

Functional pulmonary atresia – a sign of severe right ventricular failure

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Abstract

Background. Functional pulmonary atresia (funPA) was reported in fetuses and newborns with severe Ebstein anomaly. Few anecdotal reports described this condition with normal heart anatomy. **Aims.** To explain pathophysiological mechanisms leading to funPA. **Methods and results.** Echocardiography results were evaluated in 12 cases of funPA: 7 fetuses and 1 newborn with Ebstein anomaly, and 4 with normal heart anatomy: 3 recipients of twin-to-twin-transfusion syndrome, 1 with severe arrhythmia. Enlarged heart, abnormal RV anatomy or function, severe tricuspid insufficiency, regurgitant flow through the pulmonary valve during systole, reverse a wave in the ductus venosus and umbilical vein pulsatility was seen in all cases. **Conclusion.** FunPA was a result of severe right ventricular failure in fetuses and neonates due to abnormal RV anatomy or impaired function. Pulmonary valve was patent, so the term “atresia” could make confusion. We suggest to name this phenomenon “systolic pulmonary regurgitation”, as comparison to “diastolic mitral regurgitation” in adult patients with severe left ventricular failure. Distinguishing between anatomic and “functional” pulmonary atresia is important for neonatal Ebstein anomaly, as those cases usually needed emergency surgery whereas “systolic pulmonary regurgitation” in a newborn with normal heart anatomy is not a ductal dependent lesion so medical treatment should be adjusted to the neonatal condition.

Key words: fetal echocardiography, fetal heart failure, functional pulmonary atresia, TTTS, Ebstein, diastolic mitral regurgitation

Abbreviations: Fun-PA – functional pulmonary atresia, dias-MR – diastolic mitral regurgitation, CVPS – cardio-vascular profile score, TTTS – twin to twin transfusion syndrome, NIHF – nonimmune hydrops fetalis, PI – pulsatility index, RV – right ventricle, LV – left ventricle

Introduction

Fetal heart failure is a very interesting, and still not fully understood subject. Cardiovascular Profile Score (CVPS) was developed by J. Huhta [1]. It is based on routine fetal Doppler examination and evaluation of fetal cardiac function. The signs, which are always analyzed during fetal echocardiography, were put together: presence or absence of hydrops, heart size, venous Doppler, arterial Doppler and cardiac function based on cardiac contractility or atrio-ventricular valves regurgitation. Healthy fetus had the score of 10/10; for each sign 1 or 2 points are subtracted. It is important to stress, that right ventricular function is crucial for good fetal condition [2], so any impairment of RV is much more severe during prenatal than postnatal life. Left ventricle is less important for fetal well-being because its function can be restored by the RV.

Functional pulmonary atresia was described as a severe sign indicating poor RV function in fetuses and neonates with severe Ebstein syndrome [3] or other problems related to RV anatomy and function, like Uhl's anomaly [4]. It is characterized by a structurally normal pulmonary valve that does not open during right ventricular systole (ejection). This can occur during the fetal or neonatal period when right ventricle is unable to pump blood against high pulmonary vascular resistance. In some cases, especially when retrograde flow is not seen in the right ventricular outflow tract, it can be difficult to distinguish between functional and anatomical atresia. There are just two articles described functional pulmonary atresia in a fetus [5] or a neonate [6, 7] with structurally normal hearts.

Many papers described cardiovascular changes in twin-to-twin-transfusion syndrome. Cardiomegaly and severe tricuspid insufficiency with poor ventricular function was described in

majority of recipients [8]. Antenatally or postnatally acquired right ventricular tract obstruction or atresia is well known finding [9]. However, funPA due to severely impaired RV function was not described in TTTS recipients. We did not find any information that such phenomenon occurred in fetuses with severe arrhythmia as well.

It is known that diastolic rather than systolic function of the heart is primary impaired during intrauterine life due to fetal heart muscle immaturity. Knowing this, deterioration of RV systolic function, especially with normal heart anatomy, seemed to be a very interesting subject for further evaluation.

Aim of the study

Basing on the current knowledge, we decided to assess echocardiography results of all fetuses in whom funPA was diagnosed and try to find pathophysiologic mechanism of this phenomenon.

Methods

Fetal echocardiography results were evaluated retrospectively in Perinatology and Perinatal Cardiology Department of the 2nd Department of Obstetrics and Gynecology, Medical University of Warsaw. Fetal echocardiography was performed using Sequoia 512 with convex 6C2 and sector 5V2 probes. 2D, M-mode, color, pulsed, continuous and tissue Doppler were used for fetal cardiovascular evaluation.

Fetal heart size, atrio-ventricular and semilunar valves Doppler tracings, obstetric Doppler studies in the umbilical artery and vein, ductus venosus and middle cerebral artery

were analyzed. Those results were put together and CVPS was counted. Echocardiography, cardiac catheterization and angiography (in two newborns with Ebstein anomaly), ECG, head ultrasounds, and laboratory tests were performed in neonates.

We did not discuss methods of treatment, as it was a retrospective study and those decisions had been made by different teams, so our goal was just to verify diagnostic findings.

Results

7 fetuses and 1 newborn (who developed funPA after pulmonary valvuloplasty) had Ebstein anomaly. There was very big atrialized portion of a right ventricle due to severe displacement of the tricuspid valve annulus (Fig. 1).

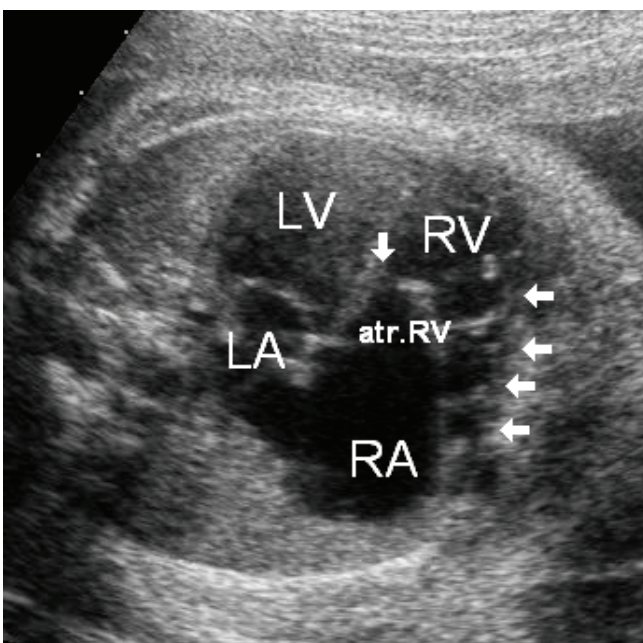


Fig. 1. Four chamber view of the 33 weeks fetus with Ebstein anomaly. The heart is enlarged. Vertical arrow: abnormal attachment of the septal leaflet. Horizontal arrows: abnormal septal leaflet, attached to the right ventricular muscle. RV – right ventricle, atr. RV – atrialized right ventricle, RA – right atrium, LA – left atrium, LV – left ventricle

It was monophasic inflow through the tricuspid valve, and severe holosystolic tricuspid regurgitation (Fig. 2). In all fetuses pulmonary valve and pulmonary artery were well developed. There was left to right shunt across the arterial duct. In all of them mild to moderate regurgitant jet through the pulmonary valve was detected in systole (Fig. 3). Basing on fetal echocardiography results prostin was administered in all. One hydroptic fetus was born prematurely at 34 weeks of gestation and died in the neonatal period. In five newborns emergency surgical treatment was needed. In three of them Starnes procedure (pulmonary and tricuspid valve were closed and central shunt between aorta and pulmonary artery was placed) in the first days of life was performed. Just one baby survived, who is 7 years old now after Fontan operation [10]. In two

babies Blalock-Taussig shunt was placed, both of them died. Pulmonary valve was opened surgically in one of them, and after this the baby developed funPA.

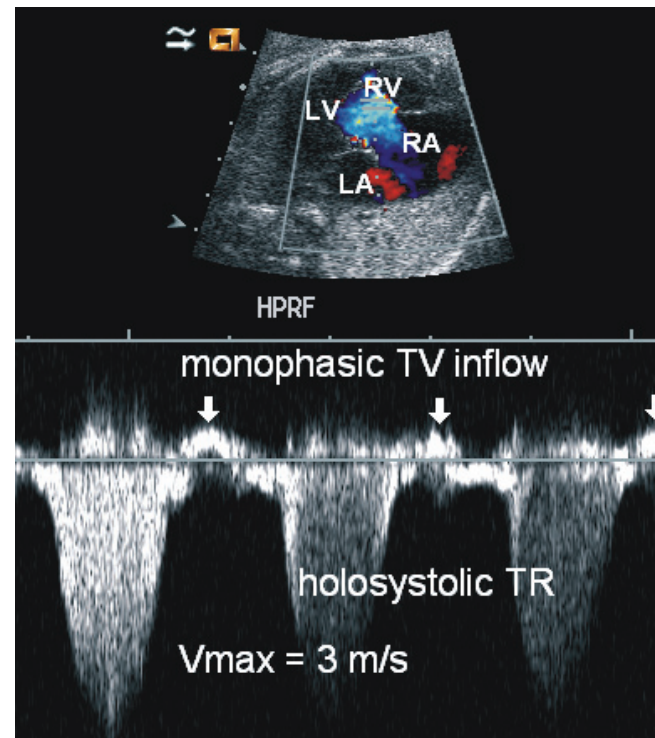


Fig. 2. Tricuspid regurgitation in the fetus with Ebstein anomaly and functional pulmonary atresia. There is a monophasic inflow through the tricuspid valve and holosystolic regurgitant jet. RV – right ventricle, LV – left ventricle, RA – right atrium, LA – left atrium

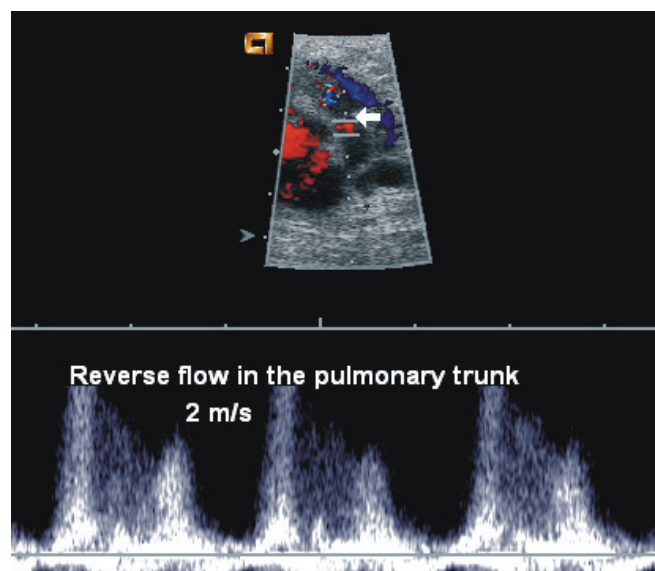


Fig. 3. 33 weeks old fetus with severe Ebstein anomaly, modified short axis view. Reverse flow in the well developed pulmonary trunk. The arrow indicated the place of the pulmonary valve. The gate is placed just over the valve

In two newborns who were in good condition, without respiratory failure, functional pulmonary atresia disappeared within first two weeks of life, due to reduce pulmonary vascu-

lar resistance. Both of them are in good general condition and they did not need any surgical intervention until now.

Four fetuses with funPA had normal heart anatomy.

Three of them were recipients in twin-to-twin transfusion syndrome. All of them were severely hydropic, had cardiomegaly with poor contractility of both ventricles.

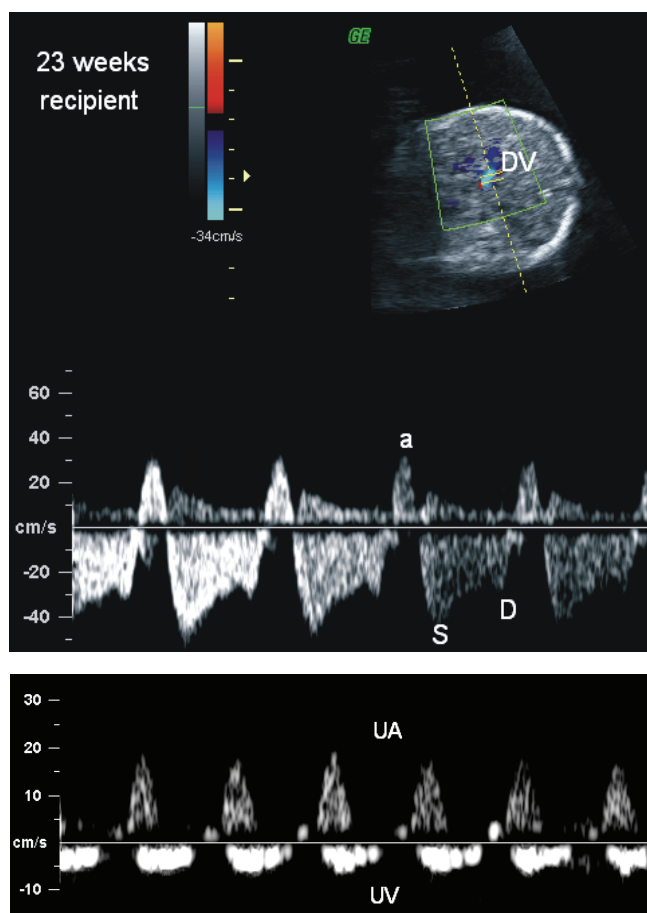


Fig. 4. Abnormal flows in the recipient twin with functional pulmonary atresia. Upper part – reverse a wave in the ductus venosus (DV). Lower part – pulsations in the umbilical vein (UV), absent diastolic flow in the umbilical artery (UA)

There was holosystolic tricuspid regurgitation of low velocity and mitral regurgitation with high velocity, reverse a wave in the ductus venosus (Fig. 4 upper) pulsation in the umbilical vein (Fig. 4 lower), low pulsatility index (PI) in the middle cerebral artery, what was a sign of fetal compromise. Left to right shunt in the arterial duct with well developed pulmonary arteries indicated functional pulmonary insufficiency in all three of them (Fig. 5). They were born in 27, 29, 27 week respectively.

From those three just one baby is alive, in whom right ventricular function improved after serial amnioreduction. The girl was born in 29 weeks of pregnancy. Her weight was 1420 g, Apgar score 3-4. There was forward flow in the pulmonary artery just after delivery.

All co-twins donors were “stuck-twins”, they had normal cardiovascular systems, two of them alive.

The fourth fetus with normal heart anatomy developed funPA at 32nd week of pregnancy as a result of RV failure due to severe arrhythmia (intermittent bradycardia and supraventricular tachycardia since 20th week of pregnancy), which did not respond for various antiarrhythmic therapy.

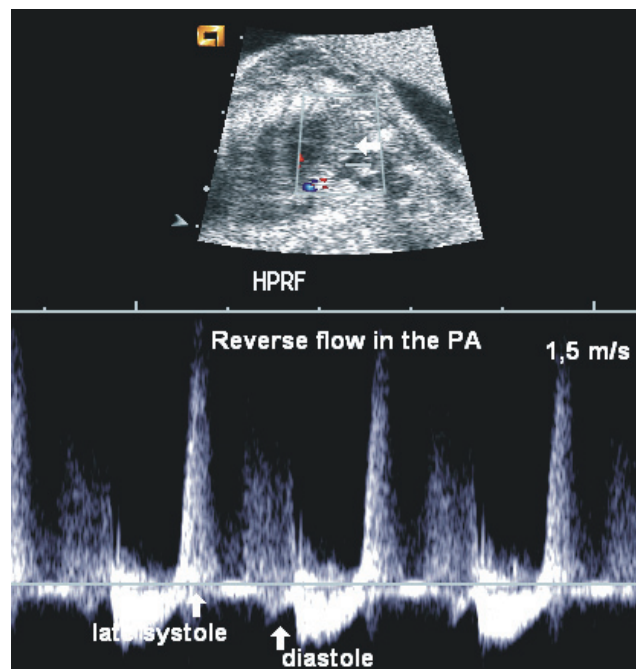


Fig. 5. Reverse flow in the pulmonary artery in the recipient twin with functional pulmonary atresia. Horizontal arrow – pulmonary valve; PA – pulmonary artery; vertical arrows showed two phased of pulmonary regurgitant flow: in late systole and diastole. There is mild forward flow from the right ventricle to the pulmonary artery, hemodynamically insufficient

Three days after appearing of funPA emergency CC was performed due to fetal compromise (pseudo-normalization in the middle cerebral artery flow). There were signs of myocarditis with severe arrhythmia and hypertrophic cardiomyopathy, with normal forward flow in the pulmonary artery in the newborn.

Discussion

In medical dictionaries the phrase “functional atresia” does not exist. However, if one searches for definition of the word “atresia”, they are as follow: *Congenital absence of a normal opening or normally patent lumen* (Stedman’s Medical Dictionary) or *Absence or closure of a natural passage or channel of the body; imperforation; Not perforated* (Websters Dictionary). Basing on those two definition, phrase “functional atresia” could be used in cases, when the valve is anatomically patent, but hemodynamically atretic. Proper prenatal diagnosis is crucial for therapeutic strategies during neonatal period. After evaluation our results we know, that decision concerning neonatal treatment made by fetal cardiologist and cardiac surgeon should be made prenatally. “Functional pulmonary atre-

sia” can be a life threatening condition in cases with Ebstein anomaly, so emergency surgery might be needed, as prostin administration did not maintain adequate pulmonary flow. In patients with structurally abnormal heart like Ebstein or Uhl anomaly, right ventricle is unable to generate adequate cardiac output to pump against high resistance pulmonary circulation. Pulmonary artery systolic pressure exceeded right ventricular systolic pressure and blood is pumped “back” to the right ventricle what created a vicious circle: left ventricle pumped blood through the arterial duct back to the right ventricle and, due to high pulmonary vascular resistance, blood did not reach lungs and can not be oxygenated. Immediate surgery during which pulmonary artery is closed should be the first emergency step of treatment.

Such situation is much more severe than anatomical atresia. Opening a pulmonary valve, what was done in one neonate many years ago, resulted in dramatic deterioration of newborn’s condition and subsequent death, as a result of creating functional pulmonary atresia. The crucial point during echocardiography is proving, that there is not just “pulmonary regurgitation” but “systolic pulmonary regurgitation” – blood is pumped back into the RV during systole, not in diastole like in true pulmonary valve regurgitation.

In fetuses with anatomically normal heart progressive deterioration of right ventricular systolic function caused functional pulmonary atresia. Due to various reason RV was unable to pump blood against high resistant pulmonary circulation. There was lower resistance in the right ventricle than in the lungs so blood was pumped from the left ventricle, to the aorta and back through the arterial duct to the pulmonary artery. Cardiac function was studied in fetuses with TTTS [11], but functional pulmonary atresia was not described as the most severe stage of right ventricular failure.

There is a phenomenon in cardiology called “diastolic mitral regurgitation” (diast-MR) which means that blood flows to the opposite direction during diastole. Diast-MR occurred when AV pressure gradient reverses during atrial relaxation, what means that the end diastolic ventricular pressures is higher than atrial. It is commonly observed during AV block of any degree, when atrial contraction is not followed by adequately synchronized LV contraction [12]. Under such condition this sign is benign, without any clinical implications. Conversely, if dia-MR occurs without AV block, it indicated severe impairment of LV function [13]. Effective ventricular contraction is mandatory for complete mitral valve closure. LV is the dominant ventricle since the neonatal period. On the contrary, during fetal life RV is dominant and its proper function is mandatory for fetal condition.

Transient neonatal period is crucial for proper treatment of neonates with funPA. The mechanism of diaMR is reverse pressure gradient between atrial and end diastolic left ventricular pressure. Reverse pressure gradient between systolic pulmonary and right ventricular pressure caused “functional” pulmonary atresia what, in fact is “systolic pulmonary regurgitation” as the pulmonary valve is completely normal and pa-

tent. In such cases, decision about proper treatment must be made carefully. In some cases lowering pulmonary vascular resistance with nitrous oxide can be the best method of treatment [14]. In other just careful monitoring could be sufficient.

In all fetuses with suspected cardiac failure careful examination of pulmonary flow should be performed during each exam, as it can change and deteriorate during prenatal life. The cause of such dramatic right ventricular failure is unknown. It is likely that it can be due to intrauterine hypoxia and some molecular unknown mechanisms. Further studies are necessary to explain it precisely.

FunPA is a unique phenomenon for fetal and early neonatal period when pulmonary vascular resistance is high. It has already been known, that in cases with Ebstein anomaly it was due to abnormal RV anatomy, which was unable to pump blood against high resistance pulmonary circulation. In contrary funPA in fetuses with normal heart anatomy is rare and not fully understood phenomenon. It could be compared to severe left ventricular failure in adult patients in whom diastolic mitral regurgitation is diagnosed. It should be kept in mind that funPA is in fact “systolic pulmonary regurgitation”, what is very important information for strategy of neonatal treatment.

Conclusion

- 1) Functional pulmonary atresia is the most severe sign of right ventricular failure during fetal or early neonatal period.
- 2) Different conditions can lead to functional pulmonary atresia.
- 3) Treatment strategy must be discussed in details before birth in such situations, and should be changed according to the neonatal condition.

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