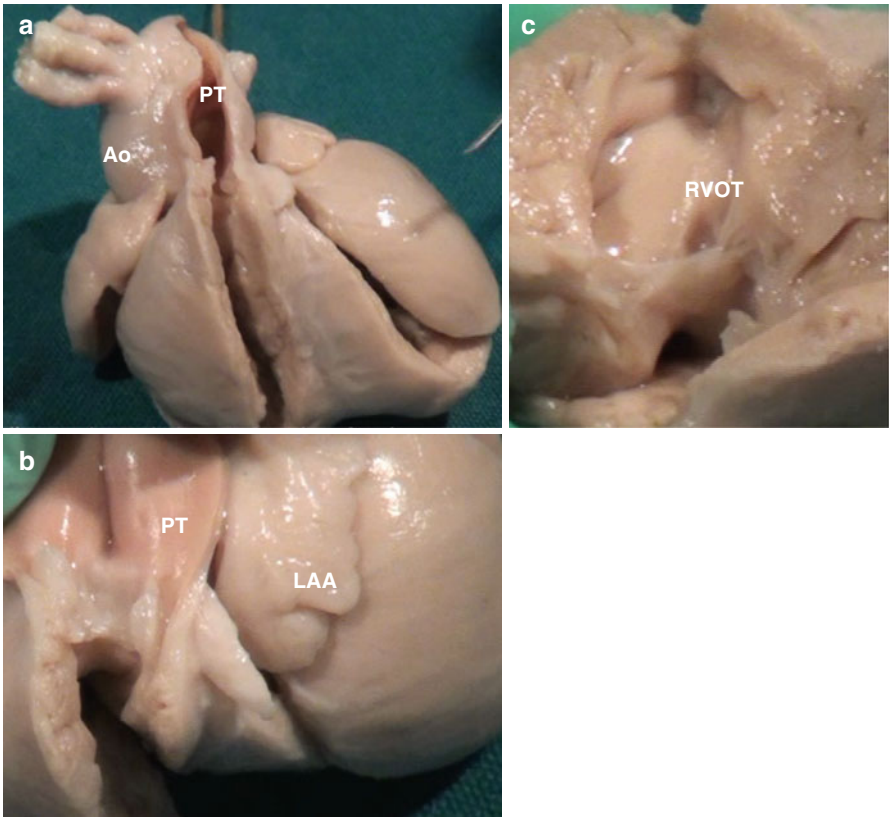

Fig. 9.4 Critical pulmonary valve stenosis with bicuspid pulmonary valve and hypoplasia of the annulus. (**a**) Anterior view of the heart with dilated pulmonary trunk. (**b**) Bicuspid and dysplastic cusps with hypoplasia of the annulus (type c). (**c**) Hypoplasia of the infundibulum and dysplasia of the tricuspid valve are present. *Ao* aorta, *LAA* left atrial appendage, *PT* pulmonary trunk, *RVOT* right ventricular outflow tract

pulmonary branches. The arterial duct is not so hypoplastic as one could expect, since it is the way through which pulmonary arterial blood flow is retrogradely guaranteed. The features of the right ventricle are similar to that of the pulmonary atresia and intact septum. In rare cases the pint-point dome-shaped valve can present with severe nodular dysplastic leaflets where it is still possible to identify three leaflets with a central hole. In other settings the three dysplastic leaflets are more developed with identifiable commissures. Histological evaluation of the leaflets showed mucoid degeneration of the fibrosa and disorganization of the leaflet structures. The right ventricular cavity is again of different sizes, mainly hypoplastic with ventricular wall hypertrophy, mainly infundibular, with subvalvular stenosis. In some cases septomarginal trabeculation can be prominent, producing the pattern of bipartitioned right ventricle.

Type c can be characterized by a bicuspid pulmonary valve with well-formed and thin bicusps, with or without a raphe but two well-formed commissures. The annulus is still smaller than in the setting of a tricuspid pulmonary valve. The right ventricle is of normal size as it is the tricuspid valve. The parietal wall is also of normal thickness. In the setting of a unicuspid valve, the morphology is that of a curtain-like cusp, with only one commissure and an eccentrically displaced hole. One or two raphes can be present as remnants of a commissure. The cusp can be dysplastic as well, and the right ventricular and atrial cavity similar to the other types previously discussed.

Conclusions

In the assessment of pulmonary atresia with intact ventricular septum/critical pulmonary valve stenosis, besides the evaluation of the valve morphology and the presence of cusp dysplasia, it is important to evaluate carefully the right ventricle dimension and hypertrophy, especially the outflow for subvalvular obstructions caused mainly by secondary hypertrophy, which is present in one third of the cases. Moreover, also the tricuspid valve desires precise assessment. Careful consideration should be given also to the left cavities since seldom aortic valve dysplasia and supravalvular aortic stenosis could be identified and could impact on fetal interventional procedure policy.

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