INTRODUCTION

Pulmonary valve stenosis (PS) is the second most common congenital cardiac malformation. Isolated pulmonary valve stenosis accounts for 10% of congenital heart diseases.[1] It is considered the most common cause obstructing the right ventricular outflow leading to an increase in the right ventricular pressure in order to force blood through the stenosed valve. Consequently, the right ventricular pressure developed is usually proportionate to the degree of obstruction.[2]

Since the first description of balloon pulmonary valvuloplasty in 1982 by Kan, the procedure became the treatment of choice. It is generally recommended that the procedure be performed for peak-to-peak gradients in excess of 50 mmHg using Echocardiography.[3]Immediate reduction of gradient and increase in jet width and free motion of the pulmonary valve leaflets with less doming have been observed following balloon dilatation. Improvement of right ventricular function and tricuspid insufficiency has also occurred. At mid-term follow-up (usually defined as <2 years), both catheterization measured peak-to-peak gradients and Doppler-measured peak instantaneous gradients remain improved.[3]The short- and intermediate-term results of pulmonary valvuloplasty in children and adults with typical pulmonary valve stenosis have been excellent.[4]Anatomically, the right ventricle (RV) is

separated into the inflow tract, the outflow tract and the trabeculated muscular apex.[5]

Quantification of RV size and function with conventional echocardiography is challenging because of the anterior position of the RV in the chest, its complex asymmetrical geometry, highly trabeculated endocardial border, impossibility to simultaneously visualize both inflow and outflow tracts and lack of realistic geometric models for volume calculation. Cardiac magnetic resonance (CMR) is the current gold-standard for quantification of RV geometry and function, but its widespread use is limited by costs, time consumption and contraindications, making it unsuitable for patient screening or monitoring on large scale.[6]As right ventricular size and function have been found to be important predictors of cardiovascular morbidity and mortality, the development of novel echocardiographic techniques including three-dimensional became a must and opened new exciting opportunities in right ventricular imaging. Three-Dimensional echocardiography has proven accuracy in measuring RV volumes and function when compared with CMR.[7]

AIM OF THE WORK

To assess the function and volumes of the right ventricle using three-dimensional & two-dimensional echocardiography before and three months after percutaneous balloon pulmonary valvuloplasty.

Chapter (1)

PULMONARY STENOSIS (PS)

The first description of pulmonary stenosis was done by Giovanni Baptista Morgagni in 1761. [8] The Severity of PS is classified according to peak pressure gradient by echocardiography into mild (PPG<36mmHg), moderate (PPG 30 to 64mmHg) and Severe (PPG>64mmHg).[9] PS can be isolated valvular (90%), subvalvular, peripheral, supravalvular obstruction, or it may be found in association with more complicated congenital heart disorders. [10]

Valvular pulmonary stenosis:

There are Different morphologies of the pulmonary valve were defined in three categories as follows:

- **Typical:** Mild to moderately thickened leaflets with evidence of commissural fusion and normal annular dimensions.
- **Dysplastic:** Severely thickened leaflets with evidence of nodular hyperplasia & annular hypoplasia.
- **Combined:** Dysplastic valve morphology as defined but with additional evidence of commissural fusion. [11]

Pathology:

Fusion of the adjacent leaflets along their commissures occurs. In the classic form, the valve is conical or dome shaped, and two to three raphes may be visible, but there is no separation into valve leaflets. Less commonly, the valve may be diffusely thickened with one, two or three leaflets and commissural fusion. The fusion along the zones of apposition is typically uniform.[12]It begins peripherally, so that the valvular orifice is narrowed to a central opening. The more the fusion extends towards the centre of the valve, the narrower will be the central opening, and the more severe will be the valvular stenosis. [13](Figure 1)

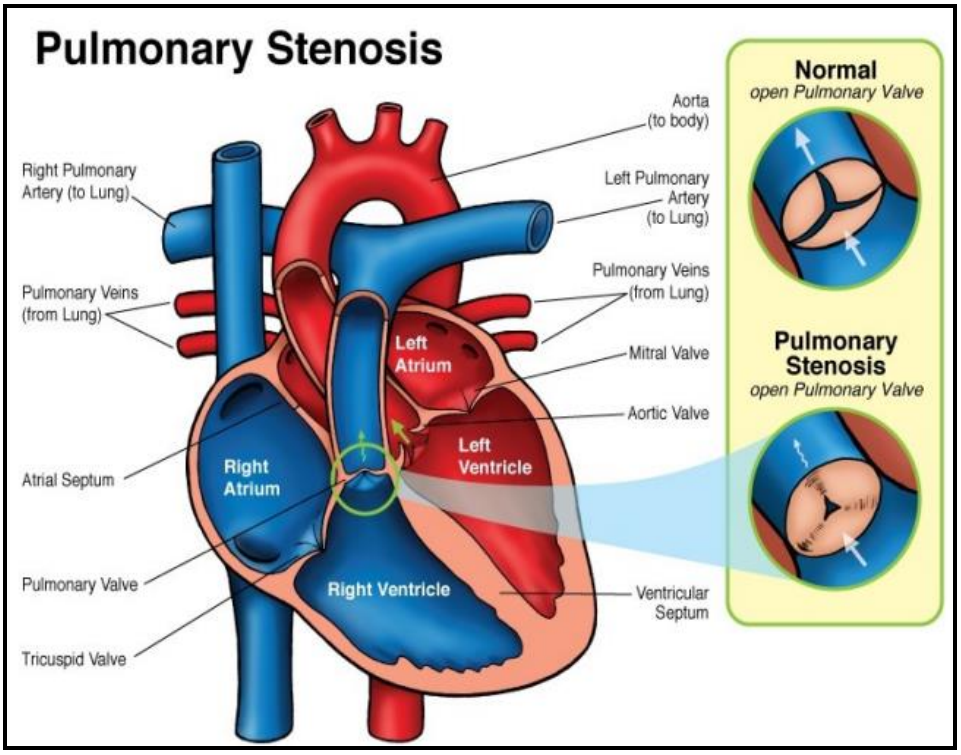

Figure 1: Showing fusion of the adjacent leaflets along their commissures in valvular PS. [13]

A distinct pathology termed pulmonary valve dysplasia has been described in 10-20% of patients. Dysplastic valves are trileaflet with markedly thickened cusps composed of disorganized myxomatous tissue and little, if any, fusion. The valve annulus is usually hypoplastic. This entity is found in most patients with Noonan syndrome and may be seen in non-familial cases. (14)

Secondary changes in the RV and pulmonary arteries can occur as a result of pulmonary valve obstruction. The RV, in particular the infundibular region, becomes diffusely hypertrophied. Hypertrophy of the infundibulum can produce dynamic subvalvar obstruction. (15)

Thickening of the tricuspid valve and chordal attachments may be present, and the valve may become regurgitant. The right atrium may be thick and dilated as a result of the increased pressure necessary to fill the hypertrophic RV. In many cases, a patent foramen ovale or, less often, an Atrial septal defect is seen. (16)

Most patients develop poststenotic dilation of the pulmonary artery trunk, sometimes extending to the proximal left pulmonary artery. One notable exception to this finding is in patients with dysplastic pulmonary valves. The degree of dilation is not necessarily proportional to the severity of obstruction, often being more pronounced in mild cases & it may result from the high velocity jet of flow ejected through the small valve orifice. (17)

Hemodynamic consequences of valvular PS:

The main physiologic effect of valvular PS is a rise in RV pressure proportional to the severity of obstruction. This elevation of RV pressure is accompanied by an increase in muscle mass where hyperplasia of the muscle cells with a concomitant increase in the number of capillaries occurs. In contrast, the adult myocardium responds with hypertrophy of the existing fibers, with no change in the capillary network. [18]

Thus, the neonatal myocardium may be better adapted to generate the high pressures necessary to overcome severe obstruction. Increased muscle mass may enable the hypertensive RV to maintain a normal stroke volume. If the size of the stenotic orifice remains fixed, however, the degree of obstruction becomes relatively more severe as the individual grows. [19] The RV eventually may dilate and fail. This process is exacerbated by the development of tricuspid insufficiency in many patients with severe PS. [20] RV failure may occur in infancy if severe neonatal obstruction is present. In patients with a patent foramen ovale or ASD, central cyanosis is observed as a result of right-to-left atrial shunting when the right atrial pressure exceeds the left atrial pressure. Progressive hypertrophy and decreased compliance of the RV, or myocardial failure with subsequent dilation, may lead to central cyanosis in some initially well-compensated patients. [15] The RV is often hypoplastic because of severe hypertrophy and the effects of reduced flow through the RV during development. At

birth, affected infants are cyanotic and have systemic or suprasystemic RV pressure. Even if the stenosis is relieved, right-to-left atrial shunting and cyanosis often persist for months after the stenosis is relieved, until there is a decrease in the RV hypertrophy and an increase in RV size.[14]

Subvalvular pulmonary stenosis:

It occurs as a narrowing of the infundibular or sub-infundibular region, often with a normal pulmonic valve. This condition is present in individuals with tetralogy of Fallot and can also be associated with a ventricular septal defect (VSD). Double-chambered right ventricle is a rare condition associated with fibromuscular narrowing of the right ventricular outflow tract with right ventricular outflow obstruction at the subvalvular level. [10]

Peripheral pulmonary stenosis (PPS):

It's is an obstruction at the level of the main pulmonary artery, at its bifurcation, or at the more distal branches. PPS may occur at a single level, but multiple sites of obstruction are more common. PPS may be associated with other congenital heart anomalies such as valvular PS, ASD, VSD or patent ductus arteriosus (PDA); 20% of the patients with tetralogy of Fallot have associated PPS.

Diagnosis:

The presentation of PS depends on age and severity. In the neonate, critical PS presents with life-threatening cyanosis, with a right-to-left shunt at atrial level producing cyanosis. Such patients are likely to depend on their arterial duct to provide the flow of blood to the lungs. Hence, palliation in the short term, by maintaining ductal patency with intravenous infusions of prostaglandin, is life-saving, until a more definitive diagnosis can be made and an appropriate intervention planned. [20] Mild or moderate PS is not likely to cause major symptoms, unless there are associated lesions or other factors. For example, patients with the typical phenotype of Noonan's syndrome may have difficulty with feeding and gaining weight, not related in most cases to the severity of the PS. [12] In patients with more severe PS, the onset of symptoms can still be delayed into late childhood or early adult life. In a small proportion of patients with PS, cyanosis can be present, especially on exercise. This is a late physical sign because the cyanotic shunt is at atrial level, depending firstly on an interatrial communication, and secondly on the diastolic properties of the RV.[21] Reported symptoms include exercise intolerance, or dyspnea. Chest pain of an ischemic nature, possibly due to subendocardial ischaemia of the RV, syncope, and severe dyspnea on minimal exertion, are late findings and should prompt rapid intervention. [12]

Upon physical examination a precordial heave along the left parasternal border may suggest severe PS. In the left upper sternal border, a systolic thrill may be palpable at the level of the second intercostal space. In valvular PS, auscultation reveals a normal S1 and a widely split S2, with a soft and delayed P2. Valvular PS typically causes a systolic crescendo-decrescendo ejection murmur in the left upper sternal border that increases with inspiration and radiates diffusely. In some patients with PS and tricuspid regurgitation, the RV pressure is high enough to cause a pansystolic murmur at the left lower sternal edge. In patients with pliable valve leaflets, a systolic ejection click may precede the murmur with increased intensity on expiration and softening on inspiration. As the severity of PS increases, the ejection murmur increases in intensity, its duration prolongs, and its peak becomes more delayed. No ejection click is heard when dysplasia or severe leaflet thickening immobilizes the valve leaflets, or if the stenosis is above or below the pulmonary valve. In severe cases; mild-to-moderately severe desaturation or frank cyanosis may be noted with right-to-left shunting through a patent foramen ovale, ASD or VSD. [10]

Careful general phenotypic assessment may show the signs of syndromic diagnosis, such as Noonan's syndrome, Alagille's syndrome, or Williams' syndrome.[22]

Chest Xray: a characteristic radiographic finding, even with mild valvular pulmonary stenosis (PS), is prominence of the main, right, or left pulmonary arteries caused by poststenotic dilatation. The intrapulmonary vasculature usually

appears normal, even in severe PS. The overall heart size usually is normal unless RV failure or tricuspid regurgitation develops. Chest X-ray may show the features of RV hypertrophy & post-stenotic dilation of the pulmonary trunk, if present. RV hypertrophy is seen as an upturned cardiac apex. The dilated pulmonary trunk is seen as a prominence of the left upper heart border, inferior to the aortic knuckle. Right atrial enlargement causes a more pronounced convexity of the right lower heart border& it may be present in as many as 50% of affected individuals. [14] (Figure 2).

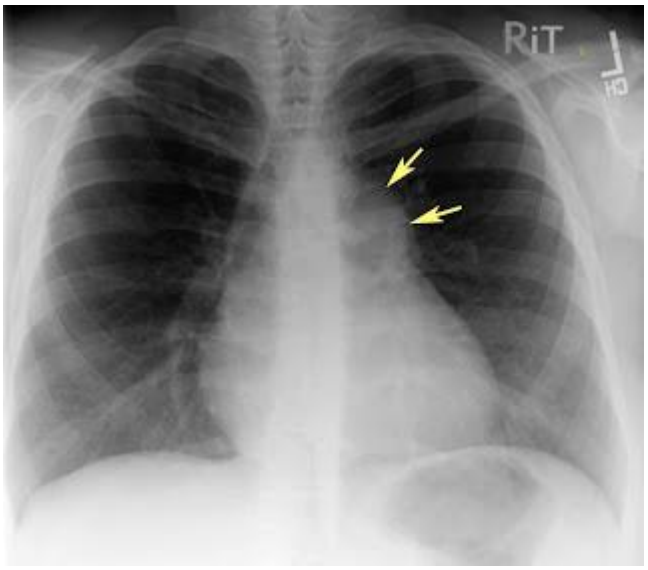

Figure 2: Chest radiograph reveals dilatation of the main pulmonary artery with relatively normal-sized right and left pulmonary arteries.[14]

The Electrocardiogram (ECG) can be useful in assessing the severity of obstruction in patients with PS. 40-50% of patients with mild stenosis have a normal electrocardiogram. Slight rightward deviation of the QRS

frontal axis is often the only abnormality. The R-wave amplitude in the right precordial leads rarely exceeds 10 to 15 mm. RV conduction delay is commonly present. [15] Right axis deviation is usually present in moderate PS. The R:S ratio in V1 is usually >4:1, and the R wave is typically <20 mm. The T waves in the right precordial leads are upright in approximately 50% of patients. [23]In severe PS, the electrocardiogram is rarely normal. Extreme right axis deviation may be seen. A pure R, Rs, or QR is the usual pattern in the right precordial leads, and the R wave is usually >20 mm. [14](Figure 3)

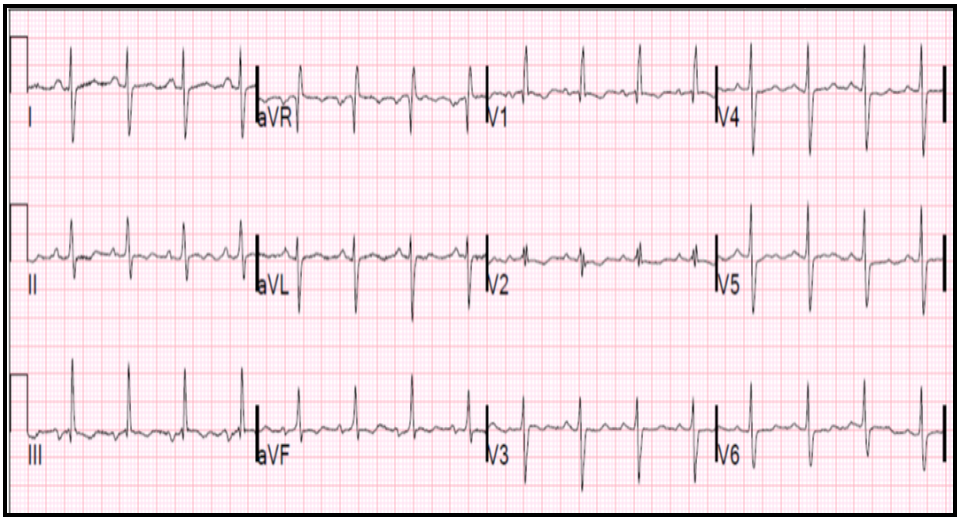

Figure 3: ECG showing right axis deviation and right ventricular hypertrophy [14]

The T waves may be upright or inverted in the right precordial leads, and the P waves are abnormally tall and peaked in lead 2 and in the right precordial leads, indicating right atrial enlargement. [15] (Figure 4)

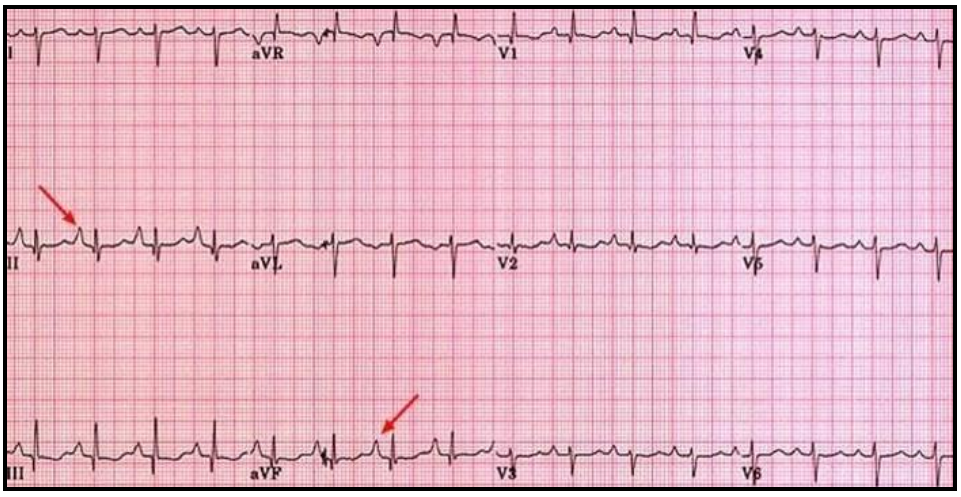

Figure 4: Right atrial abnormality is so obvious that the amplitude of the P wave in lead II is above than that of the following QRS complex. In severe PS, also a higher than expected R wave amplitude in lead V1 is usually observed.[15]

Two-dimensional echocardiography clearly demonstrates the typical features of the stenotic pulmonary valve from the parasternal short axis, high parasternal short-axis and long-axis views as well as the subcostal sagittal views.[24] (figure 5) The valve leaflets usually appear prominent because of thickening. Systolic motion is restricted along with doming. Associated features, such as poststenotic dilation of the main and branch pulmonary arteries, also are easily recognized.[25] (Figure 6). RV hypertrophy, contractility of the RV, as well as anatomy and function of the tricuspid valve should be assessed. Evidence of dynamic subvalvular PS should be thought but the severity may be impossible to estimate in the presence of more than mild valvar stenosis. [26]

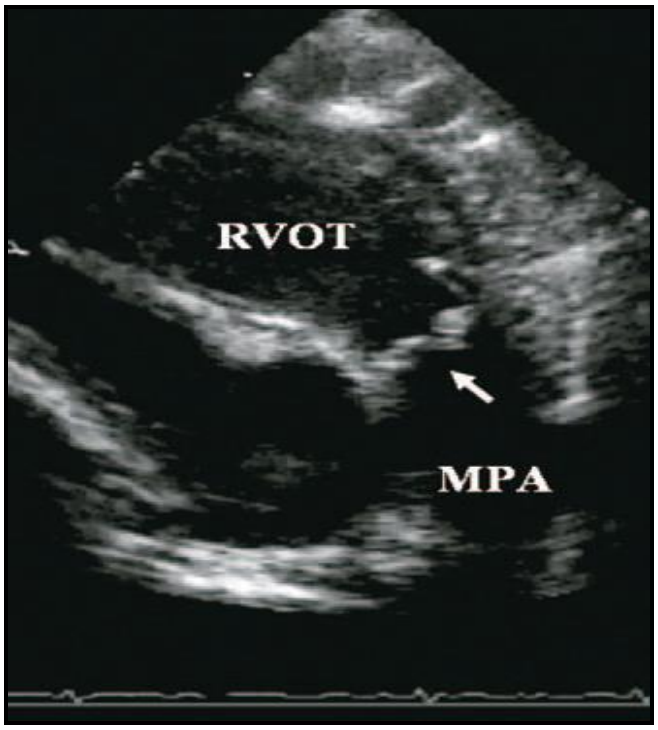

Figure 5: The arrow is pointing to thickened domed PV leaflets in the RV outflow view. (14)

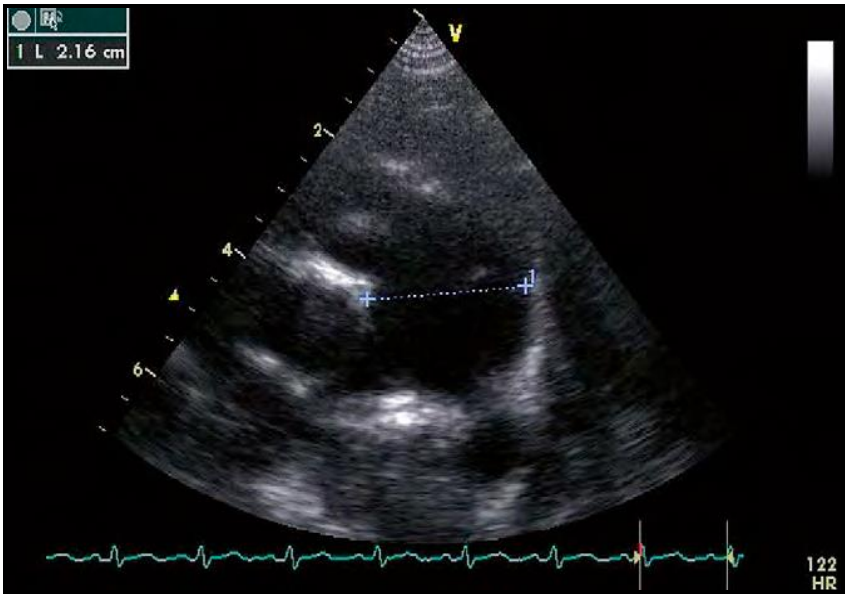

Figure 6: 2D echocardiography image showing post-stenotic dilation of the pulmonary trunk. (25)

Doppler echocardiography allows quantitative assessment of severity of PS by estimating the pressure drop across the pulmonary valve. The simplified Bernoulli equation $\mathbf{P = 4V^2}$ is used, where P is the peak instantaneous pressure gradient, in millimeters of mercury, across the obstructed pulmonary valve, and V^2 is the peak flow velocity, in meters per second, distal to the obstructive orifice.[26](Figure 7). If tricuspid insufficiency is present, the Doppler technique can be used to calculate the pressure difference (P) between the right atrium and RV by measuring the peak flow velocity (V) of the tricuspid insufficiency jet. RV pressure then can be estimated by adding the pressure gradient to the estimated right atrial pressure. [27]

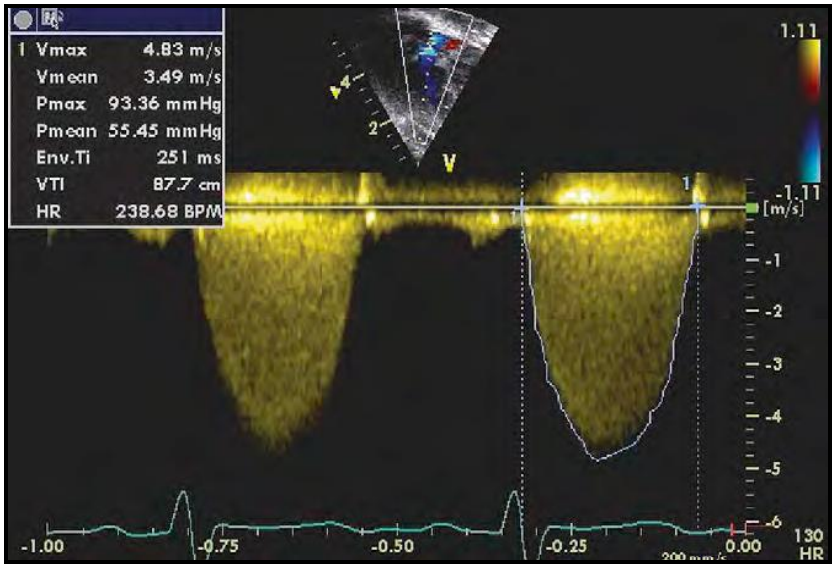

Figure 7: Continuous wave spectral Doppler across the pulmonary valve demonstrates a high velocity of flow, and calculated peak instantaneous and mean gradients across the valve. [26]