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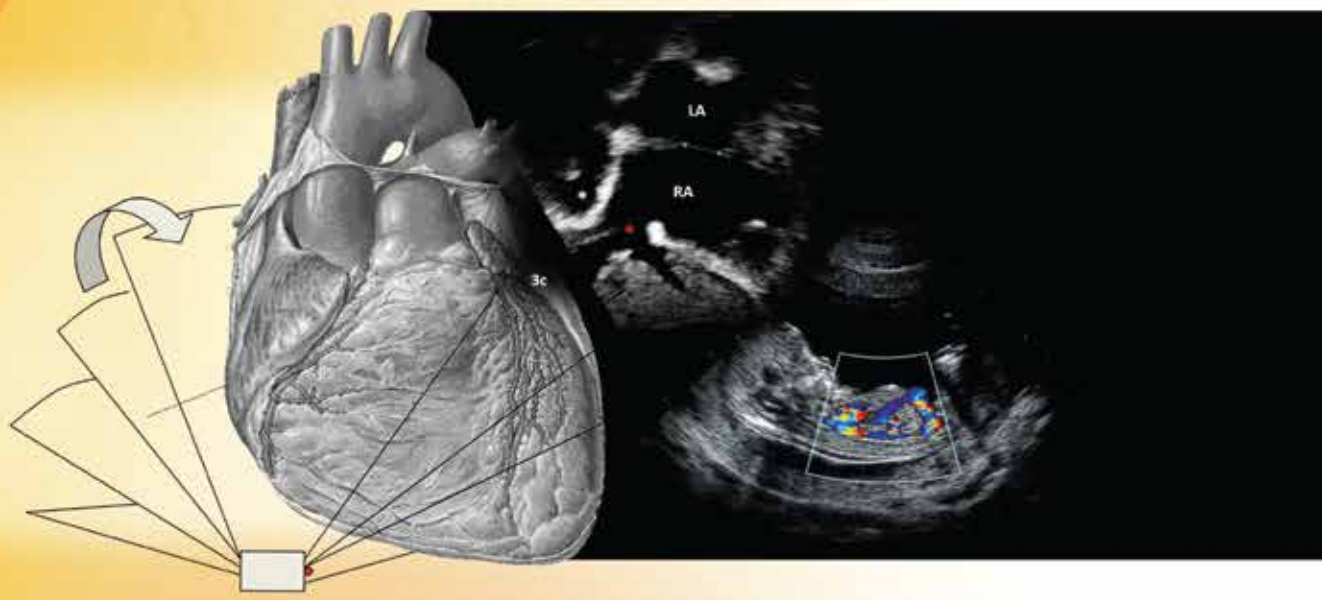
Kerala Journal of Cardiology



Focussed topic: **CONGENITAL HEART DISEASES**

“The dream begins, most of the time, with a teacher who believes in us,
who tugs and pushes and leads us on to the next plateau,
sometimes poking us with a sharp stick called truth.”

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The Beginning of a New Dream!

Abhilash S P

Associate Professor in Cardiology, SCTIMST, Thiruvananthapuram, Kerala

Dear Teachers and Friends,

The original dream began two decades back. Despite turbulences, medical profession remained a noble and very satisfying career. On dreaming back, the picture of a 17 year old boy getting ready to medical school comes to mind. They were the glorious years in life – with friends, an electrifying campus at Medical College, Alappuzha, and yes of course; the mammoth but still exciting academics too. Though I said exciting academics, books remained more or less dull for a student of normal intelligence. But the campus had a lot more to offer….

"*When a patient comes to you with head ache, don't forget to check his BP." "Any patient with fever should be examined for neck stiffness." "Check the lower limb pulses of any newly diagnosed hypertensive patient."*

I could never find these sentences in any text book. But even after 20 years, I could recollect like yesterday; the teachers who taught those pearls to us. I could remember with love and warmth, the professor who used to come to ward much before most us, meticulously examined all the patients and demonstrated clinical signs at bed side. We could see the passion in teaching, we could feel the passion of learning and lot more. Those teachers taught us medical profession was much more than reading a few books and earning a lot of money.

"Auscultate the patient prior to doing echo so that we won't miss a small VSD". "Don't complete echo without checking lower limb pulses so that we won't miss a CoA". "Check all the pulses of a patient who has come with acute coronary syndrome". "Always auscultate and look for pansystolic murmur or early diastolic murmur in any patient with STEMI"

Pearls continued to pour in during specialisation and super specialisation too. Again none of them were easily found in text books. The great teachers continued not only to teach but also to inspire. Most of us have fond memories of at least a few masters in the field who loved us, nurtured us and made us what we are. The new dream - dream of this journal, Kerala Journal of cardiology (KJC) published by Indian College of Cardiology, Kerala Chapter is to provide a platform for all those masters to share their experience and wisdom. Yes, those precious gems acquired over decades of selfless hard work and passionate learning!

KJC is being planned as a journal with some difference compared to regular journals in the field. We know there is no scarcity of good quality journals in cardiology. Here the aim is to deviate a little bit from the rigid frame work of traditional journals and approach academics in a lighter and informal way. Of course, the editorial board is well aware of the fact that there is only a thin line separating it from becoming too casual. We will make sure quality is not compromised and best of the articles will be chosen. Target audience of the journal will be fellows in training and young cardiologists.

The journal will have two sections. The first section will be known as **"KJC-Diamonds"** and this section will feature a focussed topic in every issue. Two or three

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master teachers will be in charge of the focussed topic. Articles by one or two youngsters who are experts in the field will also be included in this section. All articles in "KJC - Diamonds" will be by invitation only.

The second section of the journal will be known as **"KJC - Pearls"**. This section is not of any lesser importance and will feature articles similar to any other journal in cardiology. It will include clinical teachings, original articles, case reports, ECG, X ray, Echo or anything of academic value. Review articles unrelated to focussed topic of section one can also come here. All readers are requested to send articles to this section.

The focussed topic of "KJC Diamonds" in this launch issue of journal is **'congenital heart diseases'**. We are fortunate to have three great teachers in the field to enlighten us and share their knowledge on this topic.

Dr Jaganmohan A Tharakan was the former director -in-charge and head of the department of cardiology at Sree Chitra Tirunal Institute For Medical Sciences and Technology, Thiruvananthapuram, Kerala. He will be dealing with clinical approach to congenital heart diseases. **Dr Zulfiker Ahmed** was the head of the department of paediatric cardiology at Medical college, Thiruvananthapuram,Kerala. He discusses important ECGs in congenital heart diseases. **Dr Krishna Kumar R** is the head of paediatric cardiology at Amrita Institute of Medical Sciences, Kochi, Kerala. He will teach us the echo approach to congenital heart diseases. In addition, KJC Diamonds will have one more article on 'systematic assessment of ASD- prior to device closure'.

KJC Pearl section carries articles on clinical teaching and recent advances. We had to restrict articles in this section of current issue due to space constraints. Response received to this section was excellent and we were having problems of plenty! Thanks to all the contributors.

Editorial board would like to thank **Dr P K Ashokan,** President of Indian College of Cardiology. KJC was his brain child and he urged us to dream big! **Dr George Koshy A,** President of Indian College of cardiology, Kerala chapter; **Dr Ramakrishna Pillai V,** Vice President of Indian College of cardiology, Kerala chapter and **Dr Mangalanandan,** Secretary of Indian College of cardiology, Kerala chapter; require special mention. They gave unconditional support and freedom to editorial board. Thank you Sirs!

We know this is a humble beginning and the character of subsequent issues of the journal depends a lot on your feedback. Please write to us whether you love it or hate it. Please send your articles, suggestions and criticisms to abhispin@gmail.com.

"A dream you dream alone is only a dream. A dream you dream together is reality."

Happy dreaming!

Abhilash S P
Editor-in-chief, KJC

Clinical Approach to Congenital Heart Diseases

Jaganmohan A Tharakan

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SECTION 1 - HISTORY TAKING

INTRODUCTION:

The clinical presentation of pediatric population with congenital heart disease is closely linked to the normal circulatory changes at birth transiting from a parallel circulation in fetus to a series circulation of the adult as well as switching from the placental source to pulmonary source for oxygenation. Structurally normal heart accommodates this drastic circulatory transition well, but structurally abnormal hearts, especially transposition physiology, critical pulmonic obstruction and systemic outflow obstructions tolerate these changes poorly and deteriorate hemodynamically. This occurs with closure of patent foramen ovale and the ductus arteriosus. Regression of pulmonary vascular resistance permits establishment of large left to right shunts through defects between the pulmonary and systemic circulation resulting in volume overload and heart failure, usually presenting by 4 – 6 weeks of life. However, if there is also pulmonary venous obstruction as in TAPVC, and mitral atresia, these babies present with pulmonary venous hypertension and severe heart failure soon after birth. All congenital heart disease destined to develop heart failure, do so, during the first year of life. It is rare for de novo heart failure to occur beyond infancy unless some acquired hemodynamic abnormality is added on to existing heart disease though rare exceptions do occur (critical progressive AS). Most asymptomatic infants will continue to remain asymptomatic or mildly symptomatic in early childhood and usually come to medical attention for evaluation of murmur or mild effort limitation.

A newborn/ neonate with critical and complex congenital heart disease presents either with **heart failure, severe cyanosis or hypotensive shock with acidosis**. One of these features dominates the clinical presentation, though it is not uncommon to see babies presenting with a combination of these features.

Neonate with heart failure

The newborn/ neonate in pulmonary edema is often in acute distress, tachypnoeic, with grunting respiration, in-drawing or retraction of lower intercostal spaces, and wet lungs. In neonate and infant, heart failure is typically biventricular failure. The neonate presents with feeding difficulty, interrupted feeds (suck - sleep cycle), diaphoresis, tachypnea, intercostal retraction, frequent and difficult to treat lower respiratory infection and

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poor weight gain. Physical findings include pre-sacral and peri-orbital edema, hepatomegaly and lung crepitus (see Table 1).

Typically, primary ventricular dysfunction, valve regurgitations (most commonly atrio-ventricular valve incompetence), tachyarrhythmias, brady-arrhythmias, and severe anemia due to any cause result in heart failure in the fetus and presents as hydrops. However most complex intra-cardiac lesions are compatible with normal intrauterine survival as the fetal pulmonary and systemic circulation are in parallel, utilizing the patent foramen ovale and the ductus which facilitate bypassing critical obstruction to RV and LV outflow. High pulmonary resistance of the non-aerated lungs does not permit any increase in pulmonary blood flow regardless of intracardiac defects.

Table 1: Clinical Presentation in neonates

Critical neonate in pulmonary edema

- Obstructed TAPVC
- Mitral atresia with intact interatrial septum, cortiatriatum, supra mitral ring, parachute MV with severe stenosis
- Critical AS
- primary LV muscle disease

Critical neonate with intense cyanosis

- Conditions with diminished pulmonary blood flow: pulmonary atresia/ critical subpulmonic obstruction.
- Transposition physiology, where effective pulmonary blood flow and systemic blood flow is critically dependent on bidirectional shunt across septal defects.
- Pulmonary conditions: Persistent pulmonary hypertension of newborn/ hyaline membrane disease/ surfactant deficiency conditions/ other gross pulmonary pathology such as eventration of diaphragm

Critical neonate in cardiogenic shock

- Hypoplastic left heart syndrome
- All critical LVOF obstructions, critical coarctation, aortic interruption
- Primary myocardial disease, tachycardiomypathy typically seen with VT/ atrial flutter

Neonate with acidosis

The newborn/ neonate with severe cyanosis, is more often a quieter child with deep respiration and dry lungs, typically with reduced pulmonary blood flow. Simple TGA is the more common congenital heart defect presenting with intense cyanosis in the new born period, due to poor intercirculatory mixing despite normal to increased pulmonary blood flow. In both the scenarios, measures to keep ductus patent, regardless of the presumptive diagnosis, can be life saving to stabilize the baby (see Table 1).

Cyanotic babies may present with hyper cyanotic spells with extreme cyanosis, tachypnea, limpness, altered sensorium, and rarely progressing to coma and death though it is often self limiting. Dehydration (reduced preload), systemic vasodilation (reduced systemic impedance-reduced afterload) and tachycardia results in increased ventricular contractility. Aggravating dynamic obstruction to pulmonary outflow, contribute to reduced pulmonary blood flow in the setting of increased oxygen demand due to increased physical activity. Hyperventilation because of hyper-sensitive respiratory center worsens the situation. Hypercyanotic spells, though typically seen in TOF and TOF like physiology (PS with large VSD or functional equivalent as single ventricle), can also occur in pulmonary **atresia** with VSD, and rarely in PS with intact IVS. Here the mechanism is systemic vasodilation compromising pulmonary blood flow which is entirely dependent on duct and/ or aorto pulmonary collaterals.

Neonate with critical cardiac lesion and significant cyanosis is often clinically recognized and echo Doppler evaluation clinches the diagnosis even with the most complex intra cardiac defects. However, neonates with duct dependent circulation can be relatively asymptomatic and pulse oximetry can detect mild systemic desaturation (O2 saturation consistently <= 95% on ambient air). Differential saturation with lower limb to upper limb saturation difference of >=3% points to duct dependent systemic circulation, typically interrupted aortic arch and critical coarctation. Wider difference will indicate absence of intra-cardiac shunt lesions while a narrow difference indicates typical VSD and left to right shunt allowing for higher PA and descending aortic saturation. Patients with very little antegrade flow across aortic valve as in HLHS, will have identical upper and lower limb O2 saturation. Routine pulse oximetry at 48-72 hours of birth prior to hospital discharge is currently recommended.

Hyperoxia test is recommended to differentiate cardiac from respiratory cause of cyanosis. Administration of 100% oxygen, ensuring adequate ventilation, raises arterial PO2 to more than 150 mmHg in respiratory conditions, and rarely increases above 50-75 mmHg in simple TGA and various reduced pulmonary blood flow conditions (TOF physiology / pulmonary atresia, VSD).

Cyanotic heart disease with admixture physiology can have arterial PO2 between 75 and 150 mmHg.

Neonate with acidosis and shock

The third presentation is a baby in cardiogenic shock/ hypotension and academia, moribund, often requires resuscitation before a detailed clinical or echo Doppler evaluation can be done. Empirically, measures to keep ductus patent, regardless of the presumptive diagnosis, can be life saving to stabilize the baby before a detailed echo Doppler examination is done. Duct dependent systemic circulation including critical AS, aortic coarctation, aortic interruption and hypoplastic left heart syndrome are the common conditions which present with hypotension, acidosis and shock like state. Primary myocardial disease with ventricular dysfunction is also a possibility. Hypoglycemia, hypocalcemia and sepsis as cause of heart failure should be excluded as these non cardiac causes are far more prevalent in the newborn.

Why does a cardiac lesion well tolerated by the fetus surviving to term in the uterus become critical at/ soon after birth?

Four important changes occur at birth and impact on congenital heart disease:

1. Pulmonary blood flow increases as pulmonary vascular resistance falls on breathing ambient air and fluid filled alveoli are now filled with air and rise in oxygen tension results in further pulmonary vasodilation.

   Increased pulmonary blood flow will cause pulmonary edema if there is obstruction to PV flow as in TAPVC/ mitral atresia/ cortriatriatum/ parachute MV/ LV hypoplasia or dysfunction as in critical AS.

   There is a simultaneous increase in systemic vascular resistance as the placental circulation is cut off, allowing the patent duct to shunt from aorta to PA, increasing the arterial PaO2 across the duct and constricting the duct.

2. Ductus arteriosus constricts with increase in O2 tension in the arterial blood on breathing room air and lung oxygenation raises arterial partial pressure of O2 to more than 80 mmHg. All duct dependent circulations will suddenly become critical. Those conditions with duct dependent systemic circulation are affected more as duct flow has to support the entire systemic circulation and any narrowing of duct is poorly tolerated due to systemic hypotension. This leads to shock like state with severe metabolic acidosis. Cardiac defects with duct dependent pulmonary circulation also can become critical if the duct constricts completely, but tolerate milder duct constriction as PBF as little as a third of systemic blood flow is adequate to maintain systemic oxygen saturation of 70%, compatible with survival. Keeping duct patent with prostaglandin infusion can be life saving before definitive therapy can be instituted.

3. The valve of foramen ovale which allowed free flow of RA blood to LA in intrauterine life now shuts off due to increase in LA pressure secondary to increased pulmonary blood flow and pulmonary venous return. On closure of the foramen ovale all cardiac conditions which dependent on obligatory right to left shunt across ASD like tricuspid atresia and TAPVC will become critical resulting in reduced systemic blood flow. Neonates with transposition of great vessels, where bidirectional shunts across septal defects represent effective systemic and pulmonary blood flow tolerate closure of foramen ovale poorly and deteriorate due to severe systemic hypoxia, unless duct is kept open by prostaglandin infusion or by creating an interatrial communication by emergency atrial septostomy.

4. Closure of ductus venosus : Ductus venosus closure can result in further critical obstruction to infra diaphragmatic TAPVC draining to portal system.

CLINICAL PRESENTATION OF CHD FROM 1ST WEEK TO ONE MONTH

Important hemodynamic changes occurring during this period:

i) Continuing risk of ductal closure for all duct dependent pulmonary or systemic circulation conditions.

ii) Rapid fall of pulmonary vascular resistance, facilitating increase in left to right shunts in patients with intra cardiac and aorto pulmonary defects and no subpulmonic obstruction.

iii) Rapid progression of dynamic subpulmonic obstruction.

iv) Replacement of fetal hemoglobin with adult hemoglobin which can result in lower O2 saturation for identical arterial partial pressure of oxygen.

With reduction in pulmonary vascular resistance (PVR) and simultaneous increase in left to right shunt, all post

tricuspid shunt lesions without subpulmonic obstruction including large VSDs, complete endocardial cushion defects, AP windows, PDAs will become symptomatic with heart failure during the first month of life, so also post tricuspid admixture lesions like single ventricle, truncus arteriosus, double outlet RV, TGA with large VSD and congenitally corrected TGA with large VSD. Direct ejection of blood from systemic ventricle to the PA in systole through unrestricted VSD maintains the PA systolic pressure at systemic level. Excess pulmonary blood flow is partly restricted by non-regression of distal PA musculature maintaining a higher pulmonary vascular resistance and also muscularization of distal pulmonary arteries and pulmonary arterioles (distal stenosis). In all post tricuspid left to right shunts, the less compliant PV-LA-LV conduit results in elevated PV- LA pressure and further aggravates symptoms attributable to accompanying pulmonary venous hypertension.

Unlike post tricuspid shunt lesions, establishment of large left to right shunt in pre tricuspid lesions like ASD, common atrium and unobstructed TAPVC is delayed, as regression of RV hypertrophy and normalization of RV compliance lags behind the regression of pulmonary vascular resistance. It takes up to 3 months for RV compliance to normalize to permit increased tricuspid inflow necessary for establishment of large left to right shunt. The ASD permits decompression of LA (LA acts as a conduit rather than a storage chamber in pre tricuspid shunts) and hence, pre tricuspid shunts do not result in pulmonary congestion. Hence large ASDs, and common atrium rarely present with features of heart failure. However, infra-diaphragmatic (almost all) and vast majority of supra-diaphragmatic TAPVCs have some element of obstruction down stream in the PV drainage and resultant pulmonary venous hypertension contributes to symptoms of pulmonary congestion and pulmonary hypertension.

BIMODAL PRESENTATION

Ebstein's anomaly: Severe cyanosis at birth and cyanosis improving in early infancy and reappearing in latter life is a common presentation of Ebstein's anomaly. Pulmonary hypertension in the new born aggravates TR, right to left shunt and reduced forward flow into the lung. With regression of pulmonary hypertension, forward flow into the lungs improves, ameliorating cyanosis. With progressive RV dysfunction and TR, cyanosis reappears, with right to left shunt across PFO/ ASD in latter life.

Post tricuspid large L→R shunts(large VSD, endocardial cushion defects, large AP window and large PDA) presents with HF in early infancy from increased pulmonary blood flow along with pulmonary venous hypertension due to increased flow into a less compliant PV - LA conduit. Improvement of HF can be expected with increase in PVR due to medial hypertrophy in the distal pulmonary arteries and pulmonary arterioles which can further progression to irreversible pulmonary vascular disease (PVD). With severe PVD, pulmonary vascular resistance exceeds systemic vascular resistance and right to left shunt with cyanosis and effort limitation ensues.

In Gasul's type VSD with a substrate for sub-pulmonic obstruction of RVOF, initial large left to right shunt and heart failure gives way to progressive RVOF obstruction reducing left to right the shunt with symptom relief. However with further progression of RVOF obstruction (pink TOF), exercise induced systemic desaturation occurs with effort dyspnea and can ultimately result in resting arterial desaturation and worsening effort dyspnea (cyanotic TOF).

Severe valvular AS: In the neonate, due to myocardial immaturity, severe valvular AS can present with LV failure. With myocardial maturity, LV compensates with clinical symptomatic improvement. Subsequently, with continuing / progressive LV obstruction with concentric LVH and diastolic followed by systolic dysfunction, symptoms of HF recurs.

GENETIC HISTORY IN CHD

Approximately 5-10% of CHD are attributable to chromosomal number abnormality and micro-deletions. Close to 5% is attributable to single gene defects and 1-3% to maternal causes.

Altered chromosome number: addition/ deletion: Trisomy 21, trisomy 1, trisomy 13, Turner syndrome (45,X)

Micro-deletions: several genes affected: William's syndrome, DiGeorge's syndrome

Single gene defect: Autosomal dominant: Holt Oram syndrome, Noonan's syndrome, Leopard syndrome, Alagille syndrome, familial ostium secundum ASD, Marfan syndrome, most cardiomyopathies, channelopathies

Single gene defect: Autosomal recessive: Elli van Creveldt's syndrome, metabolic disorders with cardiac involvement

Single gene defect, X linked: muscular dystrophies, LV muscle disease

Single gene defect, mitochondrial inheritance: cardiomyopathies

MATERNAL HISTORY

Diabetes, smoking, alcohol ingestion are implicated in higher incidence of CHD in the offsprings, diabetes being at the highest risk with hazard ratio 3 to 1.

Maternal phenyl ketonuria, and retinoic acid ingestion are implicated with hazard ratio more than 5:1. Exposure to antiepileptic drugs like phenytoin, sodium valproate also carry small increased risk to the fetus.

Rubella is well documented to affect the fetus, as part of the rubella syndrome with peripheral PS and PDA.

SECTION 2 - BASIC APPROACH TO CONGENITAL HEART DISEASES

Five basic questions

1. Is the patient's condition acyanotic or cyanotic?
2. Is pulmonary arterial blood flow increased?
3. Does the malformation originate in the left or the right side of the heart?
4. Which is the dominant ventricle?
5. Is pulmonary hypertension present?

These five questions still remain foremost, in clinical approach to a patient with congenital heart disease.

1. Is the patient's condition acyanotic or cyanotic?

In the days when systemic oxygen saturation was not available as a clinical tool, it was logical to use clinical cyanosis to classify CHD as acyanotic or cyanotic. Needless to reiterate that recognition of cyanosis can vary with individual observer, patients' complexion (easier to appreciate cyanosis in fair population), level of hemoglobin as well as quality of peripheral circulation (vasoconstriction with cold extremities/ vasodilation with warm extremities). Consistent recognition and agreement on cyanosis is possible when systemic desaturation falls below 85%, in absence of anemia. However, a child breathing ambient air has systemic oxygen saturation 95% or above. In effect, a large number of children with CHD and systemic oxygen saturation 85% to 95% will not be classified as cyanotic and one will go astray at step 1. Most patients with cyanotic CHD and increased pulmonary blood flow will have O2 saturation in the 85 to 94% range, so also some of the cyanotic CHD with decreased pulmonary blood flow where the pulmonary blood flow is marginally less than systemic blood flow (e.g. pink TOF). This situation is unacceptable in modern clinical medicine when a simple and reliable point of care pulse oximeter gives accurate systemic oxygen saturation in less than 30 sec, on applying to the finger tips. Hence, today, triaging of the CHD should start with the question of whether the patient has systemic desaturation of cardiac origin or not. Cyanosis is certainly not synonymous with systemic desaturation, as a patient with polycythemia and hemoglobin 25gm% may appear cyanosed but with oxygen saturation >95%. Similarly, systemic oxygen desaturation and clinical cyanosis should be dissociated from systemic/ arterial partial pressure of oxygen as in methemoglobinemia, sulfhemoglobinemia and various hemoglobinopathies. In these conditions arterial PaO2 is normal but oxygen saturation will be low (Note: blood gas analyzers compute oxygen saturation from arterial partial pressure of oxygen).

2. Is pulmonary blood flow increased?

The PV-LA-LV-Ao circuit is a less compliant, high pressure, high impedance system compared to systemic veins-RA- RV – PA circuit which can be described as more compliant, low pressure low impedance system. Any communication between the two circulations at various levels will necessarily permit shunting from the PV-LA-LV-Ao circuit to systemic veins-RA-RV-PA circuit e.g. anomalous PV drainage (PV to SVC/ IVC), ASD (LA to RA), VSD (LV to RV) and aortopulmonary window or PDA (Ao to PA). All these defects will necessarily increase the pulmonary blood flow. In complex intra cardiac defects too, in absence of pulmonic outflow obstruction

or stenosis, pulmonary blood flow will increase due to shunting of blood form the high impedance systemic circulation to the low impedance pulmonary circulation.

Increased pulmonary blood flow due to significant left to right shunt results in cardiomegaly proportionate to shunt. Pretricuspid left to right shunts result in RV cardiomegaly while post tricuspid shunts result in LV type of cardiomegaly. Flow murmurs across atrioventricular valves should be looked for. Large left to right shunts at atrial level and ventricular level result in wide split of S2, while aortopulmonary shunts may actually cause reverse split of S2.

Cyanotic CHD with increased pulmonary blood flow are typically admixture lesions like TAPVC, common atrium, single ventricle, DORV, and truncus arteriosus and transposition physiology like TGA and Taussig Bing type DORV. Physical findings of increased pulmonary blood flow are similar to acyanotic shunt lesions in addition to systemic arterial desaturation and cyanosis. Cyanosis and systemic desaturation are inversely related to pulmonary blood flow in admixture lesions . In TGA physiology, cyanosis is often severe unless large ASD / large VSD permit bidirectional shunt across the anatomical defects(effective pulmonary blood flow).

The next automatic question is whether it is a condition with reduced pulmonary blood flow. It is to be noted that as the pulmonary and systemic circulation are in series, systemic cardiac output is entirely dependent on pulmonary blood flow and survival is not possible with markedly reduced pulmonary blood flow, as it results in low cardiac output state and systemic hypo-perfusion. However survival is possible with additional right to left shunt which supplements and maintains systemic blood flow and systemic pressure within physiological range for survival. Intuitively, patients with reduced pulmonary blood flow will have right to left shunt to maintain the systemic blood flow for survival, at the cost of systemic desaturation. It is to be noted that intra-cardiac right to left shunts do not increase the systemic blood flow above the physiological limits as it is under autonomic control. However, conditions permitting aortic run off as PDA and aorto pulmonary collaterals are not under autonomic control and systemic blood flow would be increased in these situations. Patients with clinical/ radiological recognizable reduced pulmonary blood flow, without cyanosis (without right to left shunt) are very ill with signs and symptoms of low cardiac output state. All patients with reduced pulmonary blood flow with normal systemic blood flow will necessarily have right to left shunt and systemic desaturation.

Chest skiagram is the most useful tool in assessment of pulmonary blood flow: Cardiomegaly goes with increased pulmonary blood flow, so also prominent central PAs, and end on pulmonary artery shadows larger than accompanying bronchus. Absence of main PA shadow should forewarn to great vessel malposition as in TGA or its absence as in truncus arteriosus where the RPA appears to take off at a higher level. Pulmonary plethora with widened mediastinum (typically figure of eight appearance) points to supra cardiac TAPVC. Large central PAs, MPA, RPA and LPA with sudden caliber change of segmental and peripheral PAs should suggest, pulmonary vascular disease in setting of increased pulmonary blood flow. A lacy pattern in the chest skiagram with absent central PAs is typical of large aorta to PA collateral circulation, typically seen in pulmonary atresia and VSD.

Pulmonary oligemia is often seen in TOF and TOF physiology . The main and segmental PAs are uniformly small. In TOF, the more severe the cyanosis (systemic desaturation), smaller the heart size. Pulmonary oligemia with significant cardiomegaly is seen in Ebsteins disease and in severe PS with intact interventricular septum and systolic RV dysfunction.

3. Does the malformation originate in the left or the right side of the heart?

There are several clues to suggest if the cardiac lesion arises from the left or right side of the heart.

Let us assume the pulmonary and systemic circulation are in series and there are no septal defects. By the continuity equation, the flow across all the valves / intracardiac conduit like structure (LVOF, RVOF) is identical, i.e CSA of the valve or conduit X velocity time integral derived from the Doppler spectral flow for all valves/ conduits is identical. Any reduction in valve/ conduit area is compensated by increase in the flow velocity and gradient resulting in turbulence.

All significant obstructive and regurgitation lesions on the right side will reflect in the right sided filling pressures depending on RV function, and RA compliance and indirectly in the jugular venous pressure and wave form. Systemic venous congestion with tender hepatomegaly, edema of feet and ascites can ensue. The left sided obstructive and regurgitation lesions when significant, will reflect in the pulmonary venous pressure and elevation of PV pressure leads to pulmonary congestion and varying grades of dyspnea. The arterial pulse wave form reflects LV function and ejection characteristics including stroke volume, rate of ejection and presence of obstruction to systolic ejection at the LV outflow. However, it is to be noted that complex intra-cardiac

defects will not fall into this simple clinical approach, for multitude of reasons: Intra-cardiac shunts, atresia or stenosis of the atrio-ventricular valves, atrio-ventricular and /or ventriculo arterial discordance and a combination of these, are a few examples.

4. Which is the dominant ventricle?

Ventricular enlargement shifts the cardiac apex to the left of the mid-clavicular line. As generally taught, enlargement of a normally placed RV shifts the cardiac apex leftward while enlargement of the LV will shift the cardiac apex leftward and downward. The LV apical impulse is discrete and limited to one interspace with some medial retraction while the RV apical impulse is more diffuse and is continuous with the left parasternal impulse and one may appreciate lateral retraction beyond the apical impulse. Left ventricular hypertrophy per se does not result in significant cardiac enlargement, but the apical impulse is often easily palpable with a sustained character. In case of RV hypertrophy, sustained parasternal lift as well as epigastric RV thrust can be appreciated. In biventricular enlargement or hypertrophy, one may appreciate a combination of these features.

Ventricular enlargement is either due to volume overload typically seen in left to right shunt lesions or valve regurgitations or due to ventricular systolic dysfunction. Ventricular hypertrophy results in a heaving and sustained cardiac impulse without much cardiac enlargement and is usually due to pressure overload or rarely due to hypertrophic cardiomyopathy and non sarcomeric forms of cardiac hypertrophy, like storage disorders.

ECG is an important investigation to identify the dominant ventricle. Normal RV preponderance of infancy does not persist beyond one year. There is a gradual transition from RV dominance at birth to near adult pattern of LV dominance by one year of life. Dominant R wave in V1 gives way to progressive increase in depth of S wave with reduction in R wave amplitude with R/S ratio changing from $>>1$ to <1. Similarly, there is progressive reduction of depth of S waves in V6 and increase in amplitude of R wave in V6 with reversal of R/S ratio from <1 to >1. T wave in V1 which may be upright at birth becomes inverted by one week and remains inverted till early adulthood and then becomes upright by middle age. Frontal plane QRS axis is often more than 90 degrees at birth and QRS axis shifts to less than 90 degrees by one year. Any LV dominance from birth to one year of life is abnormal (Leftward QRS axis in frontal plane less than 30 degrees, large LV voltages represented by R in V6 and S in V1 and R in aVL)

5. Is pulmonary hypertension present?

Clinically, pulmonary hypertension is suspected by symptoms of effort dyspnea, effort syncope and rarely hemoptysis. PA pulsation in the second left intercostal space, and RV heave (parasternal lift) points to pulmonary hypertension, corroborated by a loud pulmonary closure sound. With development of pulmonary hypertension and increase in pulmonary impedance, the pulmonary closure sound becomes louder, and moves closer to A2. In VSD and proximal AP window, P2 comes very close to A2 and appear as a single second sound and in this situation, pulmonary hypertension is suspected because of the palpable PA, a vascular ejection click and RV heave. In all other situations, inspiratory split can be appreciated separating P2 from A2. With onset of RV dysfunction, P2 may again move away from A2 due to prolonged RV ejection. Pulmonary hypertension due to large pulmonary blood flow, (hyperkinetic pulmonary hypertension), results in loud P2 but the S2 split is often wide and mobile due to prolonged RV ejection time and increased hang out interval. Aorto-pulmonary shunts are the exception and LV volume overload and prolonged ejection time into aorta can narrow the S2 split and can be paradoxical. Features of increased flow include cardiac enlargement, flow murmurs across structurally normal atrioventricular valves and across normal pulmonary valve.

Pulmonary hypertension can be secondary to PV hypertension as in cor-tiatriatum, supramitral ring, parachute MV with stenosis, TAPVC, mitral incompetence, and LV dysfunction from any cause. Pulmonary artery hypertension results from increased pulmonary blood flow due to shunt lesion with increased PVR. Cardiac lesions with systemic desaturation such as TGA and SV, can accelerate the development of pulmonary vascular disease. PV hypertension and increased pulmonary blood flow play a role in pulmonary hypertension, in shunt lesions with LV inflow obstruction.

Cardiac situs and position

The heart is normally positioned with normal visceral situs and levocardia in the vast majority of the normal population and hence a simple approach as described above suits most situations. However, situs abnormality and cardiac malposition form a significant minority of population with heart disease and this proportion increases in patient population with more complex heart defects as well as those presenting critically with heart defects in early infancy. The spectrum of heart disease in situs solitus and levocardia (normal arrangement) is well described. Incidence of heart disease in situs inversus and dextrocardia (mirror image visceral disposition/

situs inversus totalis) is not significantly different, though literature states incidence close to 3-5%. As most people with situs inversus with dextrocardia are asymptomatic and do not report to a cardiologist this is overestimation of prevalence of CHD in this group. The spectrum of heart disease in situs inversus totalis is similar to situs soltus and levocardia. However, in situs inversus with levocardia, almost all subjects have heart disease, so also situs sollitus with dextrocardia. A quarter of patients with clinically diagnosed situs solitus with dextrocardia and more than two third of those with situs inversus and levocardia have heterotaxy (ambiguity of visceral situs, described as bilateral right sidedness or bilateral left sidedness). These patients tend to have systemic venous drainage anomaly, pulmonary vein drainage anomaly, endocardial cushion defects and varying degrees of pulmonary outflow obstruction. Bilateral right sidedness associated with asplenia almost always have severe pulmonary outflow obstruction, with endocardial cushion defect and often have total anomalous pulmonary venous drainage. Bilateral left sidedness is commonly associated with polysplenia and have IVC interruption in more than two third of patients, endocardial cushion defects, varying degree of pulmonary outflow obstruction, and partial anomalous PV drainage often due to mal-development of septum secundum and left ward shift of septum primum. In situs solitus with dextrocardia, congenital heart disease is present in> 95% and AV discordance, double outlet RV with subpulmonary obstruction are common. The great vessels are almost always malposed. The presence of AV discordance makes usual clinical assessment of ventricular dominance and assessment of second heart sound error prone.

In summary, patients with visceral heterotaxy and those with viscera-atrial discordance form a significant minority of patients with complex CHD, and usual clinical assessment can be difficult and unreliable.

It is recommended that, before embarking on the five clinical questions as an approach to CHD, one first establish situs and cardiac position. Ambiguity of visceral situs and cardiac malposition makes clinical assessment difficult and error prone as almost all cardiac defects are complex, TOF and simple TGA being distinctly uncommon in this sub population so also simple VSD and ASD.

SECTION 3 - GENERAL PHYSICAL EXAMINATION

General examination often reveals dysmorphic features which point to well described syndromes associated with congenital heart disease. Down's syndrome, Noonan's syndrome, Ellis Van Creveld syndrome, William's syndrome, Turner's syndrome, Di George's syndrome, Holt Oram syndrome are a few examples of the more commonly seen syndromes with typical dysmorphic features and specific heart defects.

Arterial pulse

Bradycardia may indicate complete heart block and common heart disease associated is congenitally corrected transposition of great arteries with complete heart block. Regular slow pulse with changing pulse volume (AV dissociation) and irregular cannon 'a' waves in the JVP confirms CHB rather than sinus bradycardia.

Arterial pulse asymmetry with bounding right brachial compared to the left brachial and femoral arteries suggest supravalvular AS. Feeble femoral arteries with brachio-femoral delay points to classical post subclavian coarctation, highlighting importance of palpating femoral artery in every child (easily palpable brachial and difficult to locate femoral artery).

Brachio – brachial delay in a child having undergone palliative surgery in infancy / early childhood points to classical BT shunt on the side of weak delayed pulse.

High volume collapsing pulse indicates aortic run off. Common acyanotic CHD with aortic runoff are aortic incompetence, ruptured sinus of Valsalva aneurysm, coronary cameral fistula, aorta to LV tunnel, hemi-truncus, aorto pulmonary window and patent ductus arteriosus. Cyanotic CHD with aortic runoff include truncus arteriosus, and conditions with aorta to pulmonary collaterals or PDA or aorta to PA surgical shunts. Other causes are peripheral run off (distal run off) and can present with high output heart failure/ hyperdynamic circulatory state (anemia, thyrotoxicosis, beriberi, systemic AV fistula).

Upper limb systolic hypertension is typically seen in classical coarctation of aorta.

Cyanosis

Uniform central cyanosis indicates > 3-5gm% deoxygenated blood in the capillary bed.

Differential cyanosis with lower limb cyanosis (desaturation) more than upper limb is seen with PDA Eisenmenger syndrome and interrupted aortic arch with PDA (these conditions invariably have pulmonary hypertension).

Reverse differential cyanosis can be seen with TGA, PDA, PAH and PA to Ao shunt .

Arterial pulse oximetry is mandatory, to confirm / exclude systemic arterial desaturation in any patient suspected to have clinical cyanosis.

Situs and cardiac position

It is mandatory that one confirms normal visceral situs and normal cardiac position in the chest. Care should be taken to exclude gross skeletal abnormality like kypho-scoliosis or gross lung pathology which can result in cardiac displacement. Having ascertained the situs and cardiac position, one proceeds with inspection and palpation of the precordium to localize and characterize the cardiac apex and presence of any other cardiac chamber/ great artery pulsation. PA pulsation and aortic pulsation (typical in L-malposition of aorta) should be looked for. RA enlargement can only be made out by percussion looking for dullness extending to the right of lower right sternal edge.

AUSCULTATION

First heart sound (S1)

Splitting of S1 is not normally appreciated as the mitral to tricuspid valve closure interval is short (MC-TC interval). However, in Ebstein's anomaly of the tricuspid valve, the TV closure is delayed by as much as 40-60ms. and is accentuated. Split S1 (sail sound) is atypical feature of this anomaly. Split S1 can also be heard in complete RBBB due to a delay in activation of the RV and occasionally in large shunt ASD.

Second Heart Sound in CHD (S2)

Second heart sound(S2) is an important clinical clue to approach to CHD, as split of the second sound is almost always appreciated in the young, unlike in the elderly, where, pulmonary component (P2) may not be audible in a significant percentage of normal population. Appreciation of split of S2, characterization of the split, relative loudness of the aortic (A2) and pulmonary (P2) component, the location where each component is best audible and supportive physical findings like palpable pulmonary artery (PAH)/ aortic pulsation (often due to L –malposition) is crucial in reaching a plausible physiological and anatomical diagnosis.

Increase in pulmonary blood flow, PA dilation with a compliant low impedance pulmonary vascular bed, increase the pulmonary hang out interval and widens the split of S2. Increase in pulmonary ejection time commonly seen in subpulmonic (valvular, subvalvular) obstruction and less commonly, large left to right shunts cause widening of the split of S2. Large pre tricuspid shunts with large unrestricted ASD as the substrate for the left to right (large ASDs, common atrium, non obstructed TAPVCs) result in fixed split of S2. The difference in pulmonary blood flow to systemic blood flow ratio is minimized as during the respiratory phases shunt across the large ASD also varies reciprocally, maintaining near identical pulmonary and systemic blood flow ratio. With reduction in left to right shunt due to pulmonary vascular disease, the split remains fixed but A2-P2 interval tends to narrow (reducing hang out interval).

In valvular PS, P2 moves away from A2 (increased ejection time and increased hang out interval) and becomes softer. Immobility of PV due to calcification (in adults) or dysplasia (Noonan's syndrome) may cause P2 to be inaudible. In subvalvular PS (infundibilar/ subinfundibular) the P2 behaves similar to valvular PS. However, in TOF where there is both hypoplasia of the infundibulum and varying degree of PV dysplasia, P2 is often inaudible. Audibility of P2 is dependent on mobility of the valve, adequacy of pulmonary blood flow to allow back pressure for its closure: negative Dp/ Dt in PA, a good infundibular chamber and proximal PA and proximity of PA to the chest wall.

With onset of pulmonary vascular disease and increase in PVR, pulmonary impedance rises, hangout interval shortens, left to right shunt decreases and P2 moves close to A2. In large VSDs and large proximal AP windows, P2 comes so close to A2 that S2 appears as a single sound. However, S2 split is often appreciable in PDA , idiopathic / primary PAH and pulmonary hypertension due to left heart disease. In pre-tricuspid shunts with ASD, the split narrows but remains fixed.

Single second heart sound due to absent P2 is typically seen in absent pulmonary valve syndrome/ pulmonary

valve dysplasia, pulmonary atresia and truncus arteriosus. P2 may be soft to inaudible in severe sub-pulmonic obstruction and is usually absent if there is diffuse hypoplasia of the infundibular chamber as seen in most severe forms of TOF. P2 may be inaudible if the PA is posterior as seen in great vessel mal-positions, where aorta is anterior and PA posterior especially if there is associated pulmonary stenosis.

In LVOF obstruction, A2 may occur later and narrow the A2-P2 interval in inspiration and A2 may follow P2 in expiration, causing paradoxical split of S2. Large aorta to PA shunt as in PDA may result in paradoxical split of S2, due to increased LV ejection time and increased hang out interval of the aortic valve.

A loud P2 component of S2 may point to large PA and large pulmonary blood flow with low pulmonary impedance (A2 P2 interval prolonged), or increased PVR due to pulmonary vascular disease with increased pulmonary impedance and reduced pulmonary blood flow (A2 P2 interval narrow).

A2 P2 interval increases with increased pulmonary blood flow (L→R shunt) as well as with subpulmonic obstruction with increased gradient across pulmonary outflow(exception: aorto pulmonary shunts were A2 moves towards P2 with paradoxical inspiratory narrowing). With pulmonary vascular disease and increasing PVR, A2-P2 interval tends to narrow.

Audible P2 in TOF physiology indicates either predominant valvular PS or good pulmonary blood flow with good PA anatomy and a well formed infundibular chamber.

Ejection Clicks

Ejection clicks as the name suggests relates to ventricular ejection into the great artery. Click can originate from semilunar valves with commissural fusion (valve click : e.g. bicuspid aortic or pulmonary valve) or from the proximal great vessel (vascular click) with onset of LV ejection. These clicks are separated from first heart sound (S1) by the pre ejection period or the isovolumic contraction interval. The isovolumic contraction period on the left side is the time for LV pressure to rise from end diastolic pressure (10-12 mmHg) to aortic diastolic pressure (80 mmHg) and is normally 60-80 ms. The isovolumic contraction period of RV is much shorter. Respiratory phase has negligible effect on this pressure difference and hence the aortic valvular as well as vascular clicks are generally constant from S1. In absence of PAH, difference between the RV end diastolic pressure and PA diastolic pressure is smal. This can be further reduced significantly by inspiration, when RV EDP increases and PA diastolic pressure decreases. Pulmonary valve is pushed to a near open position by end diastole, shortening the isovolumic contraction period, making the S1 to pulmonic click interval shorter and click softer in inspiration. The click becomes louder and moves away from S1 during expiration (phasic variation of pulmonic ejection click of valvular PS). The pulmonary vascular click of PAH is constant as the PA diastolic pressure is very high compared to RVEDP. However, the pulmonic vascular click in idiopathic PA dilation has also been variably described as constant.

Systolic murmurs

Systolic murmurs are described, in relation to the timing with respect to S1.

- **S1 coincident murmurs: Murmurs starting with S1**

  Pansystolic murmur starts with S1 and goes up to and beyond S2, often spilling into Isovulumic relaxation interval (eg. Rheumatic MV incompetence, small to moderate VSD, TR due to RV hypertension)

  Early systolic murmur starts with S1 and ends before the S2 (eg. non hypertensive TR as in organic TV disease, Ebstein's disease, large VSD with reduced left to right shunt due to pulmonary vascular disease, acute mitral incompetence: equalization of pressures in the receiving chamber towards later part of systole reducing flow and turbulence)

- **Mid systolic murmur starting a short interval after S1 (separated by isovolumic contraction interval) and ends before the closure sound of the semilunar valve on the same side.**

  These murmurs are typically due to ejection from the ventricle to the great artery, hence often referred as ejection systolic murmur.

- **Late systolic murmurs start well after S1 beyond the isovolumic contraction interval and continues up to S2 and often spills over into isovolumic relaxation period:**

  eg. Mitral valve prolapse/ hypertrophic obstructive cardiomyopathy with mitral incompetence.

Diastolic murmurs

- **Early diastolic murmur:** Starts with semilunar valve closure obliterating the isovolumic relaxation

interval. (Aortic incompetence, pulmonary incompetence secondary to PH). The low pitched early diastolic murmur of non hypertensive pulmonary incompetence starts a short while after P2, is low pitched and does not have the decrescendo character of AR murmur or Graham Steel murmur.

- **Mid diastolic murmur:** Starts after opening of atrio-ventricular valve (following the isovolumic relaxation interval) and is due to excess flow across a normal AV valve or flow across stenosed AV valve.

- **Presystolic murmur:** Coincides with atrial systole and extends to S1. Presystolic murmur points to significant AV valve obstruction though Austin Flint murmur of free AR also can extend to pre-systole due to functional obstruction to the mitral valve. Presystolic murmur is not dependent on atrial systole and indicates continues gradient between the atrium and ventricle in late diastole suggesting significant AV valve stenosis. Atrial systole accentuates this murmur.

Continuous murmurs

They begin in systole and extend into diastole over the second sound, without change in quality/character. Continuous murmurs almost always are vascular in origin. Entirely intra-cardiac lesions rarely result in continuous murmur (continuous murmur of flow across a restrictive ASD in Lutenbacher's syndrome is an exception)

Flow murmurs

Flow murmurs are clinical clues to quantify flow across normal valves and depends on the mild turbulence caused by excess flow through normal cardiac structures typically across the heart valves and the flow murmur is located at a distance from the defect itself. It does not apply to flow across abnormal structures / defects as flow is highly turbulent and quantification is not possible. When flow across a normal mitral valve increases by more than 70% per cardiac cycle, (stroke volume increase by >70%) faint mid-diastolic murmur across mitral valve is audible. Hence presence of mid diastolic murmur across a normal mitral valve indicates stroke volume >170% of normal or left to right shunt more than 1.7:1 (eg. all post tricuspid shunts like VSD/ AP window and PDA) or mitral incompetence with regurgitation fraction >70% of forward stroke output.

Similarly, if flow across the TV is increased by 100%, a flow murmur can be audible across TV in mid diastole indicating that flow across TV is twice normal and hence, either left to right shunt is about 2:1 or there is significant tricuspid incompetence (TV has a larger orifice area than the mitral valve and requires a larger flow to cause a flow murmur). All pre tricuspid left to right shunt lesions like ASD, PAPVC, TAPVC can have tricuspid flow murmur in presence of large left to right shunt.

Loud systolic murmurs

As discussed earlier, flow turbulence (Ref Reynaud's number) is directly (linearly) related to flow and flow velocity and only to the square root of gradient. Hence loudest murmurs are more often due to increased flow with mild to moderate gradients (mild stenosis), rather than with severe valvular obstruction with large gradients and normal flow.

Regardless of precordial murmurs, murmurs over the lung fields and murmurs well audible in the mid axilla should raise concern of associated peripheral PS. Peripheral PS is comparable to resistance in parallel, and higher resistance will result in lower flow to that lung segment. Hence, louder murmur does not localize critical peripheral PS to side of loud murmur when bilateral peripheral PS is present. Severity of peripheral PS is assessed by the absolute pulmonary blood flow to the affected lung segment.

Innocent murmurs

Venous hum in the right supraclavicular area is a common finding in young children (>70% children)

Quantification of Shunts

Quantum of pre-tricuspid left to right shunt is assessed by cardiomegaly, flow murmur across TV and flow murmur across RVOF. Grade 4/6 systolic murmur in PA suggests MV disease / LV disease contributing to increased left to right shunt or mild valvar PS.

Quantum of left to right shunt at ventricular level is assessed by LV type cardiomegaly, and flow murmur across the left AV valve (mitral). Very loud systolic murmur at the 3rd / 2nd LICS often points to mild PS and large left to right shunt, in presence of LV type cardiomegaly.

Quantum of left to right shunt at aorto-pulmonary level is assessed by high volume pulse, LV type cardiomegaly, and flow murmur across left AV valve.

which is audible in the sitting position and promptly disappears with compression of the internal jugular vein or on lying down. Rarely TAPVC to left vertical vein draining to left innominate vein can result in a continuous murmur in the left supraclavicular area due to large flow. Vibratory murmurs in the 3rd , and 4th LICS is not uncommon, usually midsystolic in timing and vibratory in quality and is attributed to mild systolic turbulence in LV outflow due to rapid ejection and this murmur can often be audible over the entire precordium. Occasionally, short mid-systolic murmurs are heard in the pulmonary area which disappear on deep inspiration and is caused by pectus excavatum or straight back syndrome, easily identified by plain chest X ray in the lateral projection. It should be kept in mind that small ASD/ PAPVC may have very subtle physical findings and any patient with a short systolic murmur in pulmonary area in inspiration, with wide persistent split S2 (audible split of S2 in inspiration and expiration in sitting position) should have an echo Doppler evaluation.

As alluded to earlier, anatomical diagnosis is only a logical deduction. The final clinical diagnosis must address all the physiological components (pulmonary blood flow, amount and direction of shunt, PAH, ventricular function, severity of valve /vascular obstruction or valve regurgitation, rhythm and functional class) supported by history and physical findings to make the clinical assessment complete.

SECTION 4 - APPROACH TO LOUD SYSTOLIC MURMUR AT 2ND AND 3RD LEFT/ RIGHT INTERCOSTAL SPACE (BASE OF HEART) IN ACYANOTIC CHD

It is not uncommon to see an non-cyanotic child with a loud systolic murmur at the 2nd/ 3rd left / right intercostal space (base of the heart). See Table 2.

- Subaortic (LVOF/ systemic ventricular outflow) stenosis

  Valvular/ subvalvular discreet membranous/ subvalvular fixed muscular tunnel obstruction / subvalvular dynamic / supravalvular stenosis

- Subpulmonic (RVOF/ venous ventricular outflow) stenosis

  Pulmonary valve stenosis, RV infundibular stenosis, supravalvular PS, subpulmonic obstruction in L-TGA.

- Shunts

  Supra-cristal VSD, perimembranous VSD

- Combination lesions (left to right shunt with outflow obstruction)

  VSD with subvalvular PS, VSD with valvular PS

  VSD with subaortic discreet membrane stenosis

  ASD with valvular PS

  Sub infundibular stenosis with VSD (double chamber RV) with / without suboartic stenosis

- Rare conditions

  Pulmonic stenosis with dysplastic pulmonary valve with LV non-obstructive hypertrophic cardiomyopathy.

  Hypertrophic obstructive cardiomyopathy with biventricular involvement

A few clinical clues

Systolic murmur in the right 2nd and 1st intercostal space (ICS) with pulse asymmetry (Right brachial>> left brachial): Supravalvular AS

Systolic murmur best in the right 2nd ICS starting with a constant widely heard ejection click and heaving/ sustained LV apical impulse with slow rising late peaking pulse: Valvular AS

Systolic murmur best in the 3rd left ICS, heaving/ sustained LV apical impulse , slow rising pulse : discrete subaortic stenosis: membranous/ muscular tunnel

Late systolic murmur, best in the 3rd LICS, increasing on standing, decreasing on prompt squatting, jerky pulse

with a double systolic peak and sustained/ heaving LV apical impulse with a presystolic impulse (S4) : HOCM

Note: All significant LVOF obstructions will result in abnormal arterial pulse.

Loud systolic murmur best in the 2nd and 1st LICS, radiating to infra-clavicular area on both sides and often to lung fields with left parasternal lift: Supravalvular PS. Note: Intensity of P2 varies, depending on site of peripherals, Isolated segmental PA stenosis behaves lie idiopathic PAH with loud P2. MPA , bifurcation and main branch PA stenosis results in normal to soft P2 as the diastolic pressure in proximal PA pressure is low (ventricularization of proximal PA pressure wave form)

Loud systolic murmur best in the second LICS, preceded by inconstant / phasic EC with wide split and often soft P2: Valvular PS

Loud systolic murmur best in the third LICS, wide split S2, soft P2, parasternal lift: Infundibular PS

Loud systolic murmur in the 3rd/ 4th LICS, wide split S2, soft to preserved P2, often with LV hyper-dynamic impulse: DCRV

Loud systolic murmur in third LICS with soft to preserved P2, and LV hyper-dynamic impulse : OS infundibular PS with left to right shunt VSD

Harsh systolic murmur in 2nd LICS, normal to wide split S2, and normal P2 with hyper-dynamic LV impulse: Supracristal VSD

Harsh systolic murmur in third LICS, cardiomegaly and LV hyper-dynamic impulse, LV S3 / short mid-diastolic murmur at apex: Subaortic VSD and left to right shunt

Harsh systolic murmur in the 2nd LICS, with sustained/ heaving LV apical impulse and palpable presystolic impulse: Noonan syndrome with dysplastic pulmonary valve stenosis and HCM

Harsh systolic murmur with wide split S2, preserved P2, parasternal pulsations and RV type cardiomegaly: ASD with L→R shunt and mild PS

Altered arterial pulse characteristics should alert one to LVOF obstructive lesions.

LV type cardiac impulse which is sustained and with presystolic impulse/ S4 should point to severe LVOF obstruction/ hypertrophic cardiomyopathy

Cardiomegaly with hyper-dynamic LV impulse points to VSD and left to right shunt.

Pure RV type of parasternal lift should points to RVOF obstruction while with RV type cardiomegaly with hyper-dynamic parasternal pulsation suggests ASD with mild PS.

It is unusual to hear tricuspid/ mitral incompetence murmur predominantly or solely in the 3rd/ 2nd LICS and hence is not further discussed here.

Though systolic murmurs have been traditionally subjectively graded up to six grades, there is no clinical value addition in describing a murmur as grade 5 or 6. However, from experience, it is noted that the loudest systolic murmurs do not result from the most severe obstruction (large gradient, normal to reduced stroke volume) but result from increased flow due to shunt (increased stroke volume) with mild to moderate obstruction (large flow with moderate gradient).

Table 2: Acyanotic CHD with harsh systolic murmur at the base of the heart

Clinical condition	Pulse	JVP	Cardiac apex and left parasternal pulsation	S2 and EC	Systolic murmur	Location of thrill/ best location of murmur	Ejection click	Maneuvers
Supravalvular AS	Increased right brachial compared to other pulses (Coanda effect)	Normal	LV type, heaving. Presystolic impulse if severe	S2 normal split, A2 normal, No EC	Mid systolic, late peaking	Typically right 1st ICS	Absent	

Clinical condition	Pulse	JVP	Cardiac apex and left parasternal pulsation	S2 and EC	Systolic murmur	Location of thrill/ best location of murmur	Ejection click	Maneuvers
Congenital Valvular AS	Slow upstroke, low amplitude pulse	Normal. Rarely Bernheim effect with prominent 'a' in JVP	LV type, heaving. Presystolic impulse if severe	S2 split varies as A2 moves towards and beyond P2 as severity of AS increases (paradoxical split)	Mid systolic, late peaking	Typically right 2nd ICS	Constant EC always, in congenital bicuspid AS, unless calcific	Handgrip reduces murmur
Discrete membrane suabaortic stenosis	Slow rising, low amplitude	Normal. Rarely Bernheim effect with prominent 'a' in JVP.	LV type, heaving. Presystolic impulse if severe	Subvalvular AS rarely severe, A2 normal to soft and S2 normal split. Paradoxic split may occur in severe subvalvular AS	Mid systolic, late peaking	Typically left 3rd ICS	Absent	Handgrip reduces murmur
Tunnel type subaortic stenosis	Slow rising , low amplitude	Normal. Rarely Bernheim effect with prominent 'a' in JVP.	LV type, heaving. Presystolic impulse if severe	S2 can be paradoxical split	Mid systolic, late peaking	Typically left 3rd ICS	Absent	Handgrip reduces murmur
Dynamic LVOF obstruction	Jerky pulse with double systolic peak	Normal. Typical Bernheim effect with prominent 'a' in JVP	LV type, heaving. Presystolic impulse common	S2 can be paradoxical split	Mid systolic, late peaking	Typically left 3rd ICS	Absent	Standing, Valsalva strain phase increase murmur. Handgrip reduces it
Supravalvular PS	Normal pulse	Prominent 'a' wave	RV type apical impulse, Left parasternal lift 2-3	Normal split and P2 can be normal to soft in proximal stenosis. P2 loud if peripheral PS is limited to segmental PAs	Mid systolic, late peaking	Typically 1st LICS, infra clavicular area and mid axilla	Absent	Inspiration, prompt squatting increase the murmur
Valvular PS	Normal pulse	Prominent 'a' wave	RV apical impulse, Left parasternal lift 2-3	S2 wide split, P2 soft and delayed	Mid systolic, late peaking	2nd LICS	Phasic EC	Inspiration and squatting increase murmur
Subvalvular PS (Os Infundibular)	Normal pulse	Prominent 'a' wave	RV apical impulse, Left parasternal lift 2-3	S2 wide split and P2 soft and delayed	Mid systolic, late peaking	3nd LICS	Absent	Inspiration and squatting increase murmur

Clinical condition	Pulse	JVP	Cardiac apex and left parasternal pulsation	S2 and EC	Systolic murmur	Location of thrill/ best location of murmur	Ejection click	Maneuvers
VSD subpulmonic	Normal pulse	Normal	Hyperdynamic LV impulse	S2 wide split, P2 normal	Pan systolic	2nd LICS	Absent	
VSD perimembranous	Normal pulse	Normal	Hyperdynamic LV impulse	S2 wide split, P2 normal	Pan systolic	3rd LICS	Absent	
VSD with mild to modertate valvular PS	Normal pulse	Normal	Hyperdynamic LV impulse	S2 wide split, P2 normal to soft	Mix of pan and mid systolic	2nd LICS	Pulmonic EC always present	
VSD with mild/ moderate subvalvular PS	Normal pulse	Normal	Hyperdynamic LV	S2 wide split, P2 normal to soft	Mix of pan and mid systolic	3rd LICS	No pulmonic EC	
ASD with mild/mod. Valvar PS	Normal pulse	'a' equal 'v, with high normal mean pressure	RV impulse with hyperdynamic LPS pulsation	S2 wide fixed split and P2 normal to mildly soft	Mid systolic with mid peaking	2nd LICS	Pulmonic EC always present	

SECTION 5 - APPROACH TO HARSH SYSTOLIC MURMUR AT THE BASE (2ND/ 3RD LEFT INTERCOSTAL SPACE) IN A CYANOTIC CHD

A cyanotic child resenting with harsh systolic murmur in the 2nd and 3rd LICS is a common clinical situation. See Table 3.

Sub pulmonic obstruction is by and large, the commonest physiological abnormality, with large unrestricted VSD as the accompanying lesion, commonly grouped as TOF/ TOF like physiology. TOF like physiology is an unconventional term, routinely used in clinical discussions. A simple definition of TOF like physiology is any anatomical cardiac abnormality with large VSD or equivalent with subpulmonic obstruction, facilitating ejection of the combined ventricular output into systemic (aorta) and pulmonary (PA) circulation, proportionate to the impedance characteristics of the two circulations. Needless to reiterate the fact that the impedance at the subpulmonic location, typically sub valvular, valvular and supravalvular stenosis in variable combination contribute to the impedance to pulmonary circulation, and greater the degree of obstruction (impedance), lesser proportion of combined ventricular output enters the pulmonary circulation. This, in effect, reduces the pulmonary venous return and subsequent reduction in combined ventricular output. As both ventricles can eject into aorta or PA, the ventricular systolic pressure is determined by the aortic pressure (systemic BP, 120 mmHg). As the PA pressure is normal to reduced (25-15 mmHg), depending on the pulmonary blood flow, the ventricular to PA systolic gradient does not differ significantly regardless of the severity of subpulmonic obstruction. Gradient remaining constant, the intensity of murmur varies linearly with the amount of pulmonary blood flow (determinants of Reynold's number). Hence, in TOF like physiology, the louder the subpulmonic outflow murmur, larger the PBF. How is this useful in our clinical approach to TOF like physiology?

TOF like Physiology

Anatomy: Large mal-aligned VSD / absent IVS or SV physiology, significant subpulmonic obstruction (variable combination of subvalvular, valvular and / or supravalvular), PBF typically less than systemic blood flow:

Physiology: Ventricular systolic pressures at systemic level. PA pressures less than 30 mmHg systolic. Ventricle to PA gradients similar across the spectrum and pulmonary blood flow typically less than systemic blood flow. Proportion of combined ventricular output entering the aorta and PA is determined by the relative impedance of the two circulations.

TOF like physiology typically has entire pulmonary blood flow obtained directly from the ventricle antegrade through the subpulmonic outlet (pulmonary atresia, VSD physiology with PDA/ aorto pulmonary collaterals will not be discussed further) and include the following conditions:

- TOF and its variants including TOF with endocardial cushion defect and TOF with absent pulmonary valve.
- DORV with subaortic VSD and PS
- DORV with subpulmonic VSD and PS
- TGA, large VSD and PS
- Corrected TGA , large VSD and PS
- Single ventricle and PS: The combined ventricular output from the single ventricle can enter the aorta through a wide patent bulbo-ventricular foramen (rarely, can be restrictive), and the PA which has variable valvular and/or subvalvular stenosis.
- Tricuspid atresia(TA), VSD and PS normally related GV (Single ventricle physiology): In tricuspid atresia with PS, the combined ventricular output from the LV can enter the aorta directly or the PA through a restrictive VSD which now acts as the subpulmonic stenosis. In TA and normally related great vessels, pulmonary valve stenosis and infundibular stenosis can coexist with restrictive VSD.

The various conditions listed under TOF like physiology, have very little else in common.

TOF, its variants and corrected TGA, VSD and PS facilitate favorable intracardiac streaming, permitting preferential entry of pulmonary venous return to enter the aorta (no wastage of oxygenated blood reentering the PA). In TGA, VSD, PS and DORV, subpulmonic VSD, PS, the pulmonary venous return reenters the PA leading to large wastage of oxygenated blood in recirculation, there by markedly reducing the effective systemic blood flow and arterial saturation. In single ventricle physiology, there is complete admixture of pulmonary and systemic venous return and admixed blood enters the aorta and PA, resulting in some recirculation of oxygenated pulmonary venous blood. DORV with sub-aortic VSD and PS behave more like TOF as the LV is favorably positioned below the aorta, connected through the VSD.

From the above discussion, it is evident that, for the same amount of pulmonary blood flow, the systemic saturation is highest for TOF, TOF variants and corrected TGA, VSD, PS (favorable streaming) and lowest for TGA,VSD, PS and DORV, subpulmonic VSD, PS (transposition physiology). Admixture lesions of single ventricle physiology, will have a systemic saturation in between. Simply stated, a loud outflow murmur and minimal cyanosis, favours, TOF. A loud outflow murmur and severe cyanosis, favor TGA , VSD, PS. In the same vein, TOF will have the smallest cardiac size and TGA will have the largest cardiac size for the same systemic saturation as TGA physiology requires a larger pulmonary blood flow for identical systemic arterial saturation.

LV type cardiomegaly favors single ventricle of LV morphology or tricuspid atresia. Palpable aortic pulsation in the third left intercostal space with palpable aortic component of S2 is characteristic of L malposition of the aorta. L-malposition of aorta is invariable in corrected TGA, seen in two third of patients with single ventricle of LV morphology and in less than 5% of DORV. Anatomically corrected L- position of aorta is a very rare entity.

Table 3: TOF like Physiology

Clinical condition	Systemic & Pulmonary venous flow into respective circulations	Cardiac size (combined ventricular output to maintain similar systemic saturation: eg. 80%	Ventricular apex	Aortic pulsation in left 3rd ICS & palpable A2	Systolic murmur: Usually described as midsystolic (exception : TA)	ECG	X ray chest
TOF	Favorable flow	Smallest size, no cardiomegaly	RV	No	Murmur Intensity Inversely related with cyanosis	RVH, RAD	Small heart, Asc. Aorta prominent, rt. Aortic arch 25-30%
DORV, subaortic VSD, PS	Favorable flow	Minimal / no cardiomegaly	RV	No	More cyanotic for the same murmur intensity, compared to TOF	RVH, RAD, counterclockwise loop, PR prolongation, mild QRS widening	Normal sized heart, right aortic arch 25%
DORV, subpulmonic VSD PS	Unfavorable (TGA physiology)	Moderate cardiomegaly	RV	No	Loud murmur, intense cyanosis	RVH, extreme RAD	Mildly enlarged heart, right Aortic arch 10%
TGA VSD PS	Unfavorable: TGA physiology	Moderate cardiomegaly	RV	No	Loud murmur, intense cyanosis	RVH, extreme RAD	Mildly enlarged heart, narrow pedicle, rt. Arch 10%
SV of LV type, PS	Admixture physiology	Mild cardiomegaly	LV	In 67% cases : L-aorta		Monotonous QRS, precordial leads	Mild increased heart size (L V type): L- aorta
SV of RV type, PS	Admixture physiology	Mild cardiomegaly	RV	---------			
TA, NRGA, restrictive VSD and or PS	Admixture physiology	Mild cardiomegaly	LV	no	Pan-systolic murmur from restrictive VSD, heard lower down	LVH, LAD, RAE	Mild increase in heart size, LV type
L-TGA VSD PS	Favorable flow	No cardiomegaly, unless AV valve regurgitation	Medially placed LV	L- malposition of of aorta In 100% of cases	Loud murmur, mild cyanosis, due to favorable streaming	Right sided ventricular (LV) dominance AV conduction blocks	Normal heart size, L- aorta on left cardiac border

A little bit of Hemodynamics

Let us assume Qp/Qs is 0.8. Qp/Qs = AO sat-MV sat/PV sat-PA sat. Mixed Venous sat. in absence of severe low CO state or extreme systemic desaturation will be 60%. In TOF, with favorable streaming, the PA saturation will be same as mixed venous saturation and PV saturation assumed as 100%.

0.8 = AO sat – 60/100 -60

0. 8= (Ao sat – 60)/40

40 x0.8 = Ao sat – 60

32 = Ao sat. – 60 There fore, Ao. Sat = 92%

In TOF: Ao sat. = 92%

Now, let us take the example of SV, an admixture physiology: Ao sat and PA saturation will be similar (Z). Assuming MV sat as 60%, PV as 100%:

0.8 = Ao sat – MV sat/ PV sat – PA sat

0. 8 = Z – 60 / 100 – Z

0.8 (100 –Z) = Z – 60

80 – 0.8 Z = Z – 60

80 + 60 = Z+ 0.8 Z = 1.8 Z

Z = 140/1.8 = 78%

In SV, systemic saturation will be 78%

In TGA physiology, the PA saturation will be more than the aortic saturation (Z). Let us assume PA saturation 10% more than aorta saturation (Z + 10)

0.8 = Ao sat – MV sat / PV sat – PA sat

0.8 = Z – 60/ 100 – (Z +10)

0.8 = Z – 60 / 90 – Z

0.8 (90 - Z) = Z – 60

72 - 0.8 Z = Z – 60

132 = 1.8 Z

Z = 73%

Aortic saturation 73%

In TGA physiology, the PA saturation will be more than the aortic saturation (Z). Let us assume PA saturation 20% more than aorta saturation (Z + 20) as an indication of poor intercirculatory mixing:

0.8 = Ao sat – MV sat / PV sat – PA sat

0.8 = Z – 60/ 100 – (Z +20)

0.8 = Z – 60 / 80 – Z

0.8 (80 - Z) = Z – 60

64 - 0.8 Z = Z – 60

124 = 1.8 Z

Z = 70%

In TGA, Aortic saturation 70%

(Please note that this is an oversimplification of the hemodynamics: In TGA, the mixed venous saturation is often in the 40% range as systemic saturation is very low and if one calculates with MV O2 sat. 40%, the aortic saturation will be close to 60%)

Inference: For the same PBF, TOF has the best arterial saturation and TGA VSD PS the least saturation. It is also evident that more the PA saturation exceeds aortic saturation, (poor inter circulatory mixing in TGA) lower is the aortic saturation in TGA physiology.

- **Let us see clinical scenario where the systemic saturation is 80%: in TOF / in SV (admixture physiology) / TGA (TGA physiology)**

1. **TOF : Favorable streaming:** MV sat = PA sat, MV assumed as 60%, PV assumed 100, Ao sat 80%: Qp/QS = Ao sat – MV sat/ PV sat – PA sat

   Qp/ Qs = 80 -60 / 100 -60

   Qp/ Qs:: 20/40 = 0.5 i.e Qp is half the Qs

   In TOF, Qp + Qs = 1.5 times cardiac output

2. **SV: Admixture Physiology:** PA sat = Ao sat, PV assumed 100%, MV assumed as 60%

   Qp/ Qs = Ao sat – MV sat/ PV sat – PA sat

   Qp/ QS = 80 – 60 / 100 – 80

   Qp/ QS = 20 /20 = 1 i.e. Qp is equal to Qs

   In SV with PS, Qp + Qs = 2 times cardiac output

3. **TGA VSD PS:** PA saturation always more than Ao saturation: let us assume PA saturation 10% more than aortic saturation

   PA saturation (Z +10) >> Ao sat (Z) as in TGA physiology, PV assumed as 100%, MV as 60%

   Qp/Qs = Ao sat – MV sat/ PV sat – PA sat

   Qp/ Qs = 80 – 60 / 100 – 90

   Qp/Qs = 20 / 10 = 2 i.e. Qp is twice the Qs

   Qp + Qs = 3 times cardiac output

Inference: To maintain systemic saturation at 80% , in TOF the combined ventricular output is 1.5 times, in SV

PS 2 times and TGA VSD PS 3 times the systemic cardiac output. Normal heart will have combined ventricular output twice systemic cardiac output.

TOF will have a smaller heart, SV intermediate size, and TGA VSD PS larger heart to maintain systemic saturation 80%.

SECTION 6 - APPROACH TO HARSH SYSTOLIC MURMUR AT THE 4TH/5TH LEFT INTERCOSTAL SPACE

It is not uncommon to see patients with a harsh systolic murmur at the tricuspid area.

Tricuspid regurgitation

- TR with RV hypertension usually functional due to RV dysfunction, as seen with severe PAH and severe RVOF obstruction with intact interventricular septum: JVP is often abnormal with large/ prominent 'v' waves with rapid 'y' descent. Left parasternal heave is present because of pressure and volume overload of the RV. Pan-systolic murmur with inspiratory augmentation and RV S3 are characteristic and a mid- diastolic murmur if TR is severe. S2 split as well as P2 intensity gives the clue as to if there is PS/ PAH. Severe PS will also have harsh systolic murmur higher up in the 3rd/ 2nd LICS.

- TR without RV hypertension: Primary TV disease as in Ebstein disease/ TV dysplasia: JVP may show large 'v' waves with sharp 'vy' descent (more common with acquired TR than in a typical Ebstein), left parasternal pulsations (described as mid to late systolic retraction), grade 2-3/6 early systolic murmur increasing with inspiration, normal split S2 with normal P2.

Muscular VSDs and DCRV

- Muscular VSDs result in early/ pansystolic murmur depending on VSD size , L→R shunt and degree of PAH/PVR (see under VSDs).

- DCRV: The intra cavitary RV obstruction and gradient due to hypertrophied muscle bundles is a difficult clinical diagnosis, but should be kept in mind as a D/D for VSD. DCRV is always associated with VSD, opening into the proximal high pressure RV chamber. The Murmur is almost always caused by the intra cavitary obstructon. Additional VSD murmur may be appreciated, if proximal RV chamber pressure is subsystemic but, it is clinically difficult to decipher and separate the two. I personally never attempt to identify and separate the mid-systolic and pan-systolic murmur which can coexist in close proximity as seen in DCRV and in infundibular PS with VSD.

Mitral incompetence

Mitral incompetence due to cleft mitral valve as a component of primum ASD/ partial ECD is always directed medially towards the lower left sternal edge. Left AV valve incompetence in corrected TGA is also directed medially. These are typically pan-systolic murmurs.

Mitral incompetence due to MVP, especially of the PML can direct the MR jet medially and is usually preceded by a mid-systolic click. It is a late systolic murmur which increasing in duration and intensity on standing.

SECTION 7 - APPROACH TO CYANOTIC CHILD WITH NO MURMUR OVER THE PRECORDIUM OR THE CHEST

Loud murmurs are produced by flow across stenotic valves/ conduits or increased flow through normal or narrowed valves/ conduits. Viscosity is an important factor in production of murmur and marked increase in viscosity with increase in hematocrit reduces turbulence and attenuates murmurs. Increased viscosity also increases vascular resistance significantly, reducing blood flow which indirectly attenuates murmurs. See Table 4.

When cyanosis is noted with normal cardiac findings, hematological causes of cyanosis such as methemoglobinemia (normal PaO2 with systemic desaturation by pulse oximetry) as well as polycythemia secondary to hemoglobinopathies with low affinity for O2 (normal PaO2, reduced arterial saturation), hemoglobinopathies with high affinity for O2 (normal PaO2, normal saturation, high hematocrit, low P50 on Hb- O2 dissociation curve) and primary polycythemia (normal PaO2 and normal arterial saturation) should be excluded.

Anomalous systemic venous connection (SVC to LA/ IVC blood directed to LA by a large persistent Eustachian valve) and pulmonary telengectasia / pulmonary artery to venous communication are the cardiac/ pulmonary causes of cyanosis with normal cardiac findings.

COPD with predominant bronchitis (Blue bloater) used to be a common scenario in the adult population. Pulmonary hypertension is invariable, but often difficult to assess clinically.

Other Important cardiac causes of cyanotic CHD with no murmurs fall into two categories:

1. Cyanotic CHD with PAH, pulmonary vascular disease and reduced pulmonary blood flow:

i) Acyanotic CHD, going on to Eisenmenger syndrome: Endocardial cushion defect, VSD, aortopulmonary septal defect, PDA, ostium secundum ASD, ostium primum ASD, sinus venosus ASD

ii) Cyanotic CHD with increased pulmonary blood flow progressing to pulmonary vascular disease and decreasing PBF and increasing cyanosis: DORV, Single ventricle, truncus arteriosus, TAPVC, common atrium

2. Cyanotic CHD with reduced pulmonary blood flow due to pulmonary atresia/ severe pulmonary stenosis

i) Severe form of TOF, TOF like physiology

ii) Pulmonary atresia, VSD with aorto pulmonary collaterals: either hypertensive collaterals without stenosis or very small collaterals with markedly diminished flow. (lack of turbulence due to hyper viscosity of blood, as well as reduced flow due to marked increase in resistance to flow due to hyperviscosity)

Table 4: Cyanotic congenital heart disease with no significant murmur:

D/D of Eisenmenger syndrome from Pulmonary atresia VSD/ severe subpulmonic obstruction(e.g. severe TOF)

Acyanotic CHD progressing to Eisenmenger: Post tricuspid shunts	Acyanotic CHD progressing to Eisenmenger Pre tricuspid shunts	Cyanotic with increased PBF progressing to Eisenmenger: Post tricuspid shunts	Cyanotic with increased PBF progressing to Eisenmenger: pre tricuspid shunt	Cyanotic CHD, severe subpulmonic stenosis	Cyanotic CHD, pulmonary atresia, AP coll./ PDA	Post palliation Cyanotic CHD
ECD, large VSD, AP window, PDA	Ostium primum / ostium secundum ASD	DORV, SV, Truncus, TGA VSD	TAPVC, Common atrium	TOF /TOF like physiology with severe RVOF obstruction	All pulmonary atresia, typically with large mal-aligned VSD and PDA/ AP coll.	All pts. With BDG/ non functioning aortopulmonary shunts(blocked/ PAH)

Acyanotic CHD progressing to Eisenmenger: Post tricuspid shunts	Acyanotic CHD progressing to Eisenmenger Pre tricuspid shunts	Cyanotic with increased PBF progressing to Eisenmenger: Post tricuspid shunts	Cyanotic with increased PBF progressing to Eisenmenger: pre tricuspid shunt	Cyanotic CHD, severe subpulmonic stenosis	Cyanotic CHD, pulmonary atresia, AP coll./ PDA	Post palliation Cyanotic CHD
HF in infancy and all clinical features related to severe HF	HF is rare feature	HF with mild cyanosis from early infancy with all clinical features related to severe HF	HF is rare in common atrium, HF more with TAPVC due to PV obstruction	Cyanotic from newborn/ infancy with hypoxic spells. Squatting from early childhood	Cyanotic from newborn period. Cyanosis worsens with duct constriction. Cyanosis can regress with development of AP coll.	H/O hypoxic spells for aorta to PA shunts or elective or emergency BDG for univentricular repair with/without PA band
HF symptoms abate by 2 years with increasing PVR and PVD, reducuing shunt	HF not a feature. Failure to gain weight	HF symptoms tend to abate by 2 years, with increasing cyanosis and increasing PVR and irreversible PVD	Cyanosis tends to increase progressively by the 2nd to 3rd decade with onset of PVD, raised PVR	Cyanosis inversely related to the outflow murmur and generally the subpulmonic obstruction progresses and the dynamic obstruction becomes more fixed due to fibrotic changes	Cyanosis increases as demand supply mismatch with growth, development of stenosis/ PAH in collaterals	Deepening of cyanosis with failing aorto pulmonary shunt: common is shunt occlusion though rarely pulmonary hypertension and PVD. Normal functioning BDG in setting of pulmonary atresia is silent and systemic saturation around 80-85%
Pulse volume unremarkable	Pulse volume unremarkable	Pulse volume unremarkable	Pulse volume unremarkable	Pulse volume unremarkable	May be increased if PBF maintained	Pulse volume normal. Classical BT shunt: weak delayed brachial pulse on shunt side
Mean JVP normal. In adult, 'a' wave can be prominent	Mean JVP can be elevated, both a and 'v' waves can be prominent with RV dysfunction	Mean JVP normal. In adult, 'a' wave can be prominent	Mean JVP can be elevated, both 'a' and 'v' waves can be prominent with onset of RV dysfunction	Mean JVP normal. In adult, 'a' wave can be prominent	Mean JVP normal. In adult, 'a' wave can be prominent	BDG will cause non pulsatile jugular vein pressure
RV impulse unimpressive	RV impulse often present	RV impulse unimpressive	RV impulse often present	RV impulse unimpressive	RV impulse unimpressive	Depends on underlying cardiac lesion
No cardiomegaly	Mild cardiomegaly	Mild Cardiomegaly may be seen	Mild Cardiomegaly common	No cardiomegaly	Mild cardiomegaly	BDG permits higher systemic saturation for the same PBF: by physiological systemic venous return to PA
P2 loud, S2 fused &single. In PDA, audible split	P2 loud, S2 usually close fixed split	P2 loud, S2 fused &single	P2 loud and S2 close fixed split	S2 single due to non audible P2	S2 single due to absent P2	S2 often single due to severe subpulmonic stenosis/ PA/ PA interruption

Acyanotic CHD progressing to Eisenmenger: Post tricuspid shunts	Acyanotic CHD progressing to Eisenmenger Pre tricuspid shunts	Cyanotic with increased PBF progressing to Eisenmenger: Post tricuspid shunts	Cyanotic with increased PBF progressing to Eisenmenger: pre tricuspid shunt	Cyanotic CHD, severe subpulmonic stenosis	Cyanotic CHD, pulmonary atresia, AP coll./ PDA	Post palliation Cyanotic CHD
Murmurs due to secondary causes: PDA: often pan-diastolic Graham Steel murmur	Pansystolic murmur of TR	Truncus: Truncal valve regurgitation EDM	Pansystolic TR murmur	No murmur	No murmur	Systolic murmur of AV valve incompetence, if SV systolic dysfunction
Palpable PA	Palpable PA	Palpable PA: D/D L-malposed aorta as in single ventricle	Palpable PA	PA not palpable D/D L-aorta	PA not palpable D/D L- aorta	Depends on underlying cardiac lesion
ECG: RVH, RAD ECD: LAD, RVH, counterclockwise loop	ECG: RVH, RAD LAD with RVH, counterclockwise loop: Primum ASD	ECG: RVH, RAD LAD with RVH , counterclockwise loop: DORV, subaortic VSD	ECG: RVH, RAD RVH, LAD, counterclockwise loop : common atrium	ECG: RVH, RAD RVH, LAD: TOF with ECD	ECG: RVH, RAD RVH, LAD: ECD, PA	Depends on underlying cardiac lesion
X ray: Prominent central PA	Prominent central PAs	MPA often not seen: malposition/ absent	Prominent central PA	MPA segment inconspicuous, branch PAs small	MPA segment absent, branch PAs depends on PA supply from PDA/ central MAPCAS/ or MAPCAS supplying distal PA	Depends on underlying cardiac lesion
Lack of murmur due to reduction in pulmonary blood flow and no substrate for turbulent flow	Lack of murmur due to reduction in pulmonary blood flow and no substrate for turbulent flow	Lack of murmur due to reduction in pulmonary blood flow and no substrate for turbulent flow	Lack of murmur due to reduction in pulmonary blood flow and no substrate for turbulent flow	Absence of murmur due to severe subpulmonic obstruction, reduced PBF due to increased blood viscosity reducing turbulence and further increasing resistance to ejection.	Absence of murmur can be due to high pressure MAPCAS, or due to small multiple collaterals with reduced flow and further reduction in murmur due to hyper viscosity (reduction in turbulence)	Lac of murmur is due to interrupted antegrade flow into PA. BDG is a low pressure no gradient shunt and does not cause murmur
Normally related great vessels	Normally related great vessels	L- aorta in SV/ L TGA, VSD	Normally related great vessels	L- aorta in SV/ L TGA, VSD	L- aorta in SV/ L TGA, VSD	L- aorta in SV/ L TGA, VSD

SECTION 8 - APPROACH TO CYANOTIC CHILD WITH CONTINUOUS MURMUR

Common conditions with cyanosis and continuous murmur:

1. Cyanotic CHD, severe subpulmonic stenosis and decreased PBF with ductus
2. Cyanotic CHD with pulmonary atresia and VSD with duct/ aortopulmonary collateral dependent pulmonary circulation
3. Cyanotic CHD, severe subpulmonic stenosis and decreased pulmonary blood flow with aorto pulmonary shunts: Classical BT shunt, modified BT shunt, Waterston shunt, Pott's shunt
4. Pulmonary artero venous fistulae / pulmonary artery to LA fistula
5. Truncus with ostial pulmonary artery stenosis
6. Pulmonary valve atresia with intact IVS and PDA
7. Severe peripheral PS and R→L shunt at atrial level
8. TAPVC with mild obstruction at the vertical vein and large flow

Normal cardiac auscultation over the precordium, normally split S2 and normal P2, with localized continuous murmur over the chest : Pulmonary artero venous fistula/ PA- LA fistula

S2 single with absent P2 with continuous murmur in PA/ 2nd LICS: PA with PDA; PA with classical BT shunt (absent / weak delayed upper limb pulse on the side of the surgical shunt): modified BT shunt (continuous murmur extending from supraclavicular to infra clavicular area)

Constant EC, continuous murmur in the 2nd/3rd LICS: Truncus with ostial stenosis of PAs

Cyanotic with single S2 , absent P2 and continuous murmur over the lung fields: Typically pulmonary atresia with VSD and aorto pulmonary collateral.

Mild cyanosis, cardiomegaly of RV type, wide fixed split of S2, continuous murmur left 2nd/3rd ICS: TAPVC, large pulmonary blood flow and mild venous obstruction at vertical vein innominate junction.

SECTION 9 - A FEW CLINICAL TIPS

Physical findings in isolated VSD

- Small VSD (muscular) : small L-> R shunt : No cardiomegaly, no Left parasternal heave, normal split S2, normal P2, physiological S3 can be present, S1 coincident early systolic murmur (muscular VSD tends to constrict with ventricular contraction).

- Small subaortic VSD: same findings as above, more often pansystolic murmur, rarely early systolic murmur if membranous septal aneurysm closes the VSD in late systole. Small percentage of patients can have early diastolic murmur of AR.

- Small subpulmonic VSD: same findings as subaortic VSD, pan systolic murmur may be best heard in pulmonary area, and high incidence of early diastolic murmur of AR.

- Moderate VSD: LV type cardiomegaly, wide split S2, P2 normal to mildly accentuated, LV S3 and short mid diastolic flow murmur across MV, pansystolic murmur, rarely early diastolic murmur of AR.

- Large VSD, large flow, hyperkinetic PAH: LV type cardiomegaly, wide split S2, P2 accentuated, LV S3 and short mid diastolic flow murmur across MV, pansystolic murmur.

- Large VSD, decreasing L→R shunt due to elevated PVR due to PVD: Mild LV type cardiomegaly, mild LPSH, narrow physiological split of S2, P2 loud, LV S3, early systolic murmur stopping short of A2.

- Large VSD, markedly elevated PVR due to PVD: No cardiomegaly, S2 close split/single with accentuated P2, palpable PA and mild LPSH, pulmonic EC (vascular), very short early systolic murmur / no systolic murmur,

- Large VSD, Eisenmenger syndrome: Mild cyanosis increasing with exercise, no cardiomegaly, S2 single with loud accentuated P2 fusing with A2, pulmonic vascular EC, no MDM, no systolic murmur, rarely Graham Steel murmur of pulmonary incompetence

- AR more common with smaller VSDs, more associated with subpulmonic VSDs, and progressive AR due to aortic valve prolapse reduces the functional size of VSD reducing the L→R shunt.

- When there is LV type cardiomegaly, mild LPSH, wide split S2 and soft P2 with a very loud murmur, one must suspect mild subpulmonic obstruction with large shunt.

Pre tricuspid L→R shunts

Small pre tricuspid shunt lesions are difficult to diagnose clinically as patients are asymptomatic and physical signs subtle. Isolated PAPVC to SVC reported as high as 1% at anatomic autopsy is rarely diagnosed clinically, so also small ASDs less than 5 mm in children and 10 mm in adults. A typical ASD with L→R shunt >= 2:1 will have cardiomegaly, mild LPS pulsation (hyperdynamic), wide fixed split S2 with normal P2 often widely audible upto apex, short early peaking mid systolic murmur at PA and mid diastolic murmur at the lower LSE especially in the young. Mobile split of S2 with other findings of ASD should point to PAPVC with intact atrial septum. Very mild systemic desaturation with other features of ASD can be Raghib's type or coronary sinus type ASD or TAPVC or common atrium. There are several other causes of systemic desaturation in ASD like IVC streaming , SVC straddling sinus venosus type atrial septal defect, TR directed to atrial septum. With progressive PVD and RV hypertension and RV diastolic dysfunction, L→R shunt decreases, cardiomegaly tends to decrease but not normalize, flow murmurs are attenuated, LPSH becomes prominent with palpable PA and loud P2 with fixed but closer split of S2. Pulmonic vascular ejection click is often audible.

Note: Patients with pre-tricuspid shunts almost always have audible split of S2 with appreciably loud P2 and is rarely a diagnostic dilemma. However, post tricuspid shunts at ventricular level and proximal aorta (large AP window) often have single fused S2. PDA in the large majority have audible mobile split of S2 with differential cyanosis.

Pitfalls in diagnosing Eisenmenger syndrome when ASD / VSD is the working diagnosis

Often, when clinical findings are overwhelmingly like an ASD with PAH, presence of systemic desaturation leads one to consider PVD and Eisenmenger state. There are several reasons for systemic desaturation in the setting of clinical features of ASD and PAH: TAPVC, Common atrium, are admixture lesions and cyanosis invariable. Raghib's coronary sinus type ASD with unroofed CS will have mild systemic desaturation as left SVC will drain through an open CS into LA. Straddling SVC in SV ASD, IVC blood directed to the fossa ovalis region and across the ASD to LA by a large Eustachian valve, and tricuspid regurgitation jet directed to the atrial septum are some conditions with right to left shunt in absence of PAH. Any TV inflow abnormality, typically Ebstein's disease and RV diastolic dysfunction as in RV EMF can cause right to left shunt.

When clinical features are like VSD and PAH, one must carefully exclude DORV with subaortic VSD. DORV with subaortic VSD behaves Iike a large subaortic VSD but with mild systemic desaturation (ref. admixture physiology with favorable streaming). Though ECG may give a clue, careful 2D echo imaging is required to confirm/ exclude the diagnosis of DORV.

Clinical assessment of admixture lesions with increased pulmonary blood flow

Typical cyanotic CHD with increased PBF with admixture physiology is single ventricle. As the systemic saturation is dependent on the proportion of pulmonary venous return to systemic venous return, arterial saturation reflects pulmonary blood flow. Typically, if one assumes mixed venous saturation as 60% and PV saturation as 100%, then systemic saturation of 80% indicates, QP = QS, clinically inoperable state due to elevated PVR in absence of PS. If the systemic saturation is 90%, Qp/QS is approximately 3:1 and PVR/ SVR ratio will necessarily be < 0.33 and will almost always be operable. However admixture lesions like DORV, subaortic VSD / DORV subpulmonic VSD is characterized by streaming and hemodynamic study mandatory to assess operability, beyond 1-2 years of life. Truncus too can demonstrate streaming and often streaming is favorable and patient can have a high systemic saturation despite severe PVD

All conditions with pulmonary atresia have pulmonary blood flow entirely from the aorta and hence pulse volume is a direct indicator of pulmonary blood flow as much as cardiomegaly.

CONCLUSION

The clinical diagnosis must address all the physiological components including quantum of pulmonary blood flow, amount and direction of shunt, degree of PAH, ventricular function, severity of valve obstruction / regurgitation, rhythm and functional class, supported by history and physical findings. Clinical examination should attempt to exclude gross anatomical malposition of the viscera and the heart and assess and quantify physiological derangement and logically deduce the underlying anatomical / structural defect for a complete diagnosis.

ECG in Congenital Heart Diseases

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INTRODUCTION

Electrocardiography (ECG) continues to be an integral part of evaluation of suspected Congenital Heart Disease (CHD). It is noninvasive, inexpensive and provides a clear direction as to the possible CHD. In an established CHD, it conveys information on chamber enlargement, presence of pulmonary hypertension (PH), specific clues to the diagnosis and possible arrhythmia substrate.

ECG can be supportive of clinical diagnosis, as in Tetralogy of Fallot (TOF). It can be affirmatory, as in ostium secundum Atrial Septal Defect (ASD). It can be virtually diagnostic, as in Ebstein anomaly or Tricuspid Atresia.

The proposed style of the presentation of this article is to open a case study, introduce an ECG to highlight the salient features of that CHD and discuss the ECG findings in a particular defect.

The standard format of reading a pediatric ECG is given below.

1. Rate per minute
2. Sinus rhythm or not
3. P wave and axis
4. PR interval
5. QRS morphology and width
6. QRS axis
7. QRS in V1 and V6 (R/S)
8. ST segment
9. T wave
10. Corrected QT interval, U wave etc

The figure one (Fig. 1) provides an illustration of how to read an ECG in a suspected CHD.

1. Rate 100 / minute
2. Normal sinus rhythm
3. **Tall, peaked P wave** - Right Atrial Enlargement (RAE)
4. PR interval 160 msec
5. QRS width normal; **rSR in V1**
6. QRS axis: **Right Axis Deviation(RAD)**
7. R/S in V6 16/10
8. ST segment normal
9. T inverted in V1-V3 (Normal)
10. QTc – Normal

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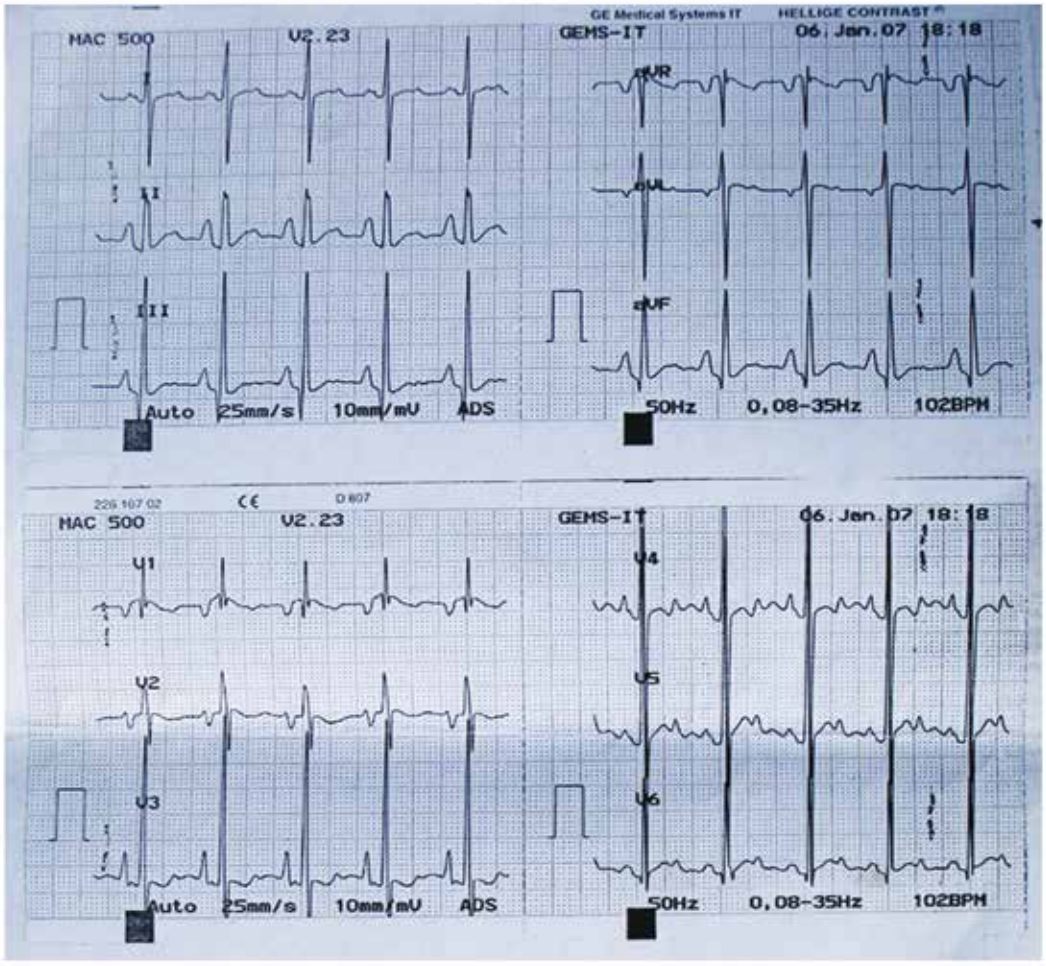
FIG :1



CASE STUDY I

A seven year old girl presents with asymptomatic murmur. She has a wide and fixed split S2. There is a grade 2/6 midsystolic murmur over pulmonary area.

- *Most likely, the diagnosis is ASD.* (Fig. 2)

- The ECG has a normal P wave and PR interval. There is RAD. rSR is evident in V1. Has normal LV forces.

OS ASD Has

1. *Normal P wave*
2. *RAD*
3. *rSR in V1 and V3R*

ATRIAL SEPTAL DEFECT (ASD)

ASDs can be ostium secundum (70%), ostium primum (20%) and sinus venosus(10%) types.

Ostium Secundum ASD

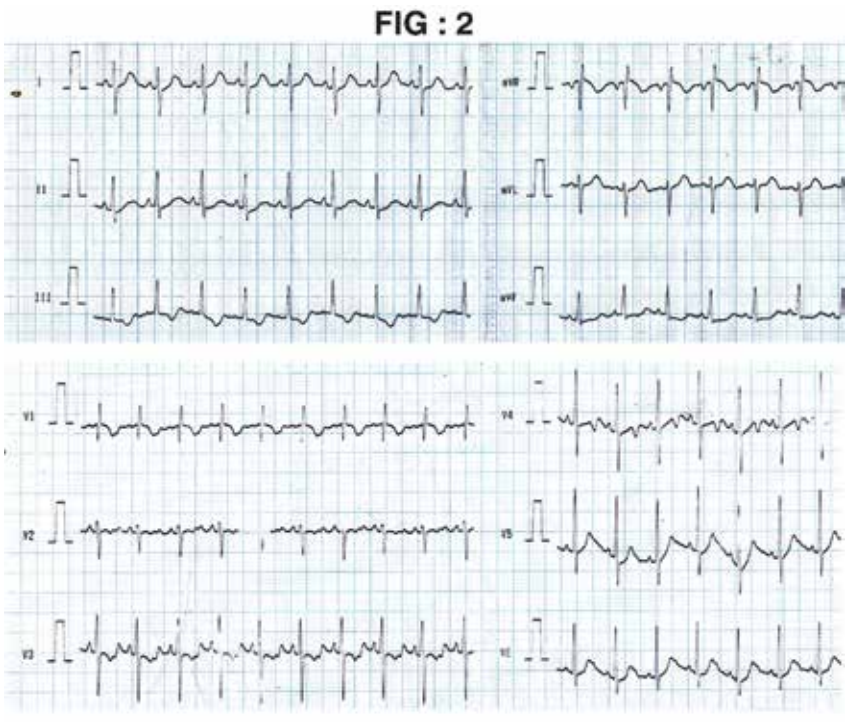
Sinus rhythm is the norm. However we can expect arrhythmias like atrial fibrillation (AF) atrial flutter and junctional rhythm in adults. P wave is peaked, but not tall. PR interval is usually normal. 10-15% of OS ASD can have prolonged PR interval.

OSASD and 1° Atrio Ventricular Block can be present in

- Familial OS ASD
- Holt Oram syndrome
- Adult with ASD
- Associated rheumatic valvar disease

QRS axis is rightward (RAD). 90% of ASDs will have an rSR pattern. The R' never exceeds 15 mm unless PH develops. There can be a notch on R wave in II. III. and avF leads (*Crochetage*)

FIG : 2



Sinus Venosus ASD (SV ASD)

rSR pattern is common to SV ASD. PR interval is normal. However P wave axis is abnormal. It is less than +15 and P waves in II,III and aVF leads may be inverted.

Ostium Primum ASD

rSR pattern is common to OP ASD. PR interval can be prolonged. Left axis deviation (LAD) is standard feature (Figure 3)

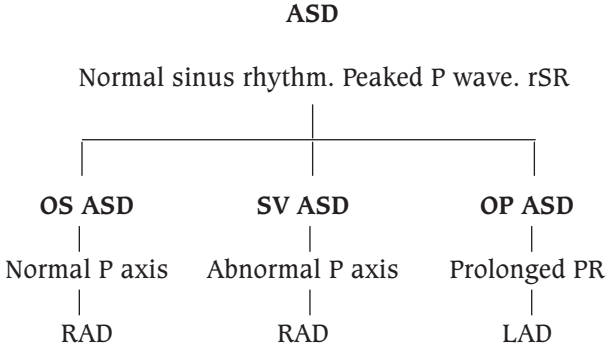
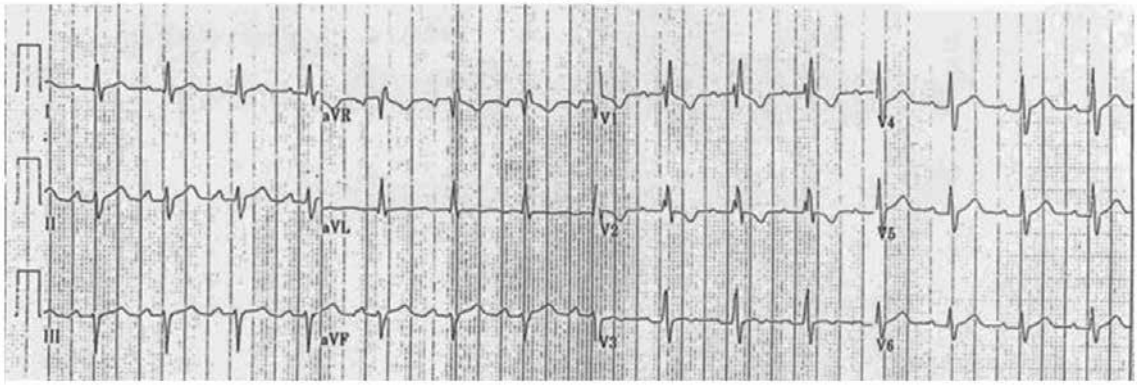


FIG : 3



CASE STUDY 2

An abnormal looking baby of six months. She has acyanotic heart disease. She is in CHF and has significant PAH. Has wide split S_2 with loud P_2 and has both pan systolic murmur and mid diastolic murmur.

- *Most likely diagnosis will be AVSD.* (Fig. 4)

- The ECG has

i. Tall peaked P wave (RAE)
ii. Left axis deviation
iii. rSR in V1. Tall R' in VI.

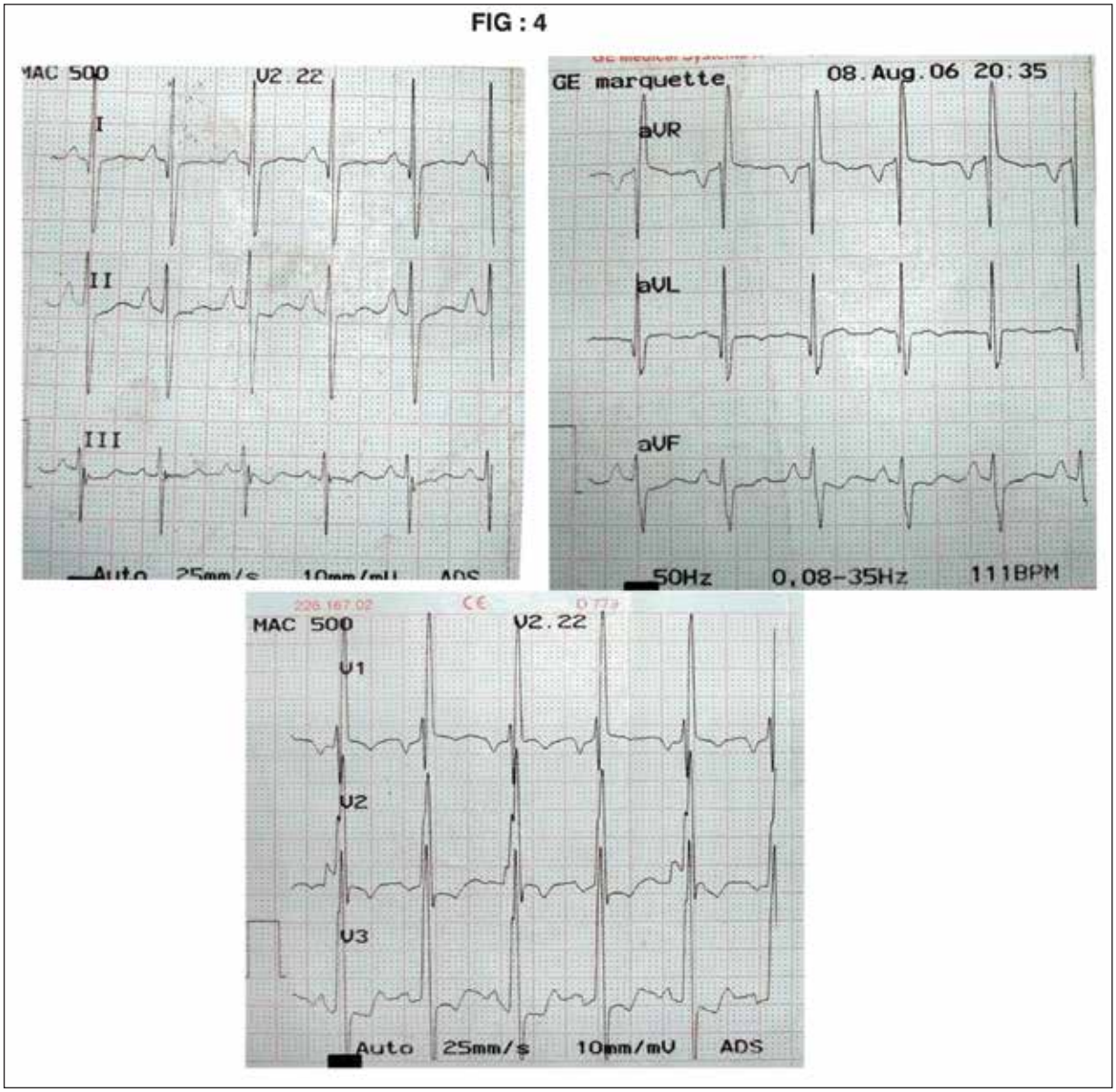
- AVSD will have

1. *Right atrial enlargement*
2. *Prolonged PR interval*
3. *Left Axis Deviation*
4. *RVH or BVH ± rSR'*

ATRIOVENTRICULAR SEPTAL DEFECT(AVSD)

AVSD is a CHD which ranges from partial - ostium primum ASD with cleft mitral valve to complete AVSD. There can be two other varieties in between, transitional and intermediate.

FIG : 4



Sinus rhythm is the rule. Right atrial, left atrial or biatrial enlargement is seen in 50% of AVSD. LAE is particularly found in severe left AV valve regurgitation.

PR interval is prolonged in 50%. QRS axis is invariably leftward. It can range from -30° to -120°. There is a counter clockwise loop (q in I, aVL). The axis is more negative with complete AVSD.

rSR', RSR', rR' can be found in 85%. 10% will have qR in V_1 or V_3R. qR in V_1 or V_3R could be found either in the presence of severe PAH or left ventricular (LV) hypoplasia.

The triad of ECG findings in AVSD are

- Prolonged PR interval
- Left Axis Deviation
- rSR ± LV hypertrophy

CASE STUDY 3

A 10 month old baby has an acyanotic CHD and has heart failure (HF). The baby is waiting for surgery. She has cardiomegaly, well split S_2 with loud P_2, pan systolic murmur and short mid diastolic murmur at apex.

- *Most likely the baby has VSD* (Fig. 5)

- The ECG has normal P wave and PR interval. Has right axis. Mid precordial leads show tall R and deep S waves. q is prominent in V_5-V_6 with deep q in II-III and aVF.

VSD will have

1. *Left atrial enlargement*
2. *Normal axis or RAD*
3. *Biventricular Hypertrophy*
4. *LV volume overload pattern*

VENTRICULAR SEPTAL DEFECT (VSD)

ECG reflects the size, shunt and pulmonary vascular resistance (PVR) in VSD.

A. Small VSD

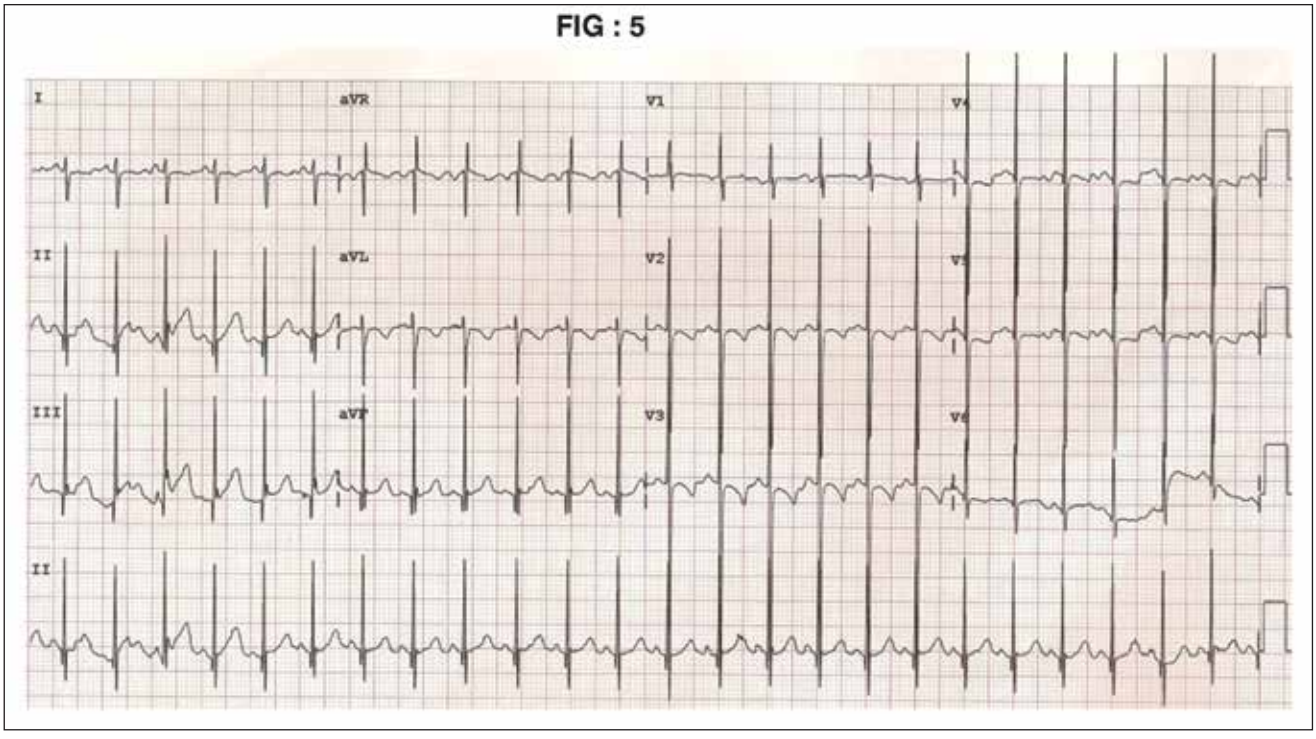
Usually normal. Occasional rSR in V_1 may be noted.

B. Moderate VSD

Normal sinus rhythm is the rule. LAE is not very common. Axis of QRS could be either normal (0° to 90°) or right axis. LV volume overload is present.

C. Large VSD

FIG : 5



LAE is found in 50%. QRS axis shifts to right. Biventricular hypertrophy is found. (Katz-Wachtel Phenomenon).

D. Eisenmenger VSD

Will have peaked P wave. QRS axis is almost always to the right. Monophasic R is found in V_1 indicating RVH.

Left axis deviation in VSD is found in

1. Inlet VSD
2. Multiple muscular VSDs.
3. VSD with septal aneurysm
4. VSD as part of AVSD.

VSD with LV volume overload can be found in

1. Large – Moderate VSD
2. Small VSD with significant Aortic Regurgitation (AR)

Clinically 'restrictive VSD' with *RVH alone* can be observed in (despite having a large VSD)

1. Pink TOF
2. VSD with PS
3. Moderate – severe PS
4. Double Chambered Right ventricle (DCRV)
5. VSD with severe PH

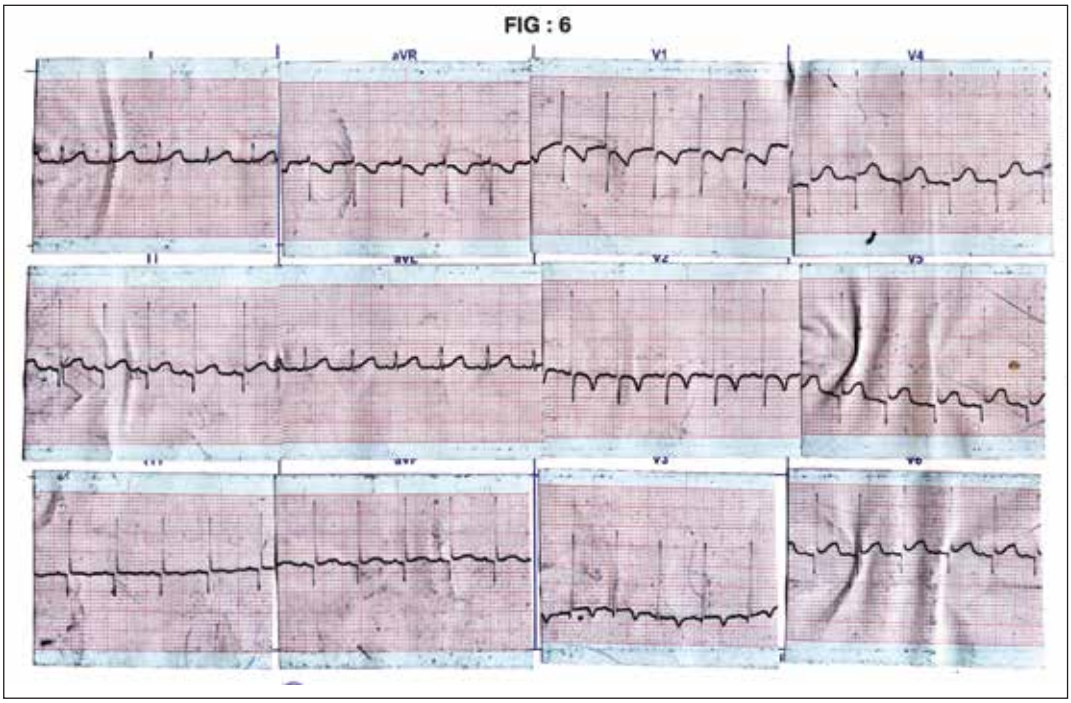
CASE STUDY 4

A 12 month old boy. Has mild CHF and has no cyanosis. Has strong femorals and a continuous murmur over left upper sternal border.

- *The most likely diagnosis is PDA.* (Fig. 6)
- ECG shows normal QRS axis. Has tall R in V_4 – V_6. Has also deep q in II III. aVF and V_4-V_6 (LV volume overload)
- PDA will have usually

1. *Normal QRS axis*
2. *LAE*
3. *LV volume over load.*

FIG : 6



PATIENT DUCTUS ARTERIOSUS (PDA)

1. Small PDA

ECG is normal

2. Moderate PDA

LAE is found in 20-50%. QRS axis is between + $0^{+}$to $+90^{o}$. LV volume over load can be found.

3. Large PDA

LAE is common 1^{o} AV block can occur in 10-20%. RAD suggests severe PAH. Biventricular hypertrophy could be found.

4. Eisenmenger PDA

There is RAE, RAD and RVH. Prominent R can be found remaining inV_5, V_6

CASE STUDY 5

A 13 year old boy with asymptomatic basal murmur. Has an ejection click over aortic area and apex. There is a long, 4/6 mid systolic murmur over aortic area.

- The most likely diagnosis is Aortic Stenosis (AS) (Fig. 7A. B)
- The ECG shows normal QRS axis, LAE (negative P in V_1), deep S in V_1 and tall R in V_5 / V_6. ST depression and T inversion is present in Lateral leads indicating LVH with strain.
- Severe AS will have

1. *Normal QRS axis*
2. *LVH ± Strain*
3. *Possible LAE*

AORTIC STENOSIS (AS)

Generally clinical severity in AS is reflected in ECG. However 20% of severe AS in children can have normal ECG.

1. Infant

P wave is normal. QRS axis can be normal or RAD. RV dominance is the rule below 1 month. Older infants will have LVH in 75% of severe AS.

FIG :7A

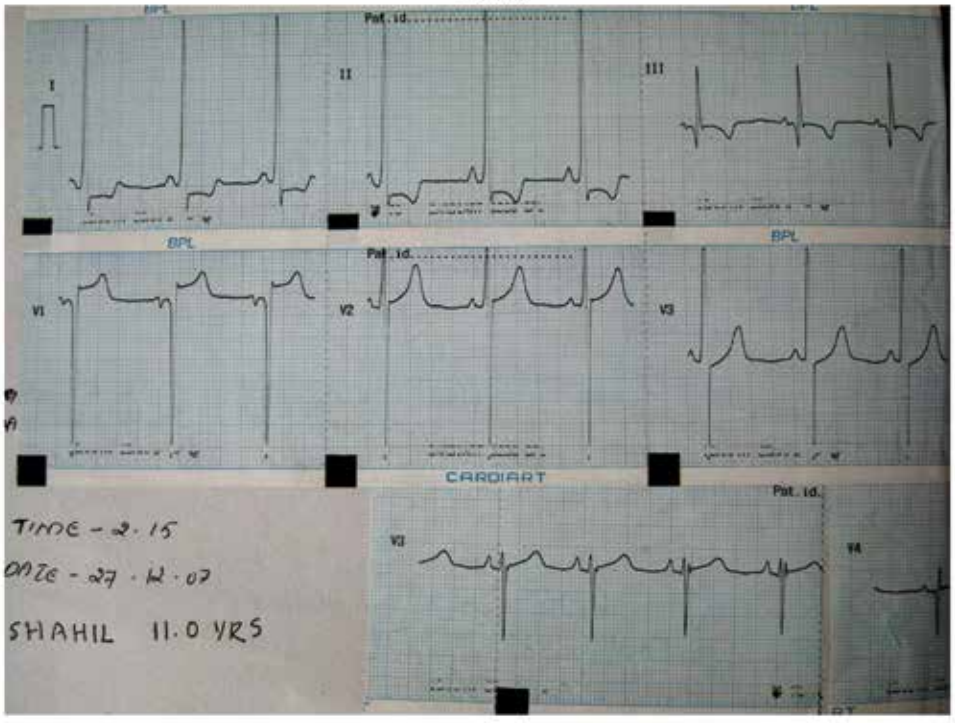
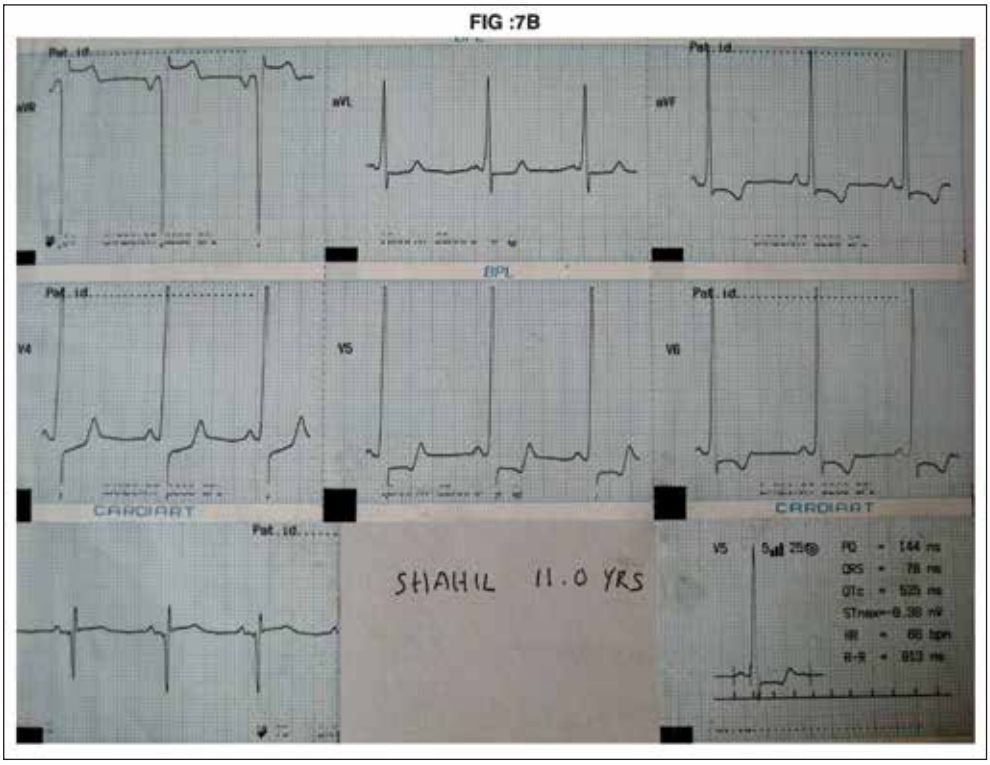


FIG :7B



LAE, if found in infants could be due to associated PDA or MR.

RVH in AS
- Below 1 month
- Supravalvar AS with pulmonary Artery Branch Stenosis (PABS)

2. Childhood

QRS axis is between $+0^{+}$ to $+ 90^{o}$. LVH is found in 40% of moderate AS and 80% of severe AS.

LVH with 'strain' occurs as
- Tall R in II. III aVF. V_5-V_6
- No significant Q in lateral leads
- ST depression and T inversion in V_5-V_6

LVH in children can occur in
1. Aortic stenosis
2. Hypertrophic cardiomyopathy
3. Coarctation of Aorta
4. Systemic hypertension

It can also occur in Pompe disease and Endocardial Fibro Elastosis (EFE)

CASE STUDY 6

A 6 year old boy has an asymptomatic basal murmur with ejection click. Both click and murmur are best heard at pulmonary area.

- *The most likely diagnosis is valvar PS.* (Fig. 8)

The ECG shows RAE, RAD, Monophasic R in V_1 and less of LV forces in V_5 / V_6

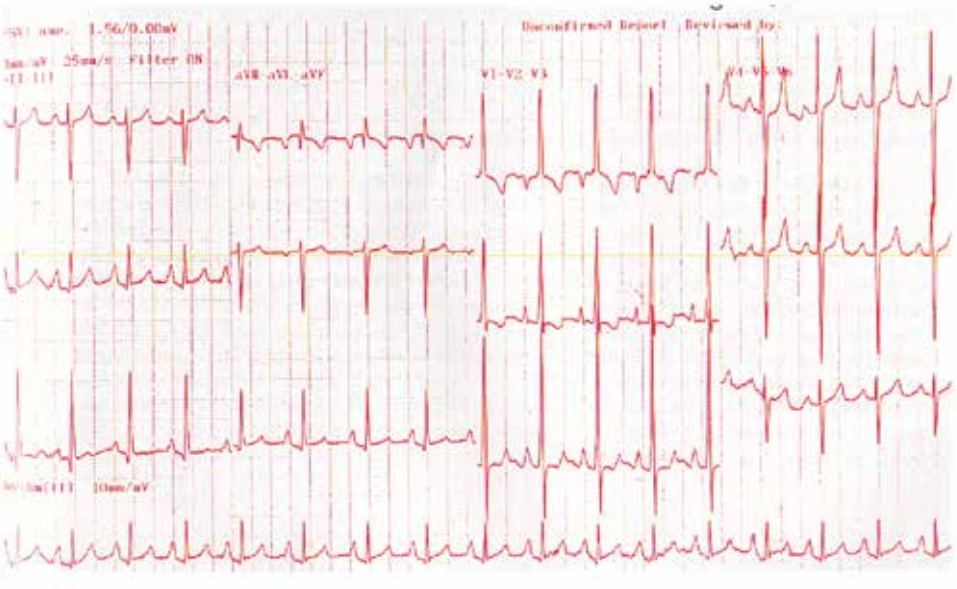
Severe valvar PS will have
1. *Right atrial enlargement*
2. *RAD*
3. *RVH*
4. *RV Strain* $\pm$

PULMONIC STENOSIS (PS)

ECG changes truly reflects the severity of PS unlike AS.

Abnormal ECG in PS	
Mild PS	50%
Moderate PS	90%
Severe PS	100%

FIG :8



1. Mild PS
   Can be normal. There could be RAD with tall R in V_1 or V_3R

2. Moderate PS
   Mostly abnormal. RAD is the rule. RVH by voltage criteria will be found.

3. Severe PS
   Always abnormal. RAE is fairly common. QRS axis is rightward. The QRS pattern could be – R, Rs and qR.

qR pattern in V_1 is found in 50% and indicates suprasystemic RV pressure. RVH with strain pattern can be found.

In children between 2 yrs and 20 yrs,
RVSP= 5 x R in mm in V_1 or V_3R
PS gradient = RVSP – 10 mmHg

Example

3 year old. Severe PS
R in V_1 = 22 mm
RVSP = 22 x 5 = 110 mmHg
PASP = 10 mm Hg
PS gradient = 110 – 10 = 100 mmHg

Right/left upper quadrant axis is found in PS.

- Noonan with PS
- Rubella with PABS

CASE STUDY 7

A 3 month old infant presents with poor femorals and CHF. There is an ejection click at apex and no significant murmur.

- *The likely diagnosis is severe Coarctation with bicuspid aortic valve.* (Figures 9A and 9B)
- The ECG in figure 9A shows RAD and RVH. There is no LVH

COARCTATION OF AORTA

Infant with Coarctation

ECG can be normal for age and may show RAE, RAD and RVH and not LVH. If LVH is found in a small infant with Coarctation, one must suspect associated AS, PDA or endocardialfibroelastosis (EFE).

Child with Coarctation

ECG will reflect long standing Coarctation and will show LVH (Figure 9B). LAD can also occur. Deep q in V_4-V_6 may indicate presence of AR due to bicuspid aortic valve. RVH in childhood Coarctation will indicate PAH and additional CHD like VSD or AS

FIG :9A

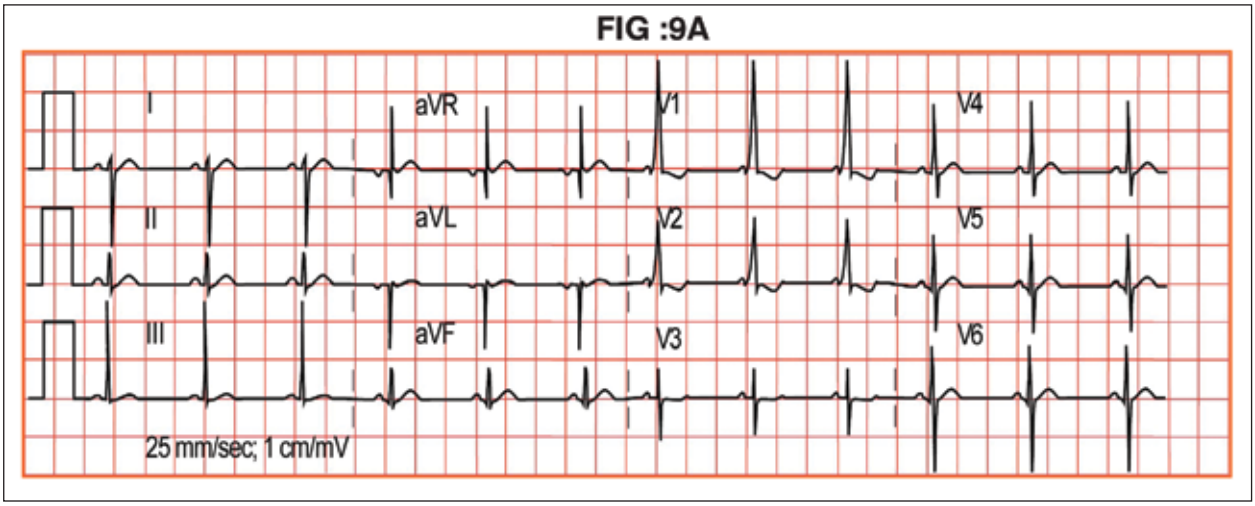
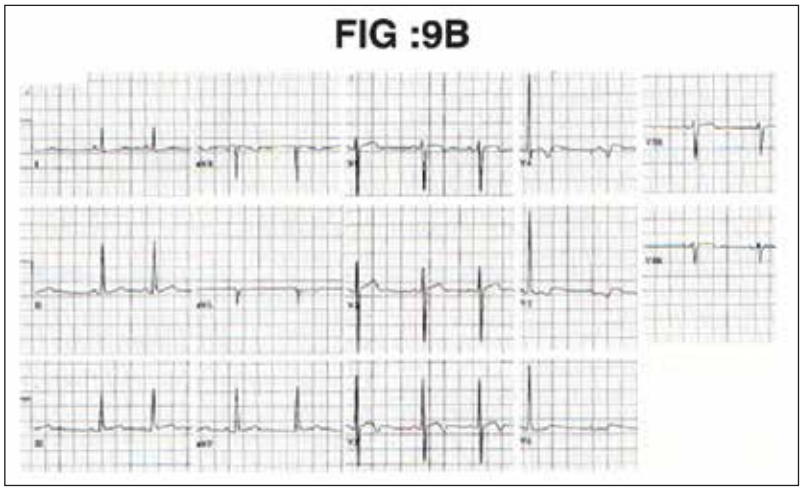


FIG :9B



CASE STUDY – 8

A 3 month old baby presents as dilated cardiomyopathy with significant LV dysfunction and grade 2/6 apical murmur.

- *This could be also due to a remediable 'DCM' like ALCAPA.* (Fig 10A and 10B)

- The ECG shows

LAD. Deep q in l, aVL, V_5-V_6 and absence of q in II. III. aVF.

There is T inversion from V_2 - V_6.

ALCAPA (Anomalous origin of Left Coronary Artery from Pulmonary Artery)

- ECG demonstrates.

1. q in I, aVL and V_4-V_6 leads.
2. Tall R in V_4-V_6
3. Left axis deviation. Axis can be normal.
4. Absence of q in II. III. aVF
5. It can also present with ST elevation in precordial leads. (Figure 10B)

Myocardial Infarction Pattern in ECG

Causes:Infants and Children

1. ALCAPA
2. Coronary AV Fistula
3. Viral Myocarditis
4. Kawasaki Disease
5. SLE
6. RSOV

FIG :10A

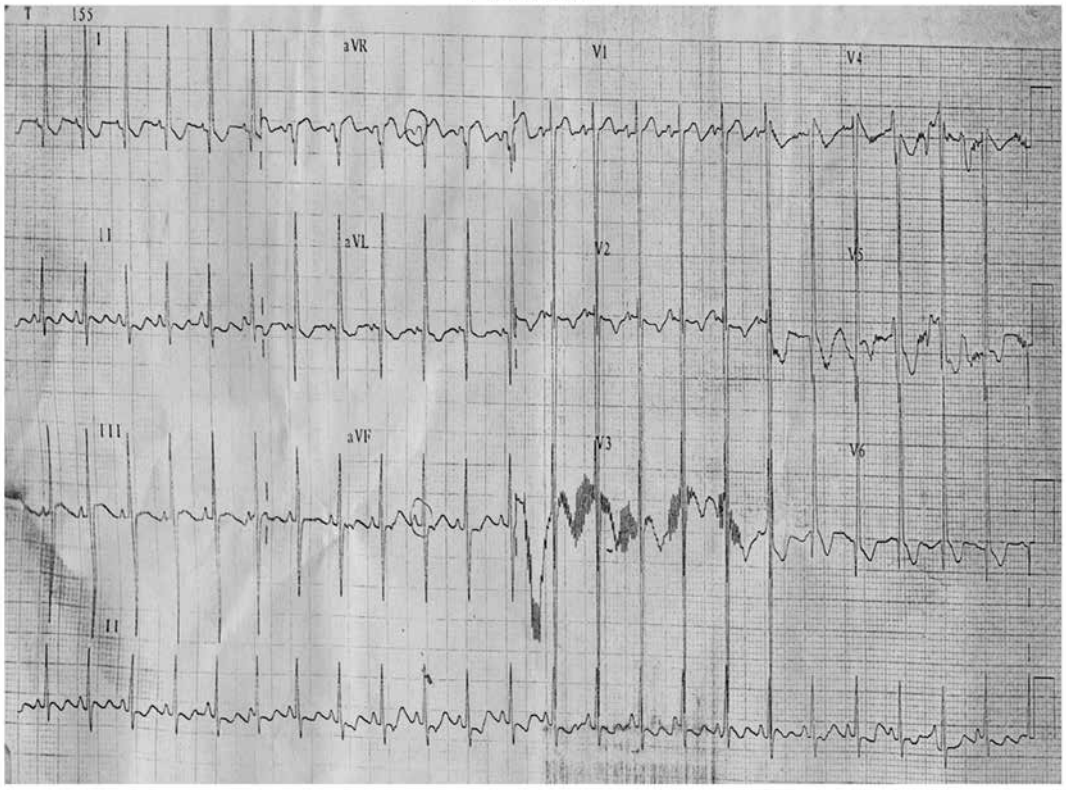
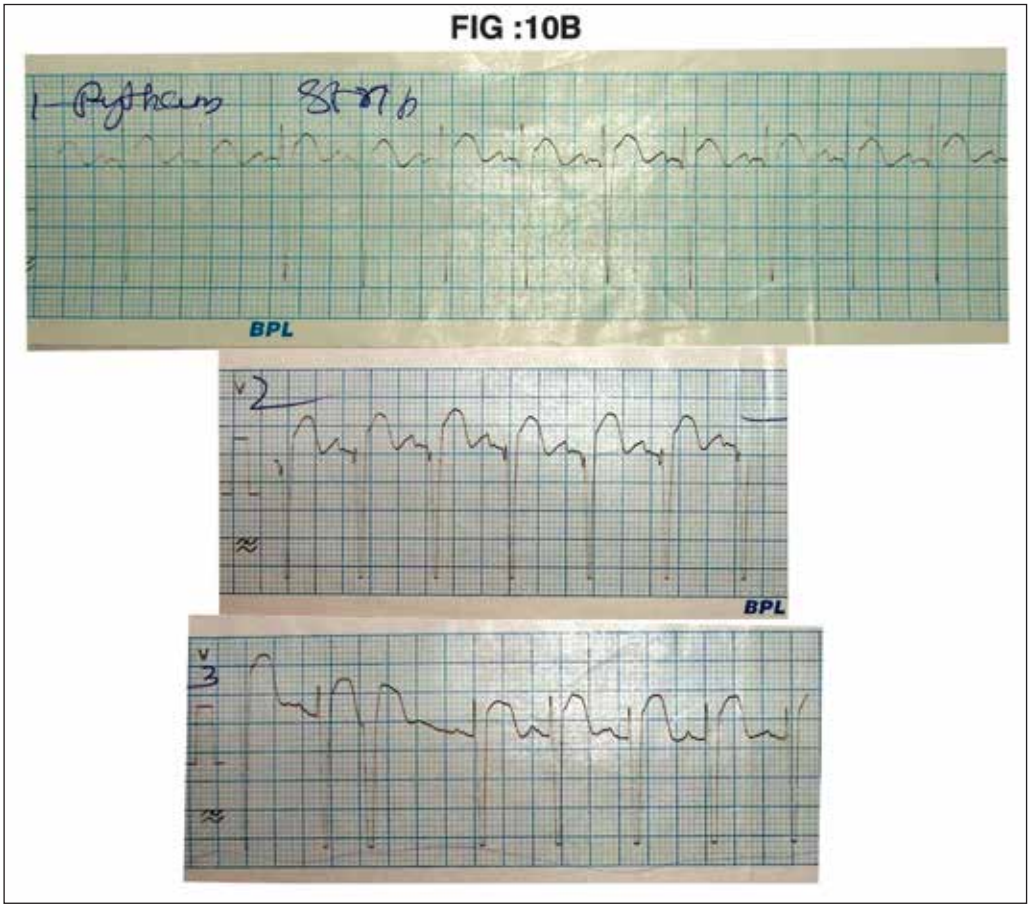


FIG :10B



CASE STUDY 9

A 10 month old baby has mild desaturation (Sat: 86%) and has a single S_2 with a grade 3/6 midsystolic murmur at midsternal border.

- *The possible diagnosis is ToF*
  (Figure 11)

- The ECG shows RAD, monophasic R in V_1 and early transition (in V_2)

TETRALOGY OF FALLOT

ECG changes reflect the hemodynamics.

Child will be in sinus rhythm. P wave can be peaked but not tall usually.

QRS axis is RAD. (+90° to + 150°). LAD in ToF could be due to AVSD with PS. There is RVH as evidenced by tall R in V_1 or V_3R, Upright T in V_1 / V_3R. The early transition in V_2 (r/S in V_2) is quite characteristic.

In pink TOF, q can be normally present in V_5-V_6 and there will be tall R in those leads. Rarely RV forces may be poor, which could be due to associated tricuspid atresia or straddling tricuspid valve.

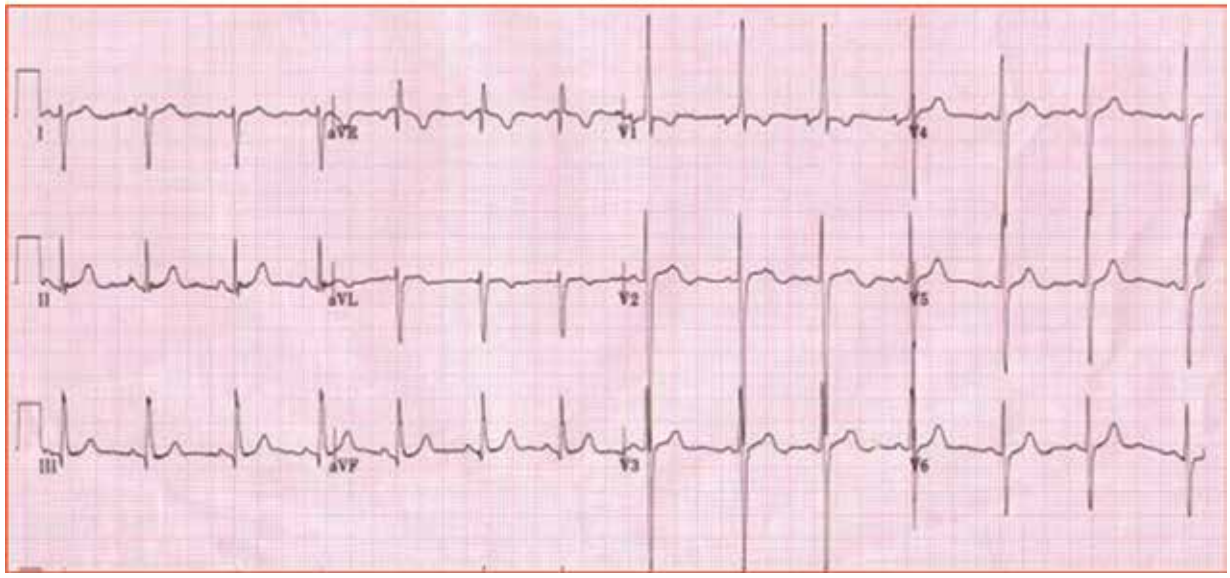
The classic 'tetrad' in TOF are
- *No upright atrial enlargement*
- *Right axis deviation*
- *RVH*
- *Early transition*

1. TOF like clinical picture with LAD
a. Tricuspid Atresia
b. AVSD. PS
c. L-TGA. VSD. PS
d. SV. PS

2. TOF like clinical picture with1° AV block
a. L-TGA VSD PS
b. AVSD. PS
c. DORV. VSD. PS

3.TOF like clinical picture with CHB
a. L-TGA. VSD. PS
b. AVSD. PS
c. L-TGA VSD PS

FIG. 11



CASE STUDY 10

A 6 days old baby has intense cyanosis and has a grade 1/6 murmur only. Saturation is 60%.

- *The most likely diagnosis is d-TGA*
  (Figure 12)

- The ECG shows

RAE, RAD and RVH (R/S – 15/4) with upright T in V_1-V_2.

TRANSPOSITION OF GREAT ARTERIES (TGA)

The normal RV dominance is seen. RVH then evolves with monophasic R in V_1.

T is upright in V_1-V_2. RAE develops within weeks.

In d-TGA Large VSD/PDA: There can be tall R in V_5-V_6 with q waves.

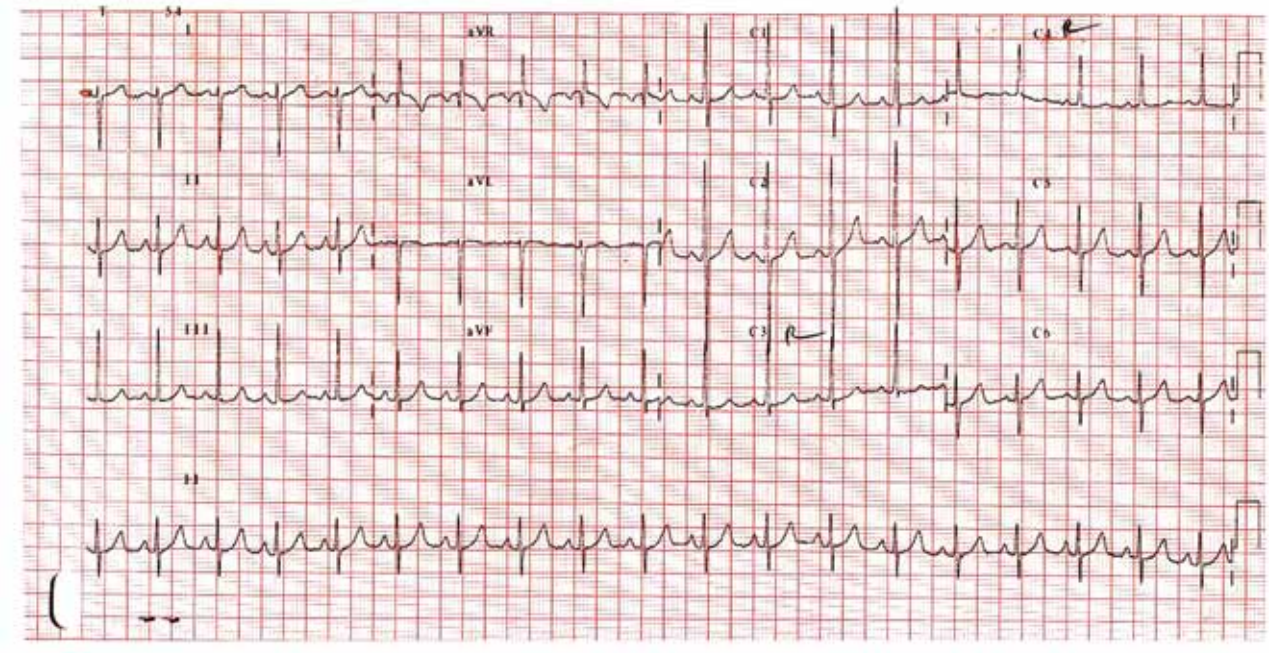
The triad findings in TGA are

- RAE
- RAD
- RVH

d-TGA with

1. Normal axis (+0° + 90°) - D-TGA with VSD / PDA
2. Biventricular hypertrophy - VSD / PDA
3. LAD - AV canal type of VSD
   Straddling Tricuspid valve
   Hypoplastic RV
4. LVH - RV Hypoplasia
   Straddling AV valve
5. Severe RVH - d-TGA. IVS
   d-TGA. VSD. PS
   d-TGA. PVOD

FIG. 12



CASE STUDY 11

A four month old baby has deep cyanosis with grade 3/6 murmur. There is RAE in chest X-ray.

- *The most likely diagnosis is Tricuspid Atresia (TA)* (Figure 13)

- The ECG shows RAE, LAD, poor RV forces and good LV forces.

TRICUSPID ATRESIA (TA)

ECG in TA are quite typical and very useful in diagnosis.

Children are in sinus rhythm. P wave is tall and peaked. PR interval could be prolonged in < 20%.

QRS axis is LAD (-0° to -90°)

TA and QRS axis

1. TA. NRGA : LAD in 90% Normal in 10%
2. TA. TGA : LAD in 50% Normal in 50%.

There is paucity of RV forces and good LV forces.

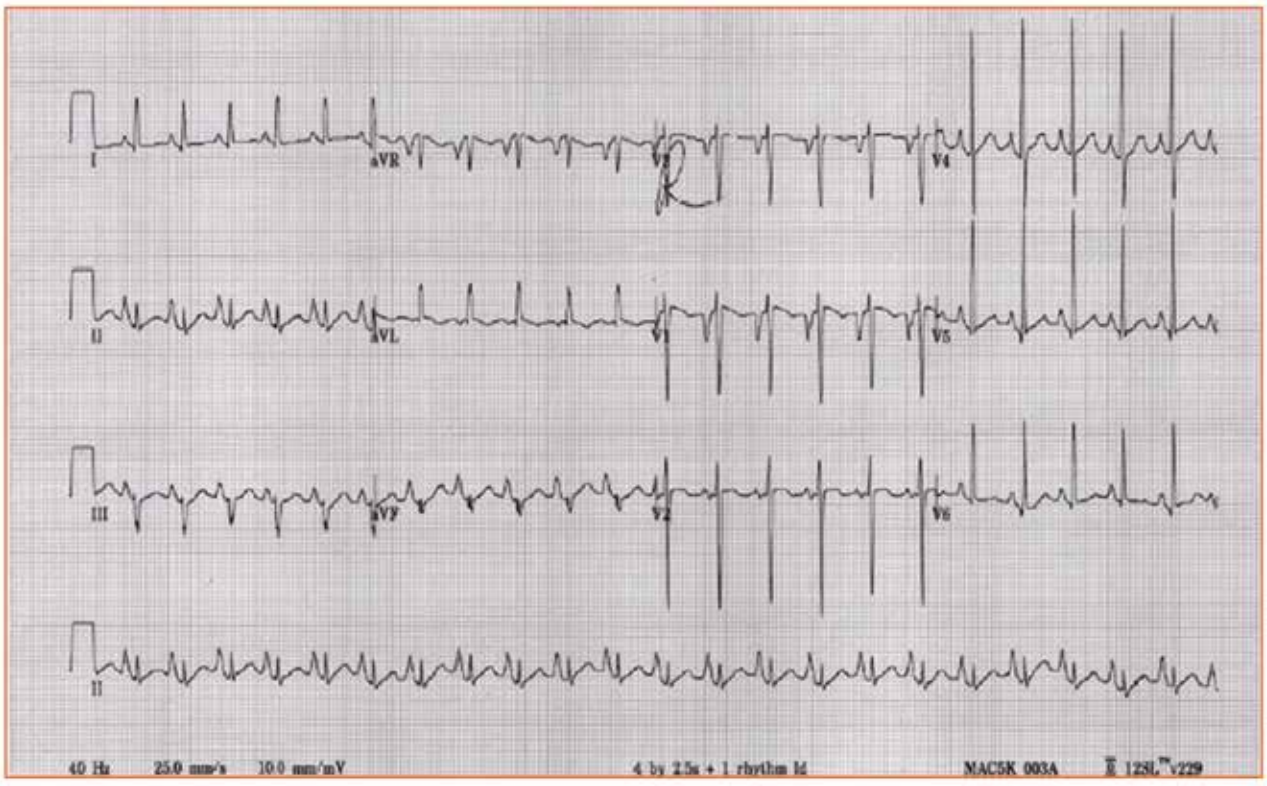
The Tetrad of features

1. RAE
2. LAD
3. Poor RV forces (r/s in V_1)
4. Good LV forces

CHD with Poor RV and good LV

1. Tricuspid Atresia
2. Pulmonary atresia with IVS
3. DILV (Single ventricle)

FIG. 13

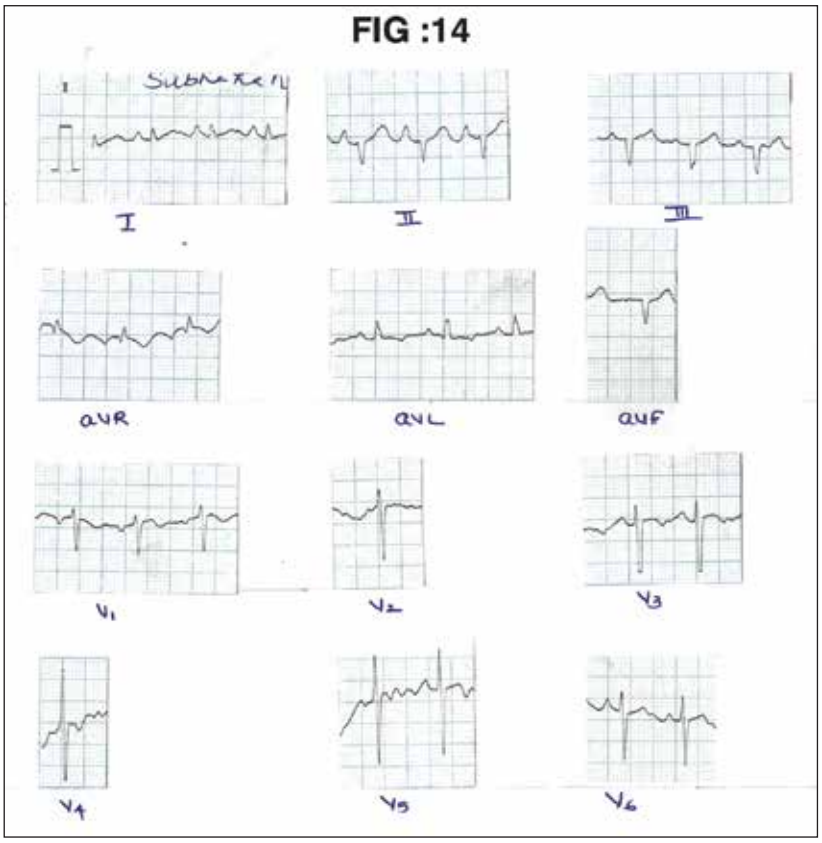


CASE STUDY 12

A 2 month old presents with CHF and tinge of cyanosis. Has both pansystolic and mid diastolic murmur with significant PAH.

- *One likely diagnosis could be DORV. VSD. PAH or Single Ventricle with PAH.*
  (Figure 14)

The ECG shows RAE, LAD and monotonously similar r/S in V_1-V_6.



SINGLE VENTRICLE

In single ventricle, ECG depends on diversity of anatomy and physiology. The standard features are

1. LAD
2. No q in V_5-V_6
3. qR in V_1 (less common)
4. r/S in V_1 – V_6

- **SV. DILV.** *Non inverted ventricle* Normal PR interval. RAE. LAD or normal LVH or stereotyped (r/S) QRS in V_1-V_6
- **SV. DILV.** *Inverted ventricle.* Prolonged PR interval. CHB. RAE RAD or normal. q in II. III – aVF
- **SV. DIRV.**
  RAD. RVH

CASE STUDY 13

A two month old baby presents with severe CHF and mild cyanosis. Has well split S_2 with loud P_2. Has multiple murmurs.

- *The likely possibility is TAPVC*
  (Figure 15)
- The ECG shows
  RAE
  RAD
  RVH with RV strain (T ↓ in V_1 – V_6)

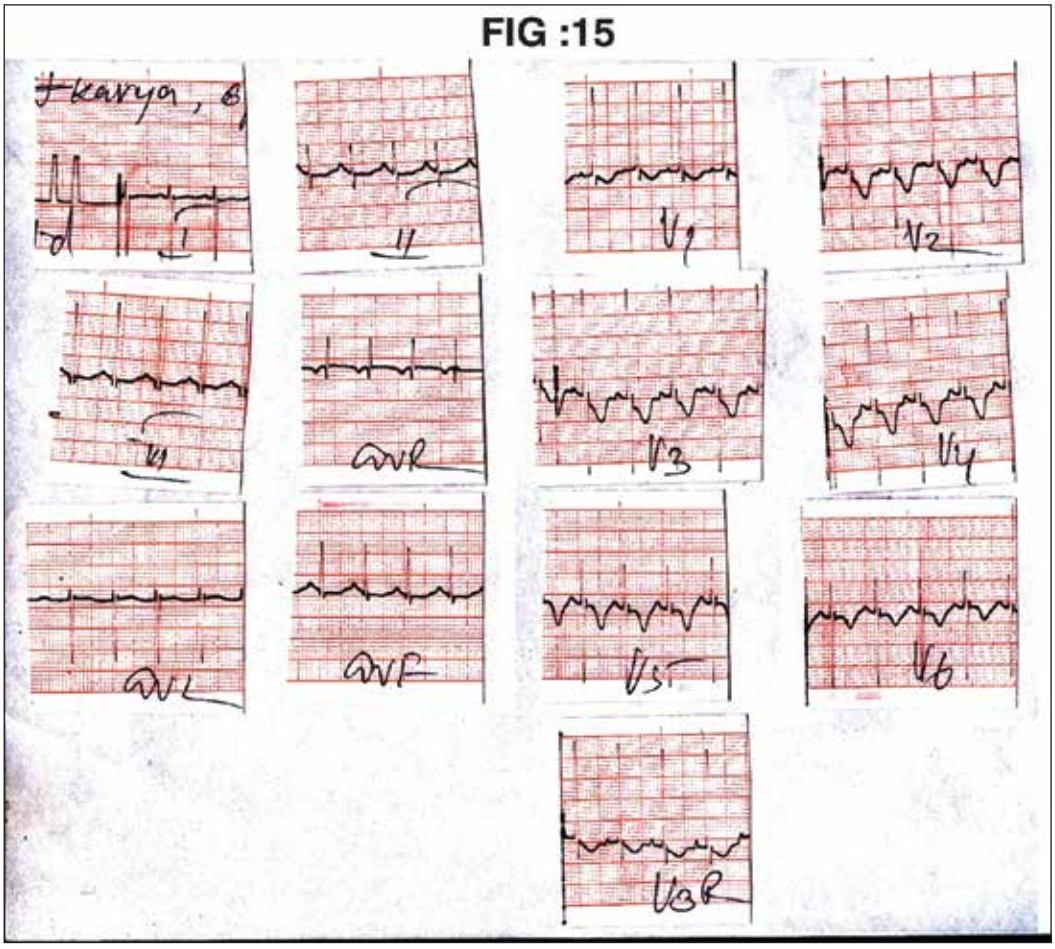
TAPVC

The TAPVC will have sinus rhythm, RAE, RAD and RVH. The QRS pattern can be rSR, rR, qR or monophasic R.

RVH with strain in new born can be due to

- PPHN
- Obstructed TAPVC
- Critical Coarctation with PAH

FIG :15



CASE STUDY 14

A four year old child has mild cyanosis. Has a loud and single S_2 and 3/6 murmur at left sternal border murmur.

One possibility is L-TGA. VSD. PS, because of a loud S_2 (?A_2)

The ECG (Figure 16A) shows LAD and q in V_4R Suggestive of L-TGA

L TGA (Congenitally corrected TGA)

P wave can be normal or inverted in I. II. III and aVF. Prolonged PR interval can be found. CHB can occur. QRS axis is leftward. There will be no q in V_5-V_6, and q in V_1, V_3R due to ventricular inversion. This q reversal is found in 75%. WPW can be found in L-TGA (left sided). Figure 16B.

The standard findings are

1. AV Block of varying degrees
2. LAD
3. q reversal in precordial leads.
4. WPW syndrome

qR in V_1 can be found with

I. Suprasystemic RVSP
- PPHN
- Severe valvar PS
- Eisenmenger ASD
- IPAH

II. RAE
- RV EMF
- Ebstein anomaly

III. Inverted ventricles
- L-TGA

FIG :16A

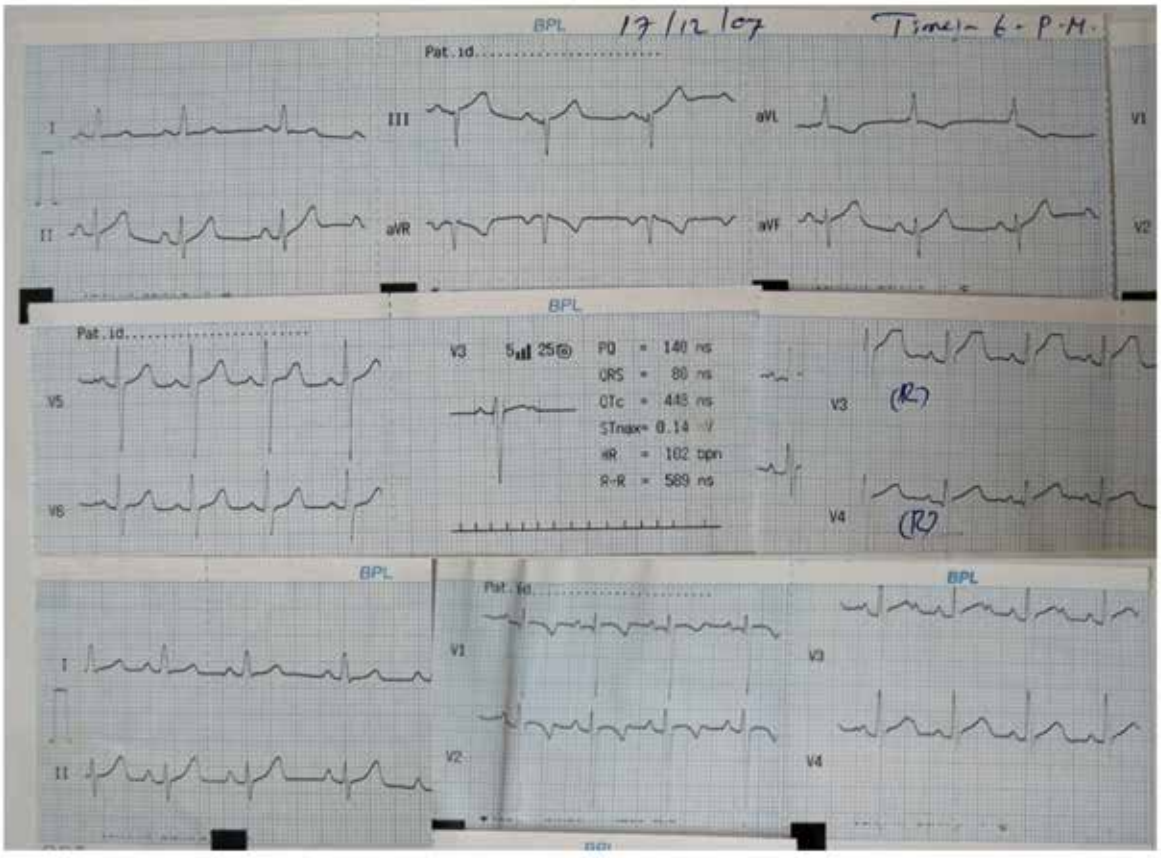
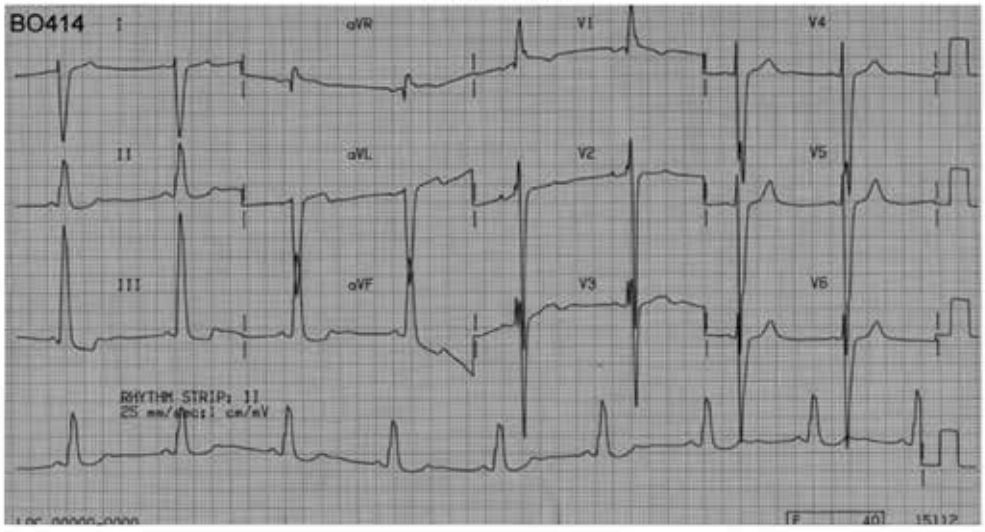


FIG :16B



CASE STUDY 15

A one month baby has both CHF and cyanosis. Has severe PAH also.

A possibility of DORV. VSD PAH is thought of
(Figure 17)

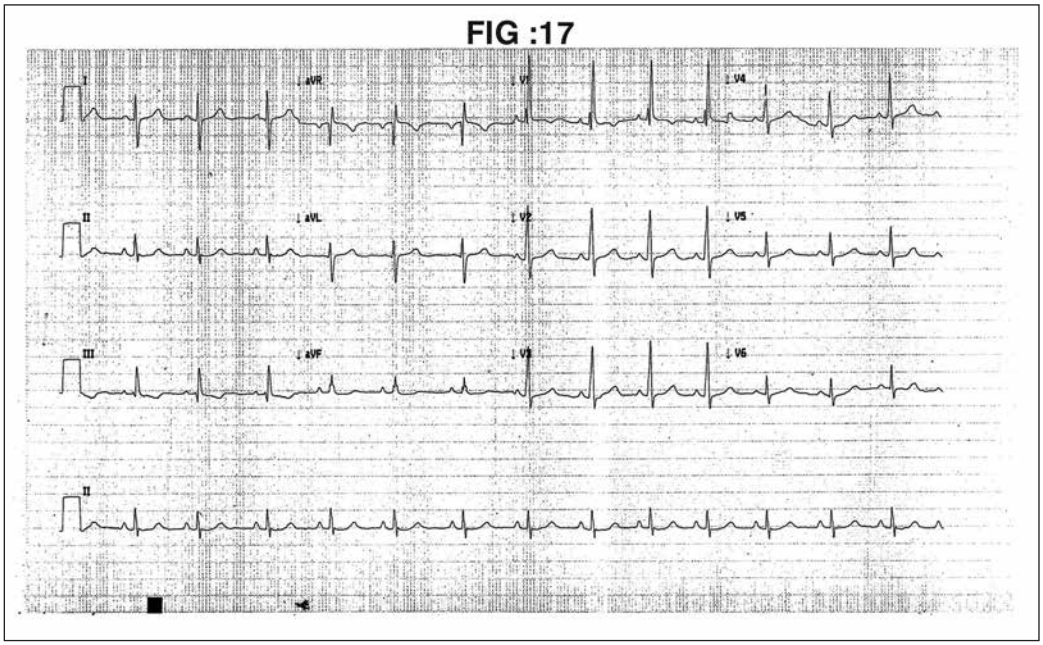
- The ECG shows RAE. RAD and Right ventricular hypertrophy.

DORV

The basic findings will be RAD and RVH as right ventricle is systemic T.he rest of findings will depend on pulmonary blood flow.

1. **DORV. VSD. PAH**
   - 1^0 AV block. LAD. CC loop and RVH
2. **DORV. VSD (Subpulmonic). PAH**
   - BVH
3. **DORV. VSD.zz PS**
   - RAE. RAD. RVH.
   - QRS axis may be more left ward.

FIG :17



CASE STUDY 16

A 9 year old boy with mild dyspnea on exertion. Has saturation of 90%. Has normal S_1, wide split S_2 and S_3. He has a pan systolic murmur also.

One must think of Ebstein anomaly
(Figure 18 A. B)

- The ECG shows RAE (very tall P), RAD, slightly prolonged PR and wide and slurred QRS with M pattern in V_1-V_2

EBSTEIN anomaly

The abnormalities in Ebstein anomaly could be

1. Himalayan P wave
2. 1^o AV block (50%)
3. RAD
4. RBBB pattern with splintered QRS
5. WPW (right sided) in 15%
6. Deep q in V_1 V_2
7. Various arrhythmias

Tall P Waves are found in

1. Ebstein
2. Tricuspid Atresia
3. Critical PS in new born
4. RV EMF

WPW and CHD

1. L-TGA (Left pathway)
2. Ebstein (Right pathway)
3. AVSD (Left pathway)

FIG. 18 A

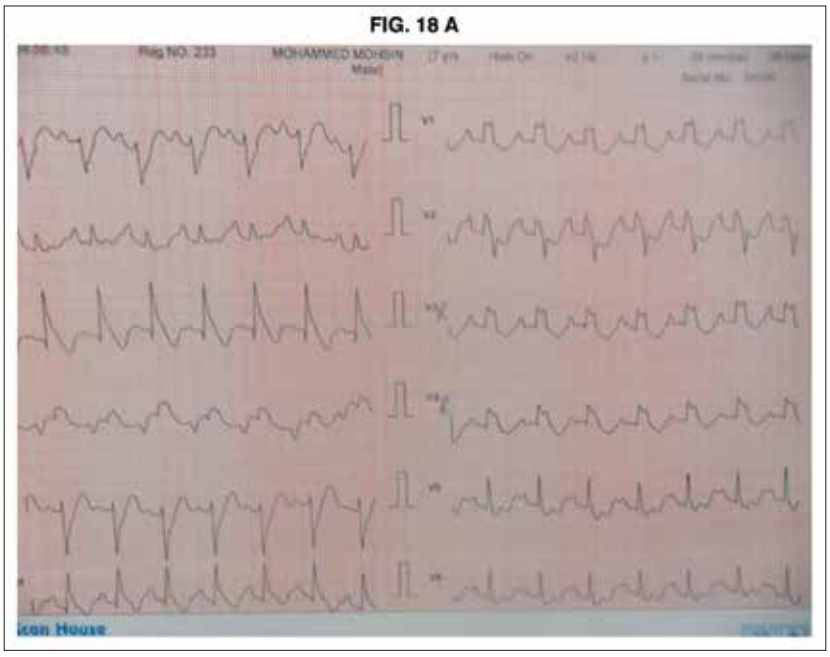
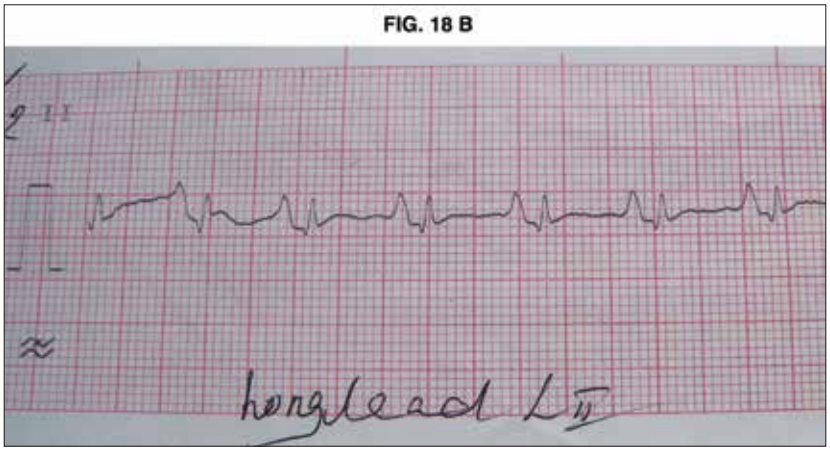


FIG. 18 B



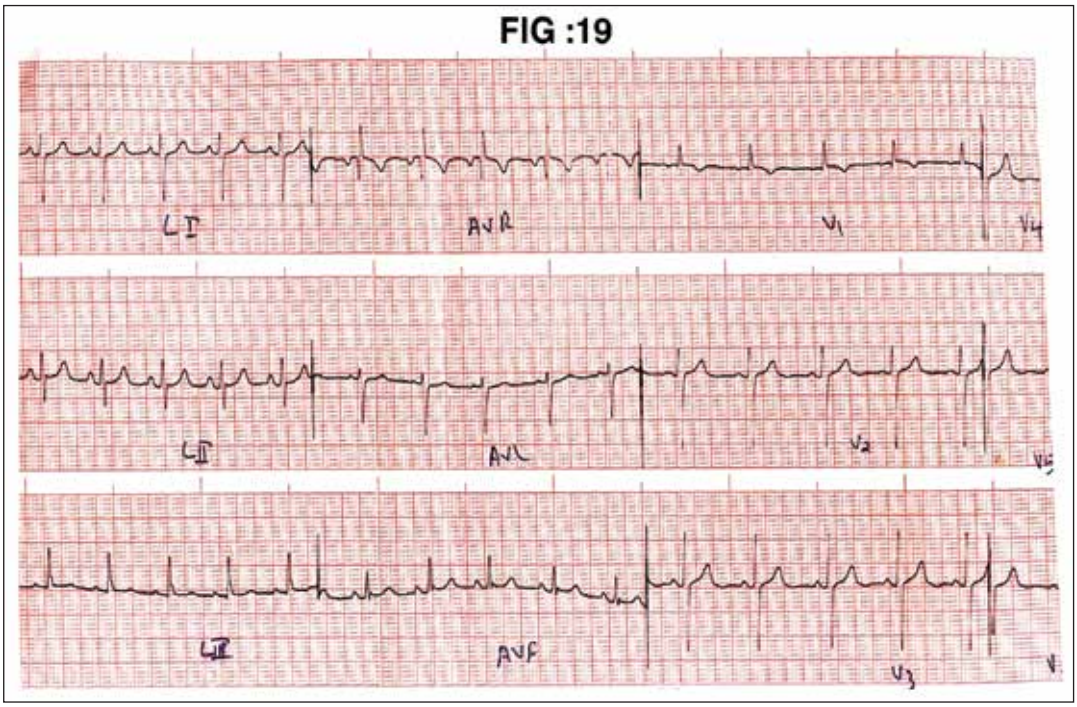
CASE STUDY 17

An 18 year old girl, who had a 'hole' in the heart in infancy and improved later. She was lost to follow up she has come back with dyspnea. Saturation is 90%.

- *Most likely diagnosis is Eisenmenger syndrome*
  Figure 19
- The ECG shows RAE, RAD and monophasic R in V_1 (RVH)

EISENMENGER SYNDROME

Eisenmenger syndrome will have characteristically, RAE, RAD and RVH. qR in V_1 can be found in ASD, Eisenmenger.



MALPOSITIONS

In cardiac Malpositions, ECG changes depend on

1. Cardiac location
2. Situs
3. Intra cardiac anomalies

In dextrocardia, additional V_4R, V_5 R and V_6 R are to be taken

ANALYTICAL APPROACH

(Fig 20 A and B)

I. P wave :

Analyze to assess situs

Situs solitus : P in I- aVF Positive
P in aVR Negative

Situs inversus : P in 1- aVF Negative
P in aVR Positive

2. QRS

In dextrocardia

V_6 R will face the right sided ventricle
V_3 will face the left sided ventricle

1. Dextrocardia. Situs inversus. AV concordance

LA	RA
LV	RV

V_5R, V_6R will be facing morphological LV and will have q in them.

2. Dextrocardia .Situs inversus .AV discordance

LA	RA
RV	LV

V_5 R and V_6R face RV and will have no q. V_3 or V_4 may have q.

3. Dextrocardia. Situs solitus.AV concordance

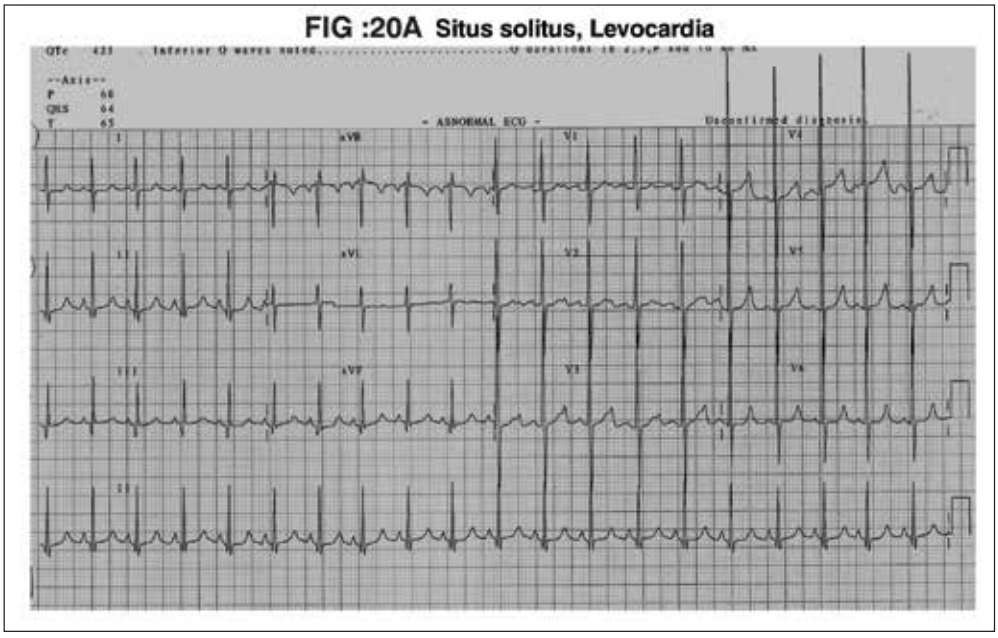
RA	LA
RV	LV

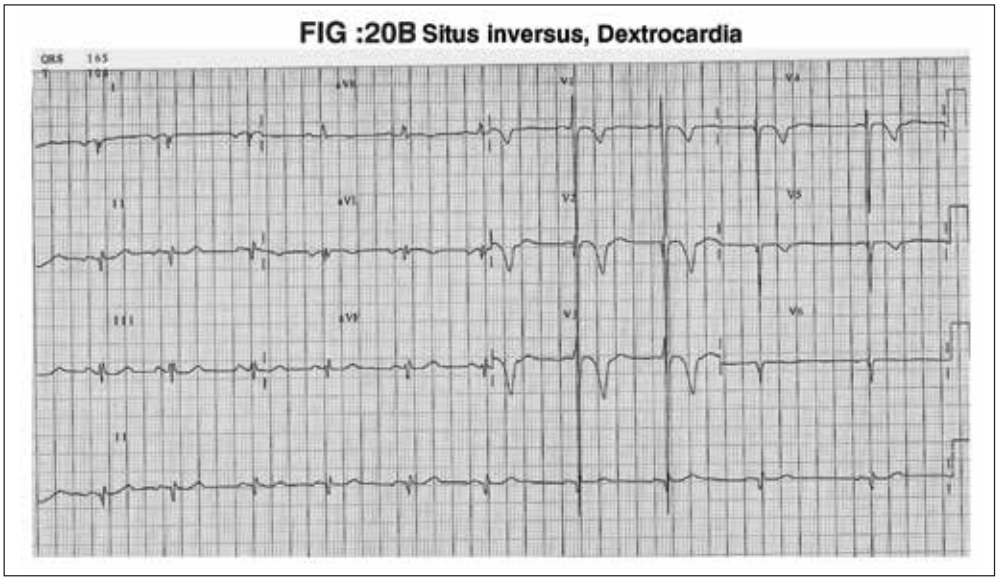
Right leads will face RV. $V_4 – V_6$ will face LV and can show q.

4. Dextrocardia Situs solitus. AV discordance

RA	LA
LV	RV

V_5R, V_6R will face LV and will have q.





Suggested Reading

1. Electrocardiography. A. Garson Jr in Science and Practice of Pediatric Cardiology Ed: A Garson Jr, JT Bricker, DJ Fisher, SR Neish Williams and Wilkins © 1998.

2. Demystifying the Pediatric ECG MZ Ahamed in Pediatric Cardiopulmonary Update 1999 Ed. MZ Ahmed, S Subramony, Iype Joseph A Pediatric Cardiology Division Publication © 1999.

3. Chou's Electrocardiography in Clinical Practice. Fifth Edition. Ed. B. Sarawicz and TK Knilans W.B. Sauders 2001.

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5. G.F.VanHare, J.N.A.Silva
The Normal Electrocardiogram in Moss and Adams' Heart Disease in Infants, Children and Adolescents, 9th Edition, 2016
Ed: H.D.Allen, R.E.Shaddy, D.P.Penny, T.F.Feltes, F.Celta
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J.K.Perloff, Saunders

Echo Approach to Congenital Heart Diseases

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INTRODUCTION

There are important differences in performing echocardiography for congenital heart disease (CHD) when compared to the standard manner in which it is done for adults with acquired heart disease. The following five principles of CHD echo illustrate the unique aspects:

1. Same systematic disciplined approach no matter what the congenital heart disease is (cyanotic versus acyanotic). *There is no unique approach for any condition. In oher words:* ***approach should not be disease specific.***

2. Anatomically Correct Display (figure 1): Understanding complex anatomy becomes a lot easier if structures are displayed in the same manner as they are situated in the body. This is often trivialized as an "upside-down" approach but it amounts to a lot more than showing structures "inverted" from traditional adult echo images.

3. A conscious attempt to stay oriented at all times with respect to the location of the transducer on the chest wall and direction of the pointer in the transducer. At all times it should be possible to clearly state the relationship of the structures being seen in the echo image to each other. (What is right and what is left? What is anterior and what is posterior?)

4. The movements with the transducer must be consciously made with awareness of the direction of the movement (superior movements generally display anterior structures, inferior movements show

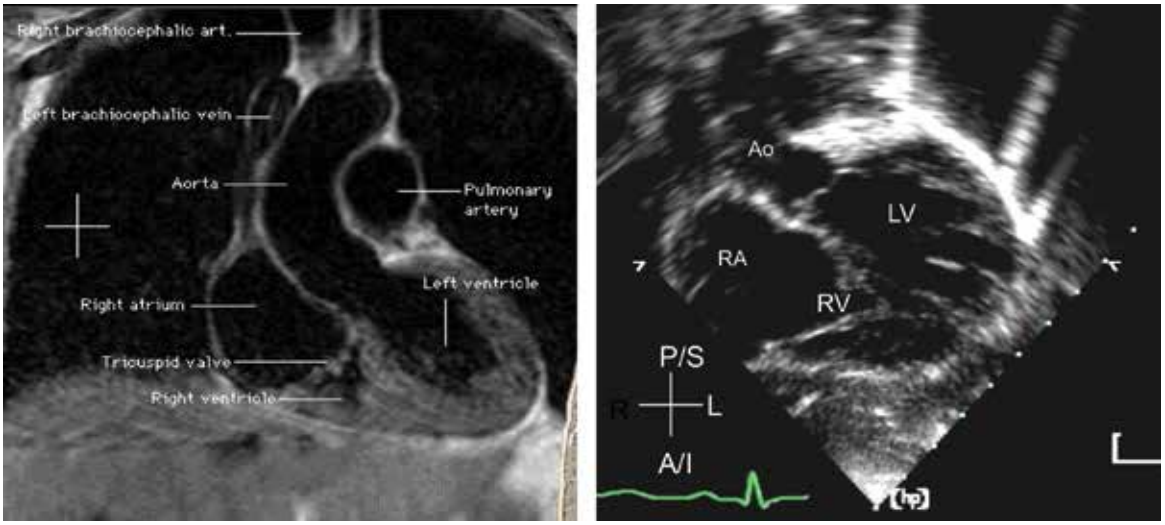

Figure 1: A comparison between a MRI scan in the coronal plane with an echocardiogram in the sub-xiphoid long-axis view. Anatomically correct display of structures allows a better orientation at all times while performing an echocardiogram

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posterior structures, right and leftward movement or tilt show respective structures); Images are obtained and recorded dynamically during the movements of the transducers (sweeps). This is different from adult acquired heart disease where information is maximized from a few representative planes.

5. A checklist (Table 1) needs to be completed for all patients with CHD. With practice this can be perfromed efficintly in a short time. Typically most reporting formats include this checklist.

Table 1: Checklist for congenital heart disease evaluation through systematic echocardiography

No.	Details
1	Cardiac position (dextro/levo/mesocardia)
2	Visceral and veno-atrial situs (solitus/inversus/ ambiguous)
3	Sequential chamber relationship: Normal, atrio-ventricular concordance/discordance, ventriculo-arterial concordance/discordance,
4	Systemic veins; inferior venacava: location, interruption etc. Superior venacava: Single, bilateral, drainage of left vanacava if present; roofed or unroofed coronary sinus, bridging innominate vein
5	Pulmonary veins: details of drainage
6	Atria: Details of the atrial anatomy, atrial enlargement
7	Atrial septum: defects, malaignment etc.
8	Atrioventricular valves: details of structure and function
9	Ventricles: Size, orientation, size, function
10	Ventricular septum Details of the atrial anatomy, atrial enlargement
11	Conotruncus or ventricular outflow tracts:
12	Semilunar valves: aortic and pulmonary valves
13	Ascending aorta and MPA
14	Branch pulmonary arteries
15	Aortic arch: Sidedness, narrowing etc.
16	Patent arterial duct
17	Coronary artery anatomy
18	A statement on the physiology of the defects

COMMON VIEWS FOR CHD EVALUATION

Some of the important differences beween echo approaches to adults with acquired heart disease are illustrated in the above listed principles. Additionally, for CHD, there much greater emphasis on the sub-xiphoid and the suprasternal views. Children tend to have excellent echo windows and these views allow acquisition of valuable information and images.

The transducer positions for the various views that are used for evaluation of CHD are shown in Figure 2. The precise transducer position may vary a little depending on variations in the age, the body habitus and position of the heart in the thorax. Because the first seven items in the checklist (table 1) are consistently seen in the sub-xiphoid view, it is often recommended that echocardiography for congenital heart disease should begin with the subxiphoid views. Information regarding the situs, position of the heart in the thorax (dextrocardia /levocardia/ mesocardia) is best seen in the subxiphoid view. This allows planning of the other views. In most infants and young children, a large amount of information can be obtained from the subxiphoid views. The apical and parasternal views supplement the information obtained from the subxiphoid views and provides additional information as well. Visualizing a structure from multiple views allows internal verifications. The suprasternal view is often reserved for the last part of the study since it is the least comfortable view and is more likely to wake up a sedated child than any other view.

After the initial sequence of evaluation has been completed it is not uncommon to return to some of the views if additional bits of information are needed. Modifications of the various views ("non-standard", "in-between" and oblique views) are often useful in further refinement of anatomic information. As outlined in the first section anatomically correct display is useful in staying oriented. For anatomically correct display the apex of the imaging sector is at the bottom of the screen in the subxiphoid and the apical views. For the remaining views the apex of the imaging sector is at the top of the screen.[1,2] For patients with dextrocardia attempts should be made to perform the same views keeping the transducer on the right side of the chest. The marker on the transducer should point in the same overall direction as for patients with levocardia. This enables consistency in image orientation and display (figure 2).

In every echocardiographic view and in each imaging plane, the examiner should slowly sweep the imaging sector across the heart and blood vessels back and forth

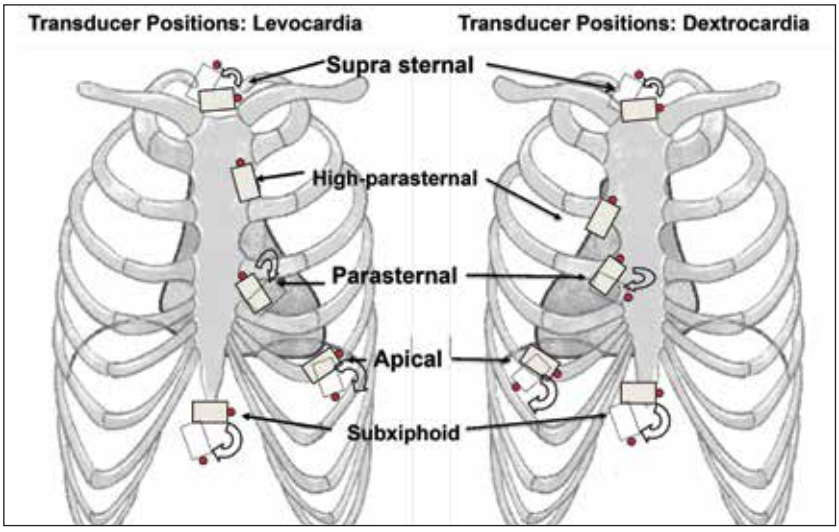

Figure 2: Transducer positions for obtaining various views for evaluation of suspected congenital heart disease in levocardia (left and Dextrocardia (right).

in a specific manner with conscious awareness of the direction of the movement without and with colour flow imaging. Color Doppler should be used only after the two dimensional anatomy is fully understood. Premature use of color can result in failure to register important anatomic details. A thorough understanding of the three dimensional spatial orientation of the cardiac chambers and the great vessels is a prerequisite for performing echocardiography for CHD. Pulsed and continuous wave Doppler should be applied whenever appropriate during scanning. Any unusual turbulence on color flow imaging should warrant careful interrogation by Doppler. The following sections will deal with how individual views are obtained and what structures are visualized in each of them in a normal heart. The sections are best understood if the accompanying illustrations are looked at simultaneously. This section will not discuss echocardiographic evaluation of individual congenital heart defects. The focus will be on core principles for accurate anatomic imaging. Specific emphasis will be on views that are unique to evaluation of congenital heart defects.

THE SUBXIPHOID VIEWS

In children excellent images of the heart and great vessels can often be obtained from the subxiphoid views.[3,4] The abdominal wall and liver provide an excellent acoustic window to the heart in young children. The short distance from the transducer to the proximal great vessels allows an overall view of the cardiac anatomy. It also demonstrates the relationship of the various structures with great clarity.

The Subxiphoid Long Axis or "Coronal" Sweep

Figure 3 and 4 show the transducer position and imaging planes for the subxiphoid long axis or coronal sweep. The transducer is often moved a little to the right to take advantage of the "liver window". Strictly speaking these sweeps starts in the axial plane and moves cranially towards the coronal plane. The subxiphoid long axis sweep begins with the transducer positioned caudal to the xiphisternum and pointing directly posteriorly. This demonstrates the relationship

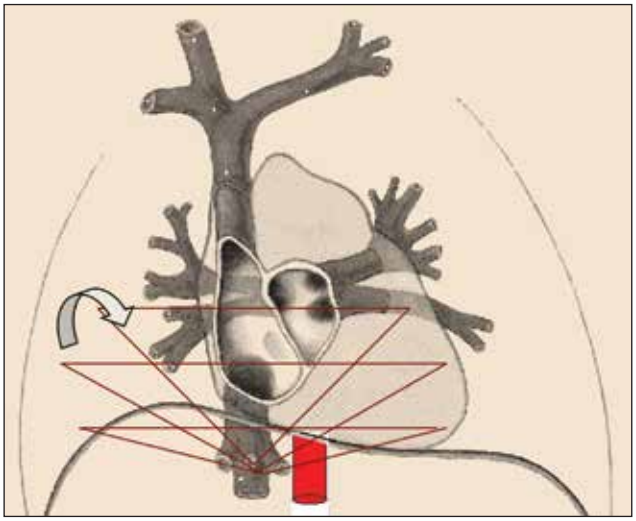

Figure 3: Transducer position and imaging planes for the subx-iphoid long axis (coronal) views: posterior cuts for identifying situs and veno-atrial connections.The first structures to be seen in the sub-xiphoid long axis sweep are the IVC and the hepatic veins along with the aorta. The side-side relationship of the IVC and the abdom-inal aorta is first identified and the IVC/hepatic veins are traced to the heart

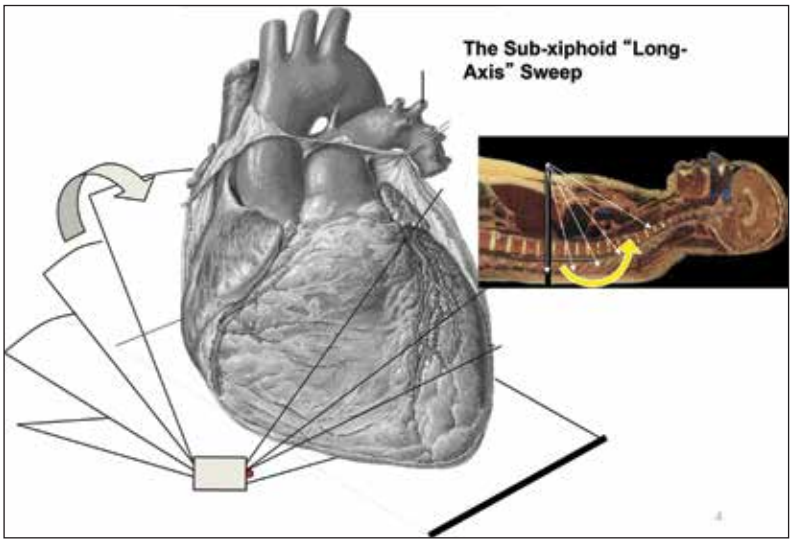

Figure 4: Transducer position and imaging planes for the subxiphoid long axis views: anterio-superior cuts. The sub-xiphoid long axis sweep starts in the axial plane in the abdomen and moves superiorly in the direction of the coronal plane

of the inferior venacava and the hepatic veins with the abdominal aorta (figure 3). The transducer is then moved in a cranial direction (figure 4). Figure 5 demonstrates structures that are seen in each of the planes as the transducer is moved cranially. The first plane (5A) demonstrates the relationship of the inferior venacava and the aorta in the abdomen. The transducer is then angulated cranially to show the posteriorly situated structures. First the relation of the hepatic veins with the IVC is demonstrated (5B). Further cranial angulation shows the coronary sinus and the posterior aspect of the atrial septum and the right upper pulmonary vein (5C). In the next plane (5D) the left atrium and the left ventricle are shown.

On superior angulation (Figure 6), all the four chambers can be visualized together with atrial septum (including the fossa ovalis region and the posterior (inlet) ventricular septum (6A). The planes in figures 6B

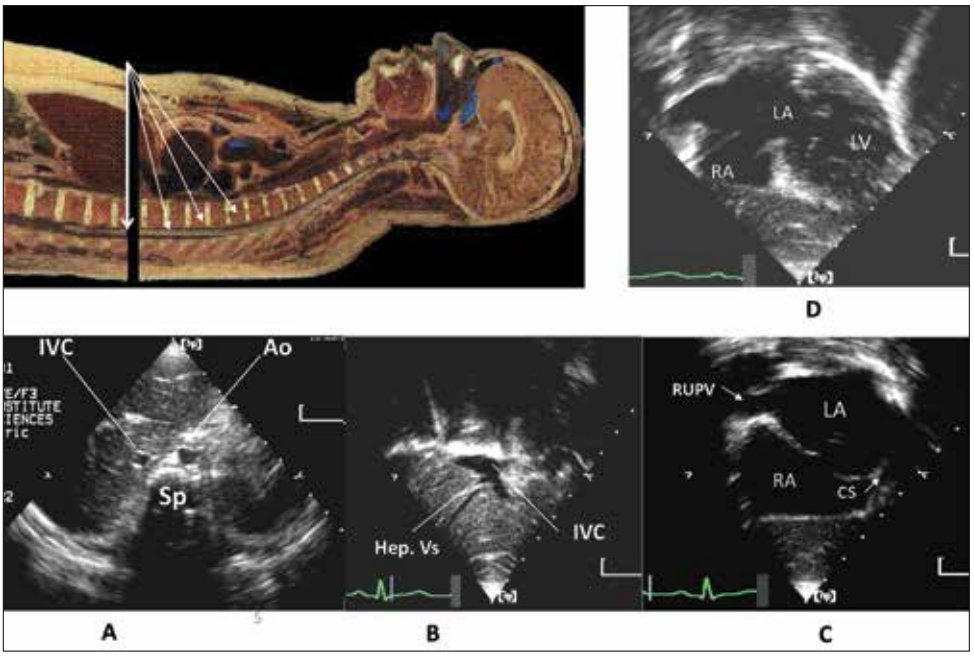

Figure 5: Sequential images obtained during the subxiphoid long axis sweep.
A. Posterior cuts for demonstration of situs. This view shows the relationship of the inferior venacava (IVC) to the aorta (Ao) and the spine (Sp). B: Demonstrating veno-atrial connections: Hepatic veins(HVs), inferior venacava (IVC) are shown to enter the right atrium (RA). C. Posterior cut of the atrium showing Right upper pulmonary vein (RUPV), Right Atrium (RA), Coronary Sinus (CS) D: Subxiphoid long axis view showing the left atrium (LA) and the left ventricle (LV).

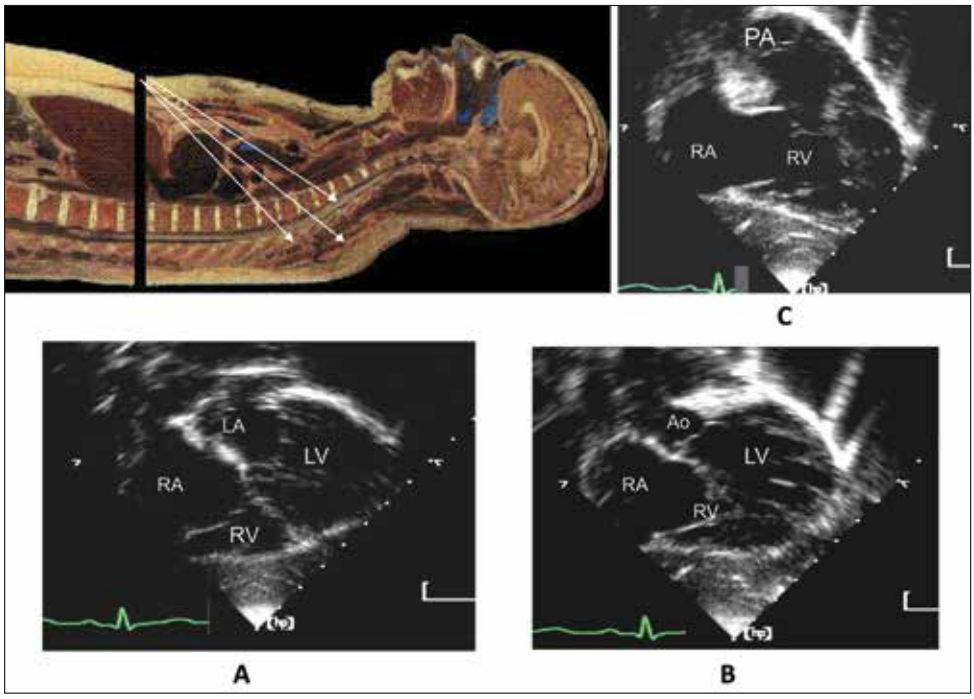

Figure 6: Anterio-superior cuts in the subxiphoid long axis view
A: The sub-xiphoid 4 chamber view showing the 4 chambers; right atrium (RA), right ventricle (RV), left atrium (LA, left ventricle (LV). B. Superior angulation from the 4 chamber plane shows the origin of the aorta (AO) from the left ventricle (LV). C. on further cranial angulation, the anterior-most structures are revealed. This plane demonstrates right ventricle (RV) and the pulmonary artery (PA)

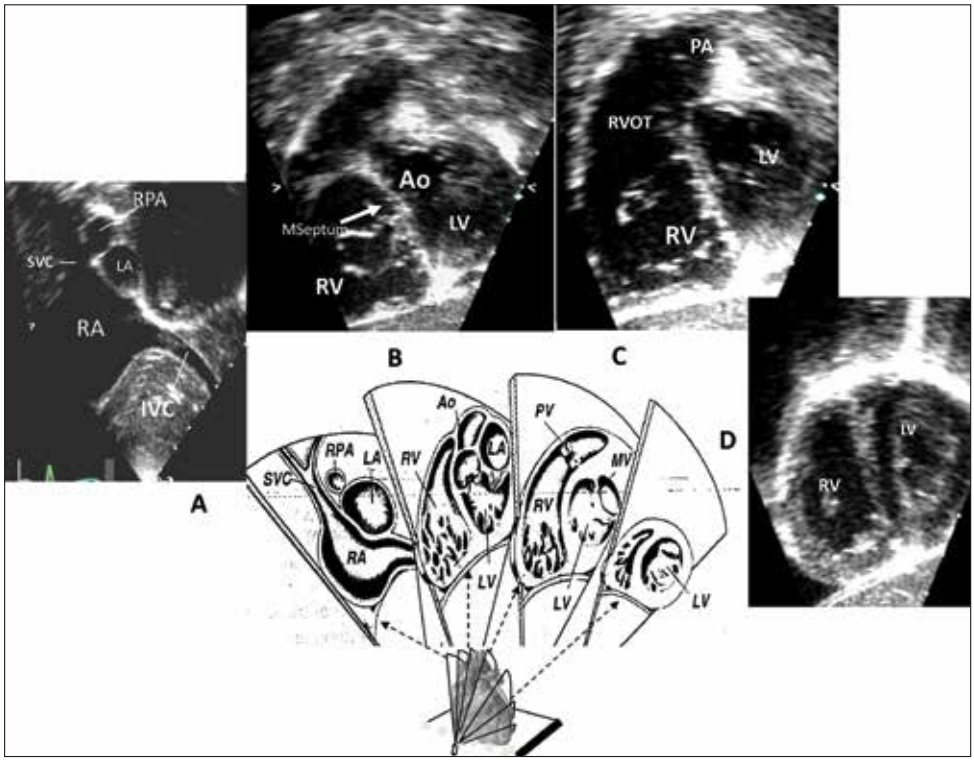

Figure 7: Transducer position and imaging planes for the subxiphoid short axis (sagital) views. The sweep should move from right to left. The rightward cut is the bi-caval view. Both the vencava (SVC and IVC) are seen. The right pulmonary artery (RPA) is seen behind he SVC. The left atrium (LA) is seen just below the RPA. B. This is at the level of the atrioventricular junction and profiles the membranous septum (MSeptum) just below the aorta (Ao); the inflows of the right ventricle (RV) and left ventricle (LV) are also profiled. C. The next frame is obtained by sweeping to the left and this profiles the right ventricular outflow tract (RVOT) and the pulmonary artery (PA). D. This cut is obtained at the level of the mid cavity of the left ventricles.

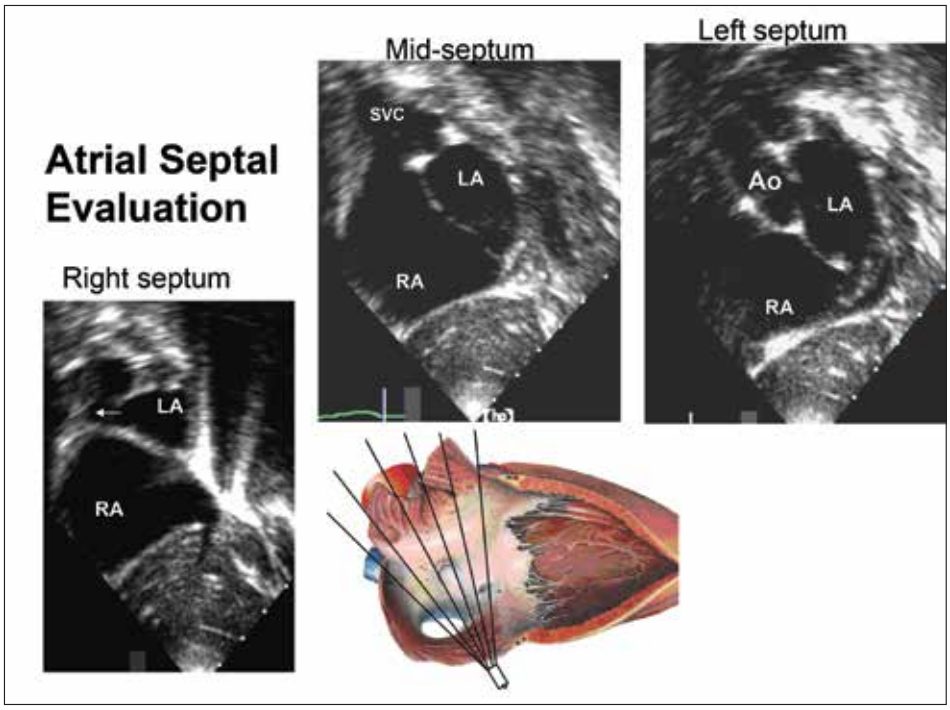

Figure 8: Sequential images obtained during the subxiphoid short axis sweep of the atrial septum. A. The rightward cut profiles the right upper pulmonary vein (White arrow) and bothe the atria as well as the atrial septum. B. This frame is obtained by sweeping slightly to the left of frame 'A'. The superior venacava (SVC) is to the left of the right pulmonary vein. C. This is the leftward aspect fo the atrial septum. The aorta (Ao) is also profiled here.

and 6C are obtained with the transducer being angulated further cranially. This allows the anteriorly located great arteries to be visualized. In a normal heart, the aorta is first visualized (figure 6B) followed by the pulmonary valve and the proximal pulmonary artery (figure 6C).

The Subxiphoid Short Axis or "Sagittal" Sweep

For the subxiphoid short axis views the transducer should be rotated by 90 degrees from the long axis view in a clockwise direction so that the marker points downwards (figure 1 and 7). The sweep should begin from the right and move gradually towards the left until the apex of the heart is imaged (figure 7). The structures visualized in the right-sided cuts include the inter-atrial septum, the right upper and lower pulmonary veins, the coronary sinus, the inferior venacava, and the superior venacava. All types of atrial septal defects can be clearly visualized in the subxiphoid views (figure 8). For visualization of the atrial septum the transducer needs to be rotated counterclockwise to a position that is in between the long axis and short axis view. Defects in the fossa ovalis region of the atrial septum are often best seen in this view. This view demonstrates the entry of the right upper pulmonary vein, a structure that seldom clearly visualized in any other view. Sinus venosus type of defects are also often best visualized in the subxiphoid short axis views.[5,6]

As the transducer is moved towards the left, the aortic valve along with the proximal ascending aorta, the mitral and the tricuspid valves can be seen (7B). By rotating the transducer a few degrees further to the left the entire right ventricular outflow tract can be seen including the pulmonary valve and the main pulmonary artery (7C). Defects in the outlet ventricular septum (the doubly committed or subpulmonic ventricular septal defects) are often best visualized in this view. Low infundibular obstructions resulting from hypertrophy of the septal and parietal bands of the right ventricle (the double chamber right ventricle) are best seen in this view. For patients with cono-truncal anomalies (double outlet right ventricle, transposition of great arteries, tetralogy of Fallot) the sub-xiphoid short view offers an excellent view of the conal (outlet) septum and demonstrates its relationship with the surrounding structures.[7] Further leftward rotation shows a cross-sectional view of both the ventricles (7D). Normally, the LV appears circular and the RV is like a crescent. Further leftward rotation from this point profiles the apical septum together with the moderator band in the right ventricle. The sub-xiphoid short-axis sweep is an excellent method for screening for muscular defects in the various parts of the ventricular septum (figure 9). Defects in the apical septum are often profiled in this view.[8]

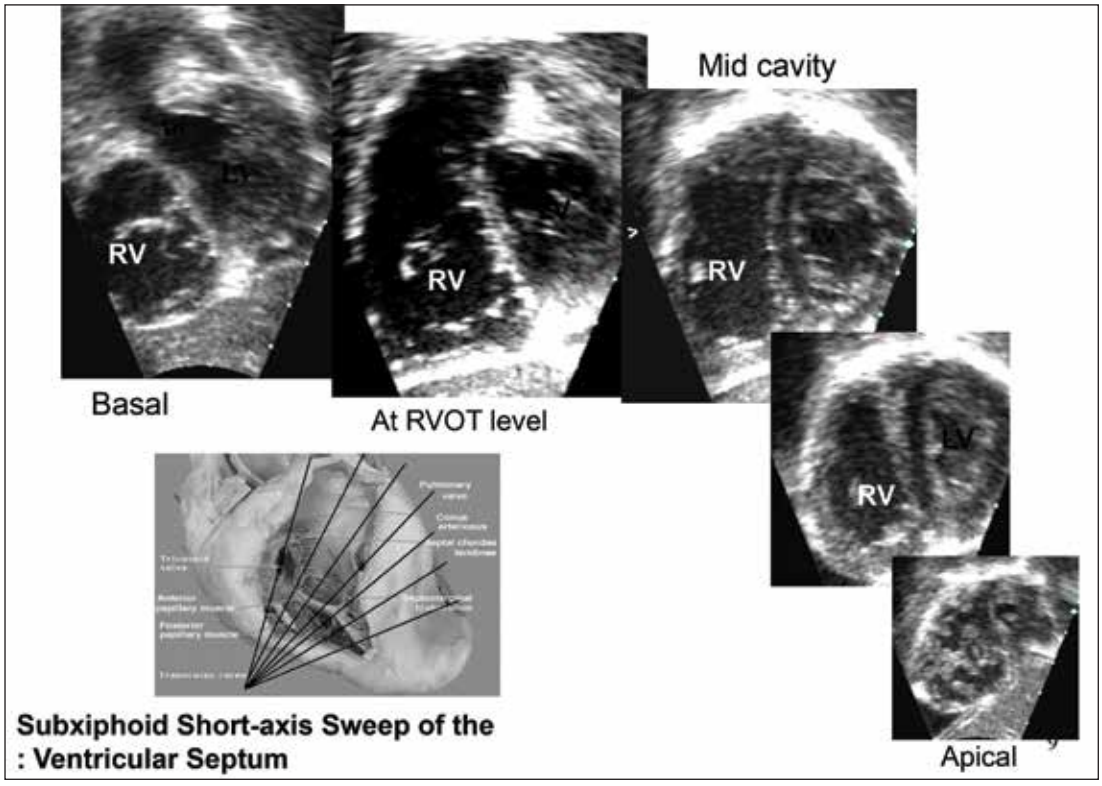

Figure 9: Evaluation of the ventricular septum. A careful sweep from the right to left in the subxiphoid view reveals the details of the ventricular septum

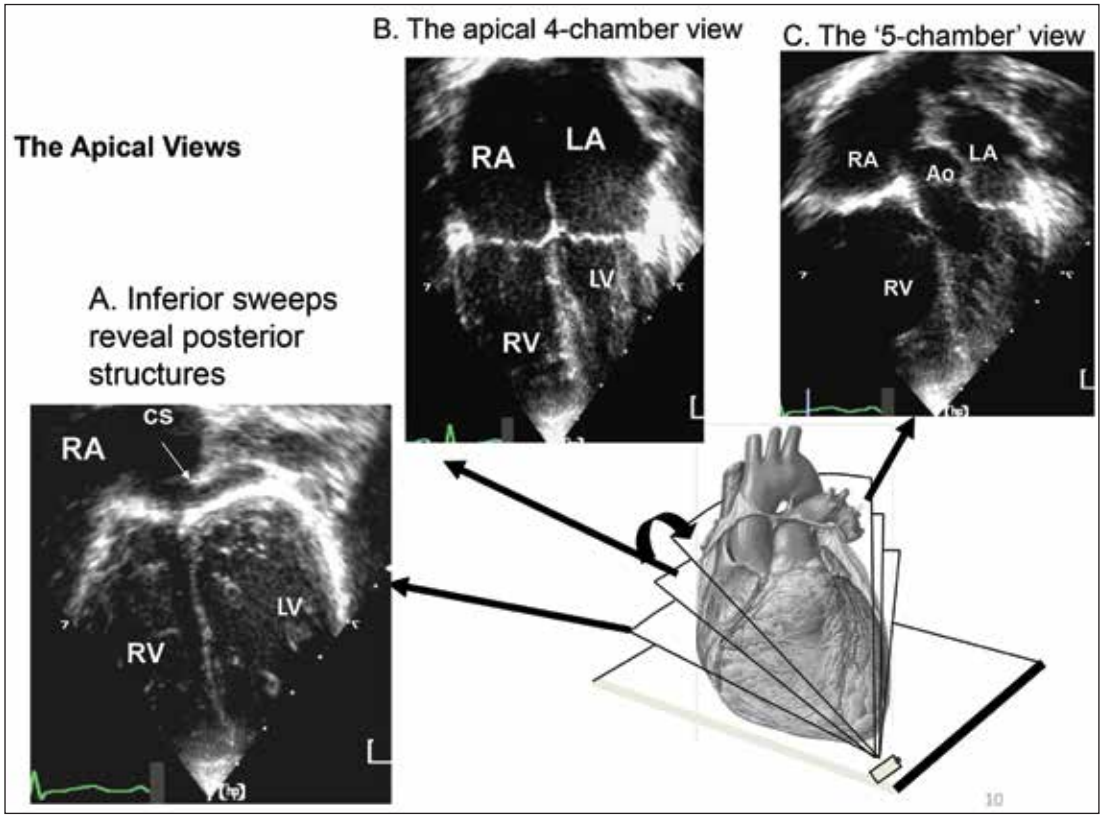

Figure 10: Transducer position and imaging planes for the Apical four and five chamber views. Posterior structures such as the coronary sinus and posterior ventricular septum are seen in the inferior cuts (A); by sweeping superiorly the mitral and tricuspid valves are profiled (Classic apical 4-chamber view); further sweep superiorly reveals anteriorly located left ventricular outflow tract and aortic valve.

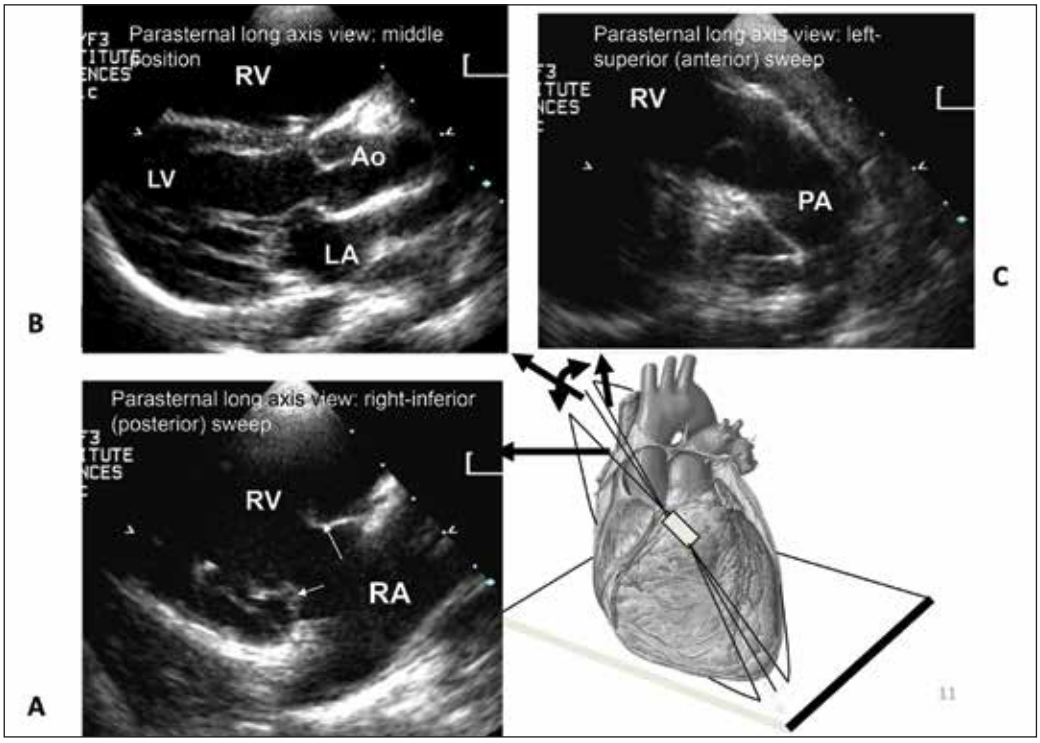

Figure 11: Transducer position and imaging planes for the parasternal long-axis views. The three images are obtained by sweeping rightwards and inferiorly (A) and leftwards and superiorly (C) from the standard parasternal long axis view (B).

THE APICAL VIEWS

The left lateral decubitus position is ideal for optimal imaging. Smaller children and infants need to be turned only slightly to the left by means of a single pillow or a small roll. The apex can be palpated easily in most children and the transducer can be placed directly on the apex. The 4-chamber view can be obtained by placing the transducer in the apex with the marker pointing to the left (figures 1 and 10). For patients with dextrocardia the transducer is placed on the right side of the chest in the right lateral decubitus position with the marker pointing to the left (figure 1). This allows consistency in orientation and image display. The exact transducer position tends to be different for each patient. The heart is scanned in its coronal plane (figure 10). The position needs to be adjusted so that the best acoustic window is obtained and the image is displayed with the septum in the centre of the screen. The two AV valves if present should be clearly profiled in the same view (10B). By angling the transducer posteriorly from this position the posterior aspect of the RV and the RA along with the coronary sinus is displayed (10A). The transducer is next gradually angled superiorly to visualize the AV valves, the left ventricular outflow tract (the apical "5 chamber" view; figure 10C) and, finally, the right ventricular outflow tract. For the right ventricular outflow tract it is sometimes useful to slide the transducer up the chest by one or two spaces. The apical long-axis view is obtained by rotating the transducer clockwise from the position used for the 4-chamber view. The left ventricular outflow tract and the inflow of the LV are often best demonstrated in this view.

THE PARASTERNAL VIEWS

The long-axis view is first obtained by placing the transducer on the third or fourth intercostal space just lateral to the sternum with the marker pointing towards the right shoulder (figure 11). The left ventricle is displayed in its long-axis with its inflow and outflow, the left atrium and the proximal ascending aorta (11B). To obtain the long-axis sweep the transducer is angled towards the right hip to visualize the membranous ventricular septum, the tricuspid valve and the right ventricular inflow (11A). The transducer is then swept towards the left shoulder to demonstrate the right ventricular outflow tract, the pulmonary valve and the main pulmonary artery (11 C).

The parasternal short axis view is obtained by rotating the transducer clockwise approximately 90^0 from the long-axis view that demonstrates the aortic valve (figure 12). The aortic valve can be seen in its cross-section. This is the best view for visualizing the individual cusps of the aortic valve.[9] Minor adjustments in the transducer position allow visualization of proximal right and left coronary arteries. The atrial septum can be visualized

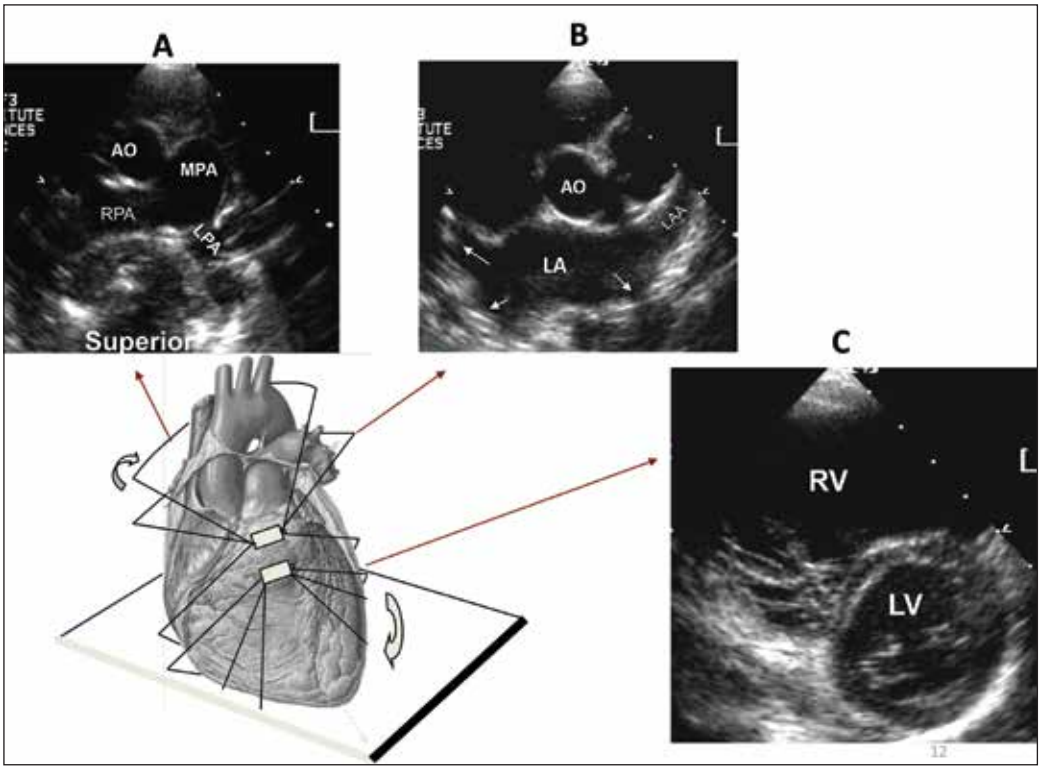

Figure 12: Transducer position and imaging planes for the parasternal short-axis views. Superior sweep (A) enables visualization of the branch pulmonary arteries (RPA and LPA), the main pulmonary artery (MPA) is seen to the left of the aorta (Ao). B. Shows images obtained using a slight downward tilt of the transducer in the parasternal short axis view. This enables visualization of the left atrial appendage (LAA) and the pulmonary veins (arrows). Frame C is obtained by sliding slightly downwards and pointing the transducer towards the apex. The ventricular cavity cross-section is profiled.

posterior to the aortic valve. Other structures that can be seen in this view include the left atrial appendage, the individual pulmonary veins. By tilting the transducer anteriorly the pulmonary valve and the main pulmonary artery can be seen. To visualize the branch pulmonary arteries it may sometimes be necessary to slide up the chest wall by one or two spaces. The right and left pulmonary arteries are oriented at approximately 90-120^0 to each other. As a result they may not be profiled completely in one view. The right pulmonary artery is transversely oriented and is best profiled in the transverse plane. To visualize the left pulmonary artery it is often necessary to rotate approximately 30^0 from the position where the mediatstinal portion of RPA is profiled.

Parasternal cross-sectional views of the ventricles can be obtained by sweeping towards the apex from the position that demonstrates the aortic valve. About 20-30^0 counter-clockwise rotation is also often necessary. These views are helpful in demonstrating a short axis of the mitral valve and profiling the various parts of the ventricular septum.

THE HIGH PARASTERNAL OR THE "DUCTAL" VIEWS

See figure 13. The ductus arteriosus is best profiled by sliding upwards (by one to two intercostal spaces) and medially (figure 2) from the parasternal long-axis view. Initially the orientation of the transducer is kept in the same direction. By sweeping towards the left one can often profile the left pulmonary artery and the descending aorta in the same image. If a patent ductus arteriosus is present it is often best profiled in this view. The entire length of the patent ductus arteriosus including the ampulla and the opening into the pulmonary artery is often profiled (figure 13D). The picture closely resembles the lateral view of an aortogram in a patient with patent ductus arteriosus. Considerable individual variations occur in the orientation of duct. The transducer position and orientation needs to be tailored accordingly. The ductal view is a must for all patients with suspected congenital heart disease. Large ducts with predominantly right to left shunting that occur in association with coarctation or aortic arch interruption can sometimes only be seen in this view. The ductal view separates the ductus arteriosus from the left pulmonary artery, and the descending aorta. These structures come in close relationship with each other

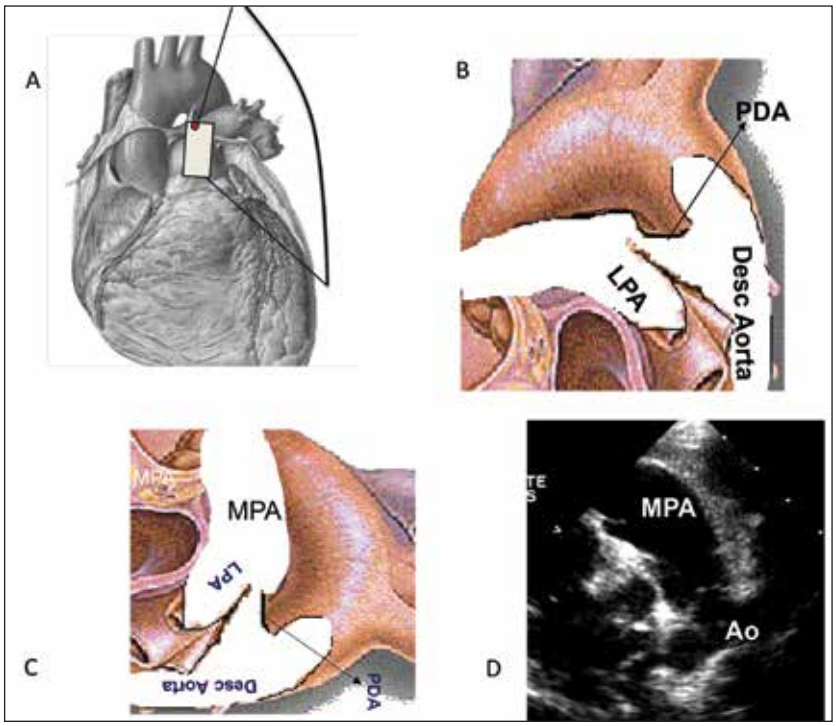

Figure 13. The high parasternal or the ductal view is obtained by placing the transducer high in the precordium, usually in the first intercostal space, (A) and obtaining a section of the MPA-LPA and the descending aorta in the parasagittal plane (B),. To understand the echo image (D) the picture in the frame 'B' has been rotated by 90^0 in a clockwise direction (C). The anterior structures are displayed closest to the transducer. Ao: Aorta, MPA: Main pulmonary artery, LPA: left pulmonary artery, PDA: Patent ductus arteriosus

and can be confused for one another in other views. This view is also very useful in demonstrating the anatomy of coarctation of aorta because it defines the portion of descending aorta adjacent to the ductus arteriosus.

The high parasternal short axis views are obtained from the first or second intercostal spaces, just to the left of the sternum. The transducer orientation is similar to the conventional parasternal short-axis views. This view is particularly helpful for demonstrating the pulmonary artery anatomy in patients with pulmonary atresia.

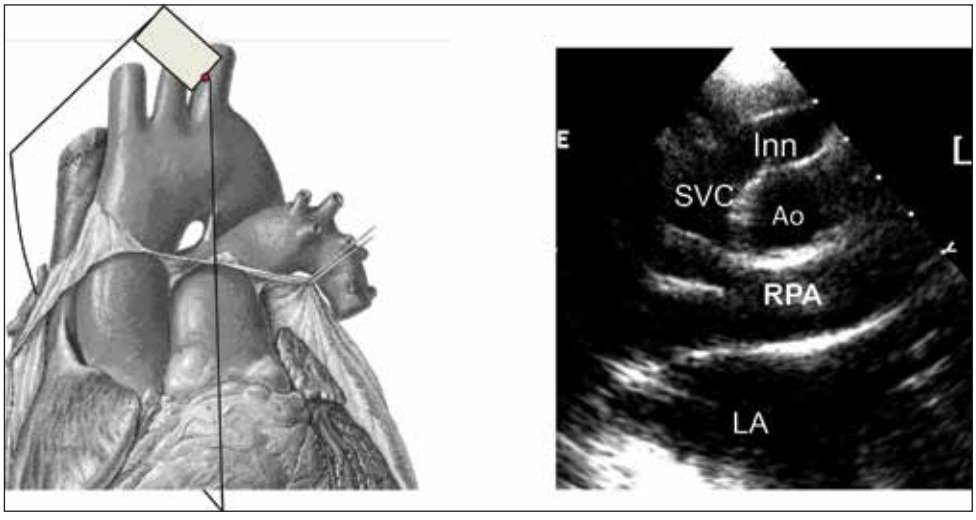

Figure 14: The suprastrenal short-axis view cuts the aorta in its short-axis (shows up as a circle) and cuts the right pulmonary artery (RPA) in its long axis. The innominate vein (Inn) is the closest to the transducer. Other structures seen are superior venacava (SVC), aortic arch (Ao) and left atrium (LA)

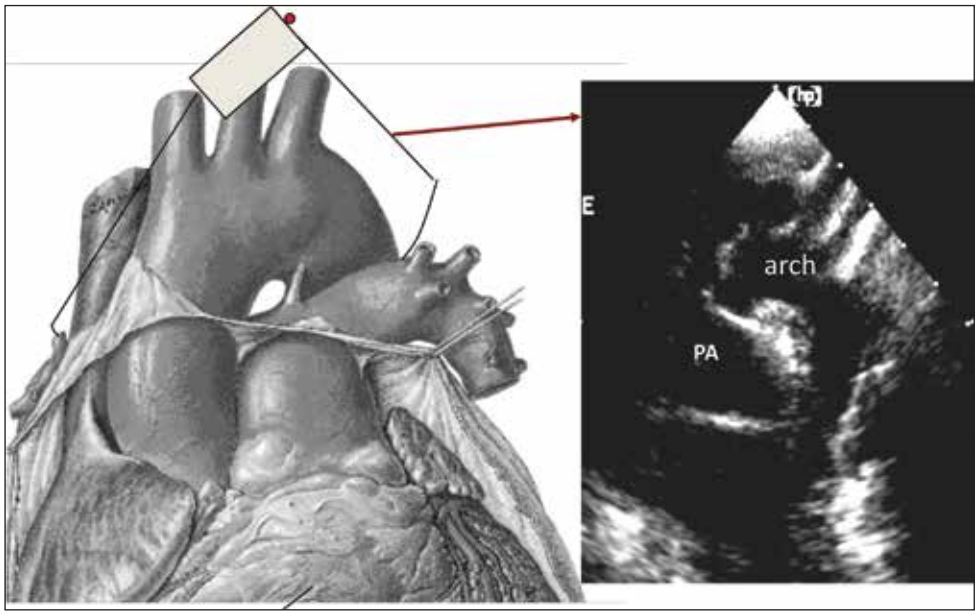

Figure 15: Transducer position and imaging planes for the supra-sternal long-axis views (left). Echocardiogram showing the structures seen in the supra-sternal long-axis view (right). PA: pulmonary artery, Arch: Aortic Arch

THE SUPRA-STERNAL VIEWS

Echocardiography for congenital heart disease is incomplete without the supra-sternal views. For optimal windows the patient should lie supine with the neck extended by a pillow or a rolled up sheet placed underneath the shoulders. The orientation of the structures visualized in this view in relation to the transducer positions are shown in figures 14 and 15. The aorta courses in an anterior to posterior and left to right direction. The suprasternal examination begins with the transducer placed in the suprasternal notch with the marker pointing towards the left shoulder (3 O' clock). The transducer is first angled in a posterior direction about 45^0 in relation to the neck. This profiles the ascending aorta in an oblique section. The entire length of the mediastinal portion of the right pulmonary artery is seen just below the aorta (figure 14). The superior venacava is seen just to the right of the aorta. The innominate vein can be visualized by tilting the transducer in an anterior direction keeping the same orientation. Tilting the transducer to the left can show the course of the vein. This is essential to exclude the presence of a left superior venacava. To determine whether the aortic arch is right sided or left sided the transducer is tilted upwards keeping the transducer in the 3 O' clock position. This profiles the distal aortic arch and the descending aorta in relation to the mid-line. By tilting further upwards and to the right the course of the innominate artery can be traced. The innominate artery is normally the first and the largest of all the branches that arise from the aortic arch. It can be seen to bifurcate into the right common carotid artery and the right subclavian artery as the transducer is tilted to the right.[10,11] In patients with an aberrant right subclavian artery the first branch that comes off the aortic arch is approximately the same size as the other branches. This is the right common carotid artery and it does not bifurcate low in the neck.

The suprasternal "long axis" view profiles the aortic arch and the proximal descending thoracic aorta. The view is obtained by slowly rotating the transducer in a counter-clockwise direction (by about 30^0)from the 3 O' clock position until the aortic arch is profiled (figure 14). In this view the right pulmonary artery appear in cross-section. By tilting leftwards the left pulmonary artery can be profiled in its long axis.

Additional Views

The right parasternal view is obtained by placing the transducer in the 1st or 2nd intercostal space with the tip marker pointing upwards (12 O' clock position). Having the patient lie in the right lateral decubitus position improves image quality. This view profiles the superior venacava in its length and the superior (sinus venosus) part of the atrial septum.

The parasternal and sub-xiphoid in-between (long-axis and short-axis) or oblique views have specific uses visualization of the fossa ovalis ASDs[5] and demonstration of all the components of the common AV valve.

CONCLUSIONS

Echocardiography for accurate diagnosis of congenital heart disease requires meticulous fulfillment of a checklist. A thorough and a disciplined approach minimize the chances of missing a lesion. Some flexibility is, however, warranted while approaching a number of situations. As far as possible one should endeavor to complete all the views and sweeps mentioned above. With practice this can be accomplished expeditiously. The expertise required for accurate diagnosis of complex situations can be acquired through thorough familiarity with echocardiographic anatomy and consistent use of a well-defined strategy for examination.

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Atrial Septal Defect – Systematic Assessment Prior to Device Closure

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Atrial septal defects (ASD) constitute the third most common type of congenital heart disease with an estimated incidence of 56 per 100,000 livebirths[1]. Nearly three-quarters of them are defects of the secundum septum and are often amenable to percutaneous device closure. Most patients remain asymptomatic throughout their childhood even with large shunts. Incidental diagnosis of ASD by evaluation of a cardiac murmur is also not uncommon in adulthood. Appropriate evaluation of the patient for ASD closure thus remains of paramount importance to decide on intervention.

CLINICAL PRESENTATION:

Most children with ASD are identified by incidental detection of a cardiac murmur by the Pediatrician. Rarely an infant with ASD may present with failure to thrive, feeding difficulties, breathlessness or recurrent lower respiratory infections. Such cases should be carefully screened for co-existing cardiac and non-cardiac anomalies. The cardiologist should carefully exclude anomalous pulmonary venous drainage and co-existing diseases of the left heart like hypoplasia of the mitral valve, congenital mitral stenosis, supramitral membrane, left ventricular outflow tract obstruction and coarctation of aorta. Presentation with cardiac failure in the older child with ASD should prompt a screen for mitral stenosis (Lutembacher syndrome).

Significant pulmonary hypertension is also uncommon in children with isolated ASD unlike with post-tricuspid left-to-right shunts. Infants who present with ASD and severe pulmonary hypertension should be evaluated for coexisting diseases as listed above. Infants with ASD who present with severe pulmonary hypertension in the first year of life often have hypertensive pulmonary vascular disease and closure of the defect could be detrimental[2]. These children may behave similar to patients with idiopathic pulmonary hypertension.

Adults with ASD may present with symptoms of effort intolerance and dyspnea and significant volume overload of the right heart chambers after a long asymptomatic period. While this could be related to long standing shunt, development of systemic hypertension, left ventricular diastolic dysfunction, ventricular and vascular stiffening also contribute to the symptomatic worsening in these patients[3]. Atrial fibrillation and flutter constitute another cause for symptomatic worsening in one fifth of these patients beyond the fifth decade.

CLINICAL EXAMINATION:

The arterial pulse and blood pressure are generally normal in patients with isolated ASD. 'V' wave as prominent as the 'a' wave in the jugular veins is a characteristic finding in children with large ASD[4]. This

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"left atrialization" of the right atrial pressures has been attributed to the size of the interatrial defect and the magnitude of the shunt. However the prominence of the 'v' wave tends to progressively diminish with age possibly due to altered compliance of the chronically dilated right ventricle[5]. A prominent 'a' wave relative to the 'v' wave in patients with ASD can be noted in cases of 1st degree atrio-ventricular block and severe pulmonary hypertension[6]. An unusually prominent 'a' wave in JVP may also be noted in adult patients with ASD and left ventricular diastolic dysfunction.

While a right ventricular type of apical impulse is often seen in patients with hemodynamically significant ASD, the presence of prominent right ventricular pulsations may suggest the presence of pulmonary hypertension or coexistent pulmonary stenosis.

A normal first heart sound and a wide and fixed second sound constitute the classical auscultatory findings in large ASD. In healthy young children, the normal split of the second sound is generally well audible and may be exaggerated and persistent in the recumbent position, which on occasion leads to the suspicion of an ASD[7]. Hence it is recommended that a final evaluation of the second sound be done in the sitting or standing position. The loudness of the pulmonary component of the second sound suggests the degree of pulmonary hypertension. Additional heart sounds may be appreciated in a patient with associated Ebstein's anomaly of the tricuspid valve.

The presence of a third heart sound and a mid-diastolic flow murmur in the left lower sternal border are characteristic signs associated with a hemodynamically significant pre-tricuspid shunt. Careful examination for features of persistent shunt are invaluable in the assessment of operability in patients with severe pulmonary hypertension. While large shunts are associated with prominent flow murmurs in the pulmonary area, they do not always suggest the degree of left-to-right shunt. Atrial septal defects are on occasion associated with varying degrees of pulmonary stenosis which can present with basal mid-systolic murmurs. One should always inspect the apical region for click and/or systolic murmurs because mitral valve prolapse is commonly noted in patients with ASD.

CHEST X-RAY:

Enlargement of the right heart chambers is an indicator of hemodynamically significant shunt in ASD (figure 1). The persistence of pulmonary plethora even with dilatation of the pulmonary arteries is an important clue to assess operability in ASD with severe pulmonary hypertension. Discrepancy between the size of central pulmonary arteries and peripheral pulmonary vasculature is a sign of pulmonary vascular

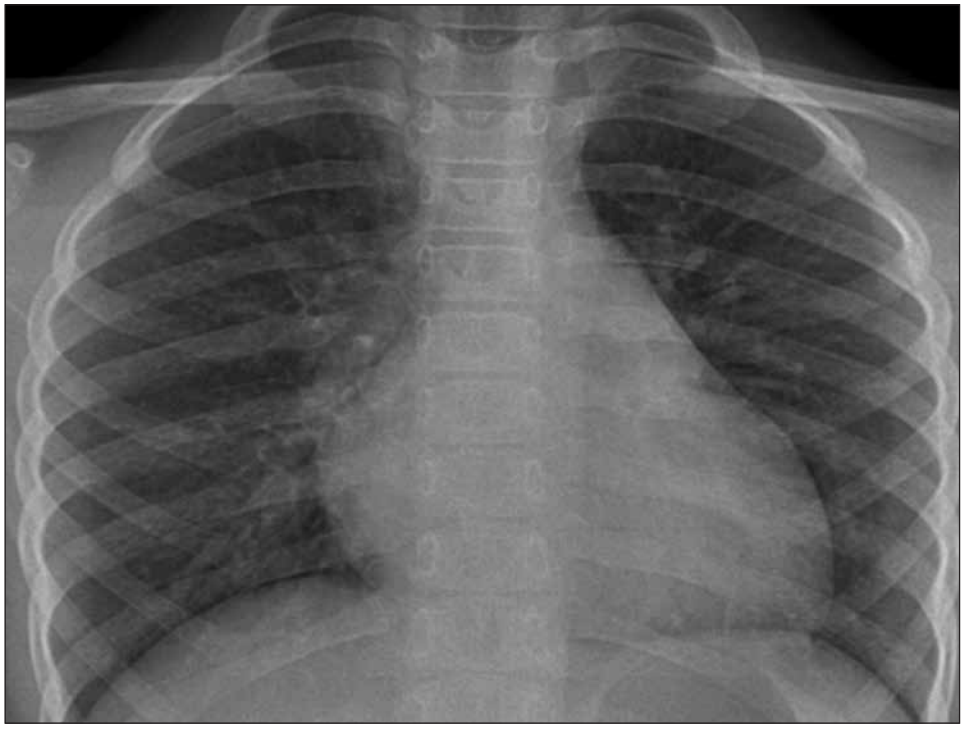

Figure 1: Chest X-ray of a child with large ASD and hemodynamically significant left-to-right shunt.

disease. While cardiomegaly is generally an indicator of significant shunt in ASD, it does not regress with establishment of pulmonary vascular disease unlike post-tricuspid shunts. Thus cardiomegaly does not automatically suggest operability in ASD with severe pulmonary hypertension.

ELECTROCARDIOGRAPHY (ECG):

Absence of sinus arrhythmia is a consistent feature of ASD. While incomplete right bundle branch block is a commonly noted in ASD, the duration of the QRS tends to be longer with increasing right ventricular volume overload[8]. Right atrial enlargement in these patients is often indicated by subtle peaking of 'p' waves with hardly any increase in its amplitude (figure 2). Right axis deviation of the QRS generally indicates presence of significant pulmonary hypertension and occasionally pulmonary vascular disease. The appearance of a notch at the apex of the 'R' wave in inferior leads, referred to as 'crochetage' is another ECG manifestation of hemodynamically significant shunt in ASD. Presence of monophasic tall R waves in the right precordial leads in these patients should prompt a screening for associated pulmonary stenosis or severe PAH. With progression of pulmonary hypertension, the incomplete right bundle branch block pattern tends to get replaced by features of right ventricular hypertrophy[9]. Atrioventricular conduction disturbances should prompt suspicion for familial ASD.

ECHOCARDIOGRAPHY:

Transthoracic echocardiography is the primary modality used for the diagnosis and characterization of ASD. Multiple views should be used to delineate the size, shape and location of the ASD and its relationship to adjacent cardiac structures. In children, the subxiphoid (subcostal) view typically facilitates excellent visualization of the interatrial septum unlike in many adolescents and adults where the parasternal windows are often required.

The subxiphoid four chamber view (marker of the probe to the left of patient) facilitates assessment of ASD rims along the antero-posterior plane from the superior vena cava (SVC) to the atrioventricular valves[10] (figure 3a). Interatrial septal aneurysms are well delineated in this view. A posterior tilt in this window shows the true posterior rim, rim along the right pulmonary vein and the coronary sinus rim of the ASD continuing into the mitral rim.

The subxiphoid sagittal view (marker looking downwards) images the atrial septum along the supero-inferior plane permitting screen with a left-right sweep (figure 3b). The SVC and IVC rims can be assessed in this view orthogonal to the four chamber view, besides identification of a sinus venosus defect. A comparison of the dimensions of the ASD in these two planes allows an assessment of the shape of the defect.

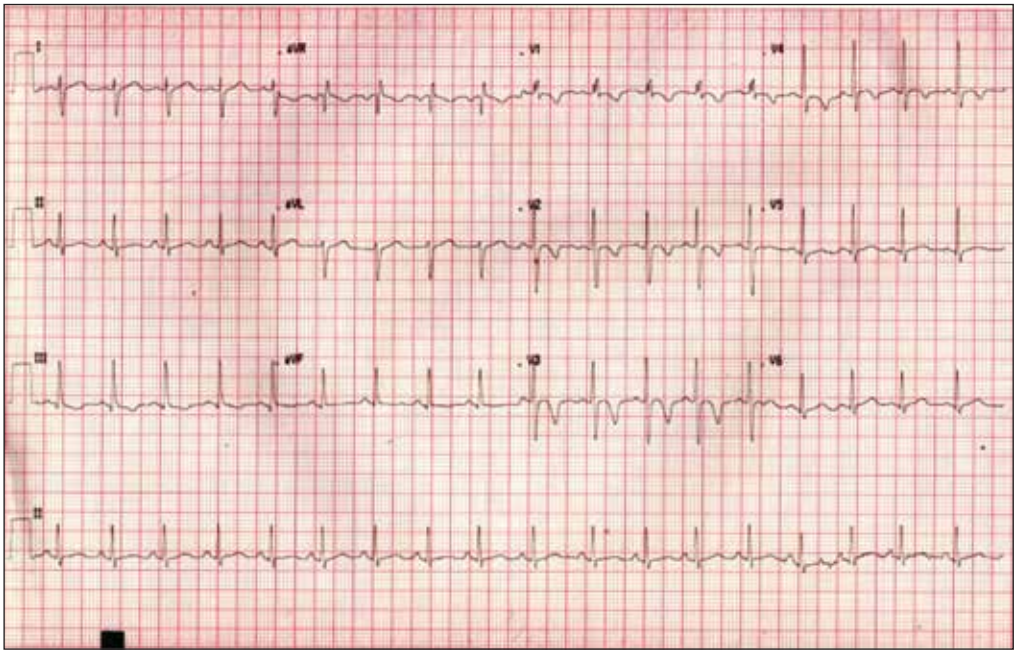

Figure 2: 12 lead ECG of a 7 years old child with large ASD and volume overload of the right heart chambers. Subtle peaking of the p wave is notable. Incomplete right bundle branch block and right axis deviation of the QRS vector is also present.

The left anterior oblique view (marker to left shoulder) can be obtained by rotating the transducer approximately 45˚ counterclockwise from the subxiphoidfour chamber view (figure 3c). This view is ideal for identifying defects of the primum septum and coronary sinus rim. The entry of the right pulmonary veins into the left atrium can be delineated in this view.

The parasternal short axis view (marker to left shoulder) is useful to assess the aortic rim of the ASD (figure 3d). It is also useful to assess the adequacy of the posterior rim. However, ASD measurements are inaccurate in this view considering the parallel beam – septum relationship.

The apical four-chamber view (marker to left of patient) is a common window of erroneous diagnosis and measurement of ASD as the interatrial septum lies parallel to the ultrasound beam (figure 3e). This view is useful, however, to assess the volume overload of the right heart chambers and the mitral rim. A medial slide of the transducer towards the sternal border yields a modified four-chamber view which permits interrogation of the ASD in patients with inadequate subxiphoid window.

The high right parasternal view (marker looking upwards) with the patient in the right lateral decubitus position and a superior-inferior orientation of the probe aligns the interatrial septum perpendicular to the plane of interrogation and is particularly useful for diagnosing sinus venosus defects when the subxiphoid window is suboptimal (figure 3f).

Tranesophageal echocardiography (TEE) and/or intracardiac echocardiography are the recommended imaging modalities for guidance of device closure of ASD in all ages. This facilitates appropriate device selection and assessment of position and stability of the deployed device before its release. Five view are used for assessment of ASD by TEE.

The upper esophageal short axis view at 0˚, 15˚, 30˚ and 45˚ images the superior aspects of the atrial septum, the roof of the atria and the posterior rim of the ASD. The drainage of the right pulmonary veins can be demonstrated by clockwise rotation of the probe and upper and mid-esophageal levels.

The mid-esophageal four-chamber view is obtained by clockwise rotation of the TEE probe in 0˚ and permits

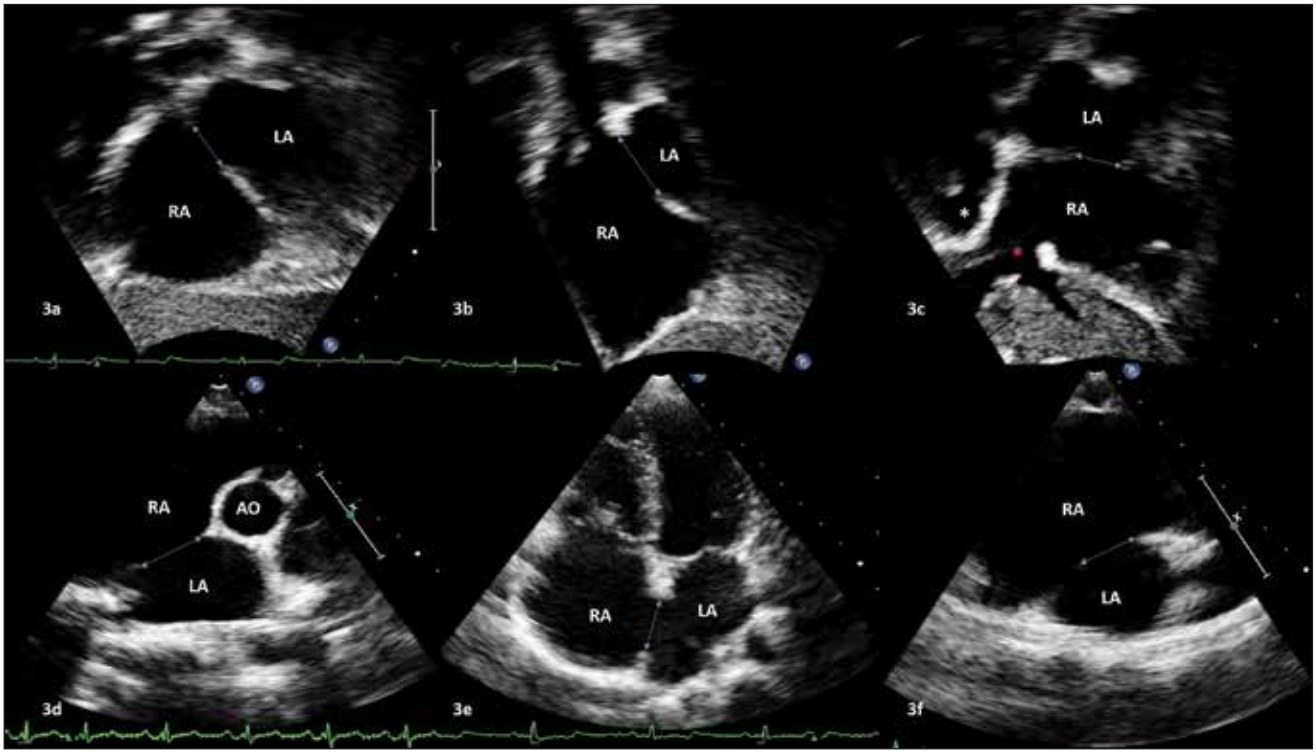

Figure 3: Panels 3a, 3b and 3c are 2D transthoracic echocardiographic images from the subxiphoid window (images upright - anatomically correct display) profiling the ASD (blue double headed arrow). Panel 3a is the four-chamber view delineating the superior rim and the coronary sinus rim. The sagittal view in panel 3b delineates the SVC rim superiorly and IVC riminferiorly. The left anterior oblique view in panel 3c shows the pulmonary venous rim and coronary sinus rim of the ASD. The drainage of the right lower pulmonary vein (white star) and hepatic veins (red star) are also clear. Panel 3d is the parasternal short axis projection showing the aortic rim of the ASD. The mitral rim of the ASD is notable in the apical 4-chamber view in panel 3e. Panel 3f is the right parasternal window showing the ostium secundum ASD. (Images 3d, 3e and 3f are conventional, ie, ultrasound beam from above).

assessment of the mitral rim. This view is also used to screen for any crossing anomalous coronary artery which could potentially get compressed by ASD device.

The mid-esophageal aortic valve short axis view at 30˚, 45˚, 60˚, 75˚ assesses the aortic (anterior) and posterior rims of the ASD.

The mid-esophageal bicaval view at 90˚, 105˚ and 120˚ assesses the SVC and inferior vena caval (IVC) rims of the ASD. This view would also clearly demonstrate the sinus venous defect of the SVC type. The mid-esophageal long axis view at 120˚, 135˚ and 150˚ shows the coronary sinus rim and part of the superior rim. Further rotation of the probe brings out the drainage of the left pulmonary veins into the left atrium.

Quite often, most information from TEE is obtained from mid-esophageal screens at 0˚, 45˚, 90˚ and 120˚ in the presence of adequate rims (figure 4). A rim is considered deficient if it measures less than 5 mm in at least three sequential multiplane views in 15˚ increments. While deficiency of the aortic rim alone does not preclude successful device implantation, deficiency of other rims, particularly the inferior rims along the mitral valve and inferior vena cava places the patient at high risk for complications during device closure. Assessment of the contralateral rim is of paramount importance in the presence of borderline rims. Imaging of the ASD by TEE is recommended for all larger pediatric patients and adults prior to device closure.

TEE is particularly useful in the assessment of atrial septal malalignment which frequently interferes with successful device deployment and constitutes a risk factor for cardiac erosion on follow up[11]. The interatrial septum may be noted to deviate leftward and towards the pulmonary artery anteriorly, often with absence of the aortic rim. While experienced interventionalists do successfully close ASDs with minor malalignment, those with greater degrees of malalignment are better managed surgically considering the risks of device embolization and aortic erosion.

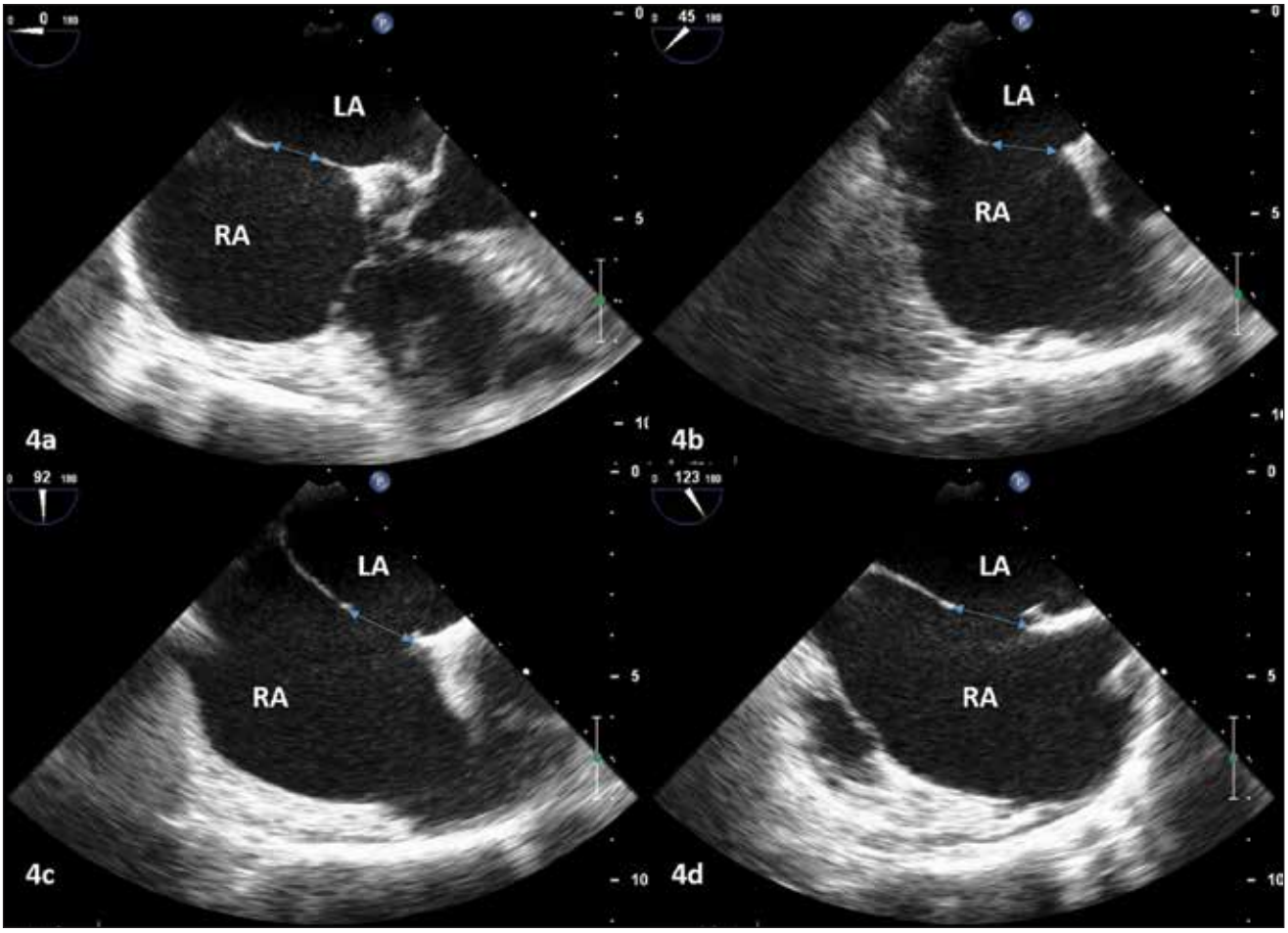

Figure 4:Transesophageal 2D echocardiographic images used in the rapid screening protocol for ASD rims. The 0˚ mid esophageal projection (panel 4a) shows the mitral rim of the ASD. The aortic rim is identified in the 45˚ projection (panel 4b). The 90˚ view (panel 4c) shows the SVC and IVC rims of the ASD. The coronary sinus rim is best visualized in the 120˚ projection (panel 4d).

CARDIAC CATHETERIZATION:

While an invasive catheterization is not required for the diagnosis of ASD, cardiac catheterization still remains the gold standard for shunt estimation particularly in patients with pulmonary hypertension. Oximetry samples should be taken from the high SVC, low SVC, IVC, main pulmonary artery, one pulmonary vein and aorta. Pulmonary venous desaturation often suggests pulmonary parenchymal disease which could interfere with assessment of operability in ASD with pulmonary hypertension. Significant oxygen step up in the low SVC often suggests anomalous pulmonary venous drainage. A mean 7% step up in oxygen saturation from the mixed venous blood to the pulmonary artery (PA) is considered a hemodynamically significant step-up at the atrial level[12]. Using the Dexter criteria, a step-up in oxygen content by 2 vol% is suggestive of a shunt at the atrial level[13]. While even a 3% oxygen step-up from SVC to PA is likely to suggest a left-to-right shunt, false positive rates are higher[14,15].

Cardiac catheterization is recommended for all patients who have clinical features of pulmonary hypertension, or doppler echocardiographic documented pulmonary artery pressure >50% of systemic pressure prior to ASD closure[16]. Baseline pressure recordings from both atria, ventricles and great arteries should be recorded. Equalization of the atrial mean pressures and ventricular end-diastolic pressures is often noted in non-restrictive ASD in adulthood. In the presence of left ventricular diastolic dysfunction, this can often mimic the hemodynamics of restrictive heart disease. Undiagnosed left ventricular diastolic dysfunction can result in pulmonary edema in adults after ASD closure[17]. Some of these patients would need optimization of medications followed by test ASD occlusion and assessment of LV end diastolic pressures and pulmonary capillary wedge pressures (PCWP) before a decision on device closure. A rise in PCWP more than 10 mm Hg from baseline or any value more than 20 mm Hg is considered a high risk subset. ASD closure with a fenestrated device / patch is a consideration in these patients[18].

Patients with baseline pulmonary vascular resistance (PVR) >5 WU may be studied again after a vasodilator challenge, preferably inhaled nitric oxide(iNO) 20 – 80 ppm, or after targeted therapy for pulmonary arterial hypertension. While 100% oxygen is often used to assess pulmonary vasoreactivity, it is fraught with limitations. As the arterio-venous difference in the carrier (oxygen) is reduced considerably, errors in oximetry tends to exaggerate the shunt and consequently reduces the estimated PVR. Oxygen consumption assumptions used at baseline are not truly validwith changes in inspired oxygen[19]. The combination of 40% oxygen and 20 – 40 ppm iNO results in better pulmonary artery vasodilator response as compared to either agent alone[20].

Patients with ASD and left-to-right shunt >1.5:1 and baseline PVR <5 WU can be considered for closure regardless of symptoms[16]. If the PVR is ≥ 5 WU but less than two-thirds of the systemic vascular resistance at baseline or after a vasodilator challenge can be considered for device closure if the net left-to-right shunt is >1.5.

Angiography is not routinely recommended in patients with ASD. Balloon occlusion pulmonary artery wedge angiography is useful when the drainage of all pulmonary veins is not fully delineated by non-invasive tests[21]. Fluoroscopic demonstration of the entry of each pulmonary vein into the left atrium by a right heart diagnostic catheter may be a useful alternative to angiography. The interatrial septum is profiled in the left anterior oblique fluoroscopic projection (LAO). A contrast injection in the right upper pulmonary vein in 60° LAO tilt is occasionally useful to delineate its anomalous drainage.

PATIENT SELECTION AND TECHNICAL CONSIDERATIONS:

Although there is no rigid lower limit for ASD closure, most centers consider patients for the same at 3 – 5 years of age. Secundum ASDs larger than 36 – 40 mm, inadequate rims, interference with atrioventricular valve function, venous drainage or atrioventricular conduction are general contraindications for device closure[22]. Nickel allergy is another contraindication for percutaneous device closure with currently available devices. This can result in mast cell activation with anaphylactic and/or anaphylactoid reaction and acute coronary syndromes[23].

Patients who have had experienced paradoxical embolism such as stroke or recurrent transient ischemic attack, in the absence of other causes (class IIa, level of evidence B), and those at risk of thromboembolic events (class IIa, level of evidence B) are rare indications for ASD closure irrespective of shunt size[24]. Patients with ASD and insignificant shunt should be kept on medical follow up and evaluated for the possibility of progression of shunt later in life.

On occasion, anomalous origin of the left coronary artery (circumflex branch) from the right sinus can have a retroaortic course rendering it susceptible to compression during ASD device closure[25]. This potentially dangerous complication can be averted by a routine screen for abnormal coronary course during

TEE. These patients may be safely managed by surgical ASD closure.

Floppy rims occasionally pose a challenge for device closure and meticulous imaging is advised. A prominent Eustachian valve can occasionally mimic an ASD rim and should be carefully distinguished from the true interatrial septum. In doubtful cases, a saline injection from the IVC is useful[26]. The Eustachian valve guards the IVC along its anterior border while the atrial septum inserts along its posterior border. Thus saline bubbles can be noted to enter the atrium posterior to the Eustachian valve, but anterior to a true interatrial septum.

Care must be taken to ensure adequate heparin use with activated clotting time (ACT) monitoring during device closure to prevent thrombus formation and embolic complications. ACT should be maintained at 200 – 300 seconds throughout the procedure. The use of positive end expiratory pressure (PEEP) during anesthesia can help in reducing the incidence of air embolism during sheath delivery and removal of the dilator.

While fluoroscopic guidance has been standard for ASD device closure, echocardiographic guidance (TEE / TTE) without fluoroscopy is fast gaining popularity, particularly for relatively simpler cases[27]. This technique permits real time visualization of the device in relation to the rims for optimal positioning besides the radiation related advantages. Several modifications have been adopted to the conventional fluoroscopic technique for device delivery in difficult ASD. The right upper pulmonary vein approach, balloon assisted technique[28], dilator assisted technique[29] have all been employed to prevent device prolapse during deployment.

CONCLUSION

Atrial septal defects have excellent long term outcomes in the current era with device or surgical closure according to indications. Careful evaluation of the patient prior to definitive management can avoid complications and therapeutic misadventures.

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KJC Pearls

Heart Failure with Reduced Ejection Fraction and the Neurohormonal Axis : Shift from Inhibition to Modulation

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INTRODUCTION:

Heart Failure with reduced Ejection Fraction (HFrEF) has been considered as a state of neurohormonal imbalance with overactivity of vasoconstrictor, anti natriuretic and pro mitotic mediators, leading to a vicious cycle of progressive deterioration in cardiovascular function.

Activation of the renin–angiotensin–aldosterone system (RAAS), along with activation of the sympathetic nervous system (SNS), play a fundamental role in this vicious cycle . Inhibition of RAAS, by ACE inhibitors (ACEI), angiotensin receptor blockers (ARBs) and mineralocorticoid receptor antagonists (MRA) as well as of SNS, by beta blockers, has become the standard for pharmacological treatment of CHF with their mortality and morbidity benefits proven over multiple randomized controlled trials (RCTs).

In addition to RAAS and SNS, another physiological system plays a pivotal role in the compensating mechanisms of HFrEF - the natriuretic peptide system (NPS) . Modulation of NPS in the pharmacotherapy of HFrEF, especially with Sacubitril - the novel Neprilysin inhibitor, will be the focus of this review .

THE NATRIURETIC PEPTIDE SYSTEM (NPS)

NPS is not a new entrant into the neurohumoral understanding of HFrEF. In fact ,the first natriuretic peptide was discovered as early as in 1978,when Atrial Natriuretic Peptide (ANP) was discovered by Adolfo de Bold and colleagues[1,2]. 10 years later , in 1988, Sudoh et al. identified a peptide in porcine brain and named it brain natriuretic peptide [BNP][3]. A third peptide, C Type natriuretic peptide (CNP), was later extracted first from porcine brain, and then from endothelial cells[4].

These three peptides, which form the NPS, are the products of separate genes that encode the respective prohormones. The pro hormones undergo proteolytic cleavage to form the three active hormones . ANP and BNP activate membrane bound natriuretic peptide receptors-A ,which in turn activate guanylyl cyclase A, increasing the intracellular concentrations of cyclic guanosine monophosphate (cGMP). cGMP activates protein kinase G, leading to vasorelaxation, natriuresis, and diuresis . ANP and BNP also inhibit renin secretion and aldosterone production thus attenuating cardiac and vascular remodelling, apoptosis, ventricular hypertrophy, and fibrosis , counteracting the negative effects of angiotensin II (Ang II) and aldosterone in HF patients[5-10].

CNP is released primarily from endothelial cells, and only trace quantities are found in the blood. In contrast to ANP and BNP, CNP does not have a marked effect on sodium or water excretion, but instead, act as a vasodilator. CNP is also synthesized in cardiac fibroblasts and may have important anti remodeling effects in the myocardium by local regulation of collagen synthesis and cellular hypertrophy inhibition[13,14] (Fig 1).

Despite the high levels of circulating NPs, HFrEF patients are thought to be in a state of relative BNP insufficiency owing to relatively higher levels of the high molecular weight proBNP, which has less biologic activity than the low molecular weight BNP, as well as

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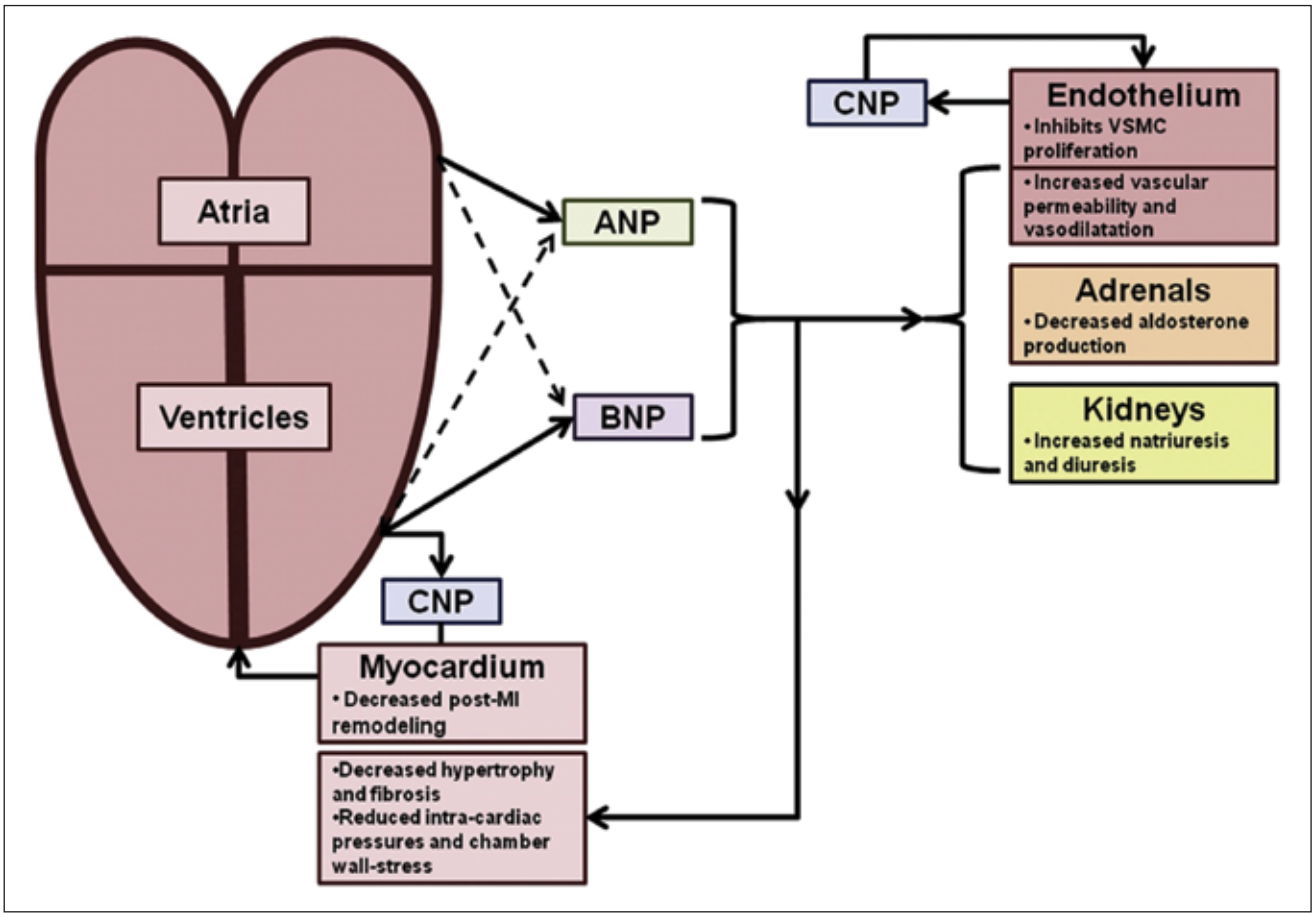

Fig. 1. ANP is predominantly released from the atria, BNP predominantly from the ventricles, and CNP is predominantly found locally in myocardium and endothelium with minimal systemic release. In heart failure, both ANP and BNP may be released from either cardiac chambers (dashed lines). ANP and BNP act on the endothelium to increase vascular permeability and vasodilatation, on the adrenals to inhibit aldosterone production, on the kidneys to promote natriuresis and diuresis, and at the level of myocardium to inhibit fibrosis and cellular hypertrophy leading to decreased intracardiac pressure and wall stress. CNP also acts on the myocardium to inhibit fibrosis and cellular hypertrophy and may decrease post myocardial infarction remodelling. CNP acts locally on the endothelium to inhibit vascular smooth muscle cell proliferation and promote vascular permeability and vasodilatation.

increased cellular phosphodiesterase, which inhibits the downstream effects of BNP on target cells[11,12].

METABOLISM OF NATRIURETIC PEPTIDES (NPS)

Circulating NPs are cleared through two principal mechanisms: NP receptor-mediated clearance and enzymatic degradation by extracellular proteases.[15]

The NP type C receptor is thought to function primarily as a "clearing" receptor that can bind all 3 NPs, resulting in receptor-mediated internalization and degradation.

The major enzyme contributing to the extracellular degradation is known as neprilysin. Neprilysin is a membrane-bound zinc metalloendopeptidase that was originally isolated in 1974 from the kidney brush border of rabbits[16]. ANP and CNP are the preferred substrates of neprilysin, whereas BNP is more slowly degraded.

Neprilysin is often considered as a 'promiscous" molecule, because, in addition to the NPs, other vasoactive peptides including adrenomedullin, (another vasodilator), substance P, Angiotension I and II, endothelin-1 and bradykinin are also its substrates. Thus, although inhibition of neprilysin would increase the levels of NPs and adrenomedullin, leading to desirable effects , there may also be increased levels of Angiotensin II and Endothelin 1 yielding undesirable effects, such as vasoconstriction and even possible side effects such as angioedema due to increased levels of bradykinin.

PHARMACOLOGIC MODULATION OF NPS

Two strategies have been attempted to try and improve outcomes in HFrEF via modulation of NPS.

1. Exogenous Natriuretic peptides :

The first method of NPS modulation tried was the administration of exogenous NPs. Intravenous recombinant human BNP, Nesiritide, initially showed promising beneficial effects on haemodynamics and natriuresis in patients with HFrEF[17]. However, in the ASCEND -HF trial, a large-scale RCT involving more than 7000 patients, nesiritide failed to improve outcomes, limiting the enthusiasm for this strategy.

Intravenous infusion of atrial natriuretic peptide (carperitide) is used in the management acute heart failure in Japan, albeit with limited data.

2. Neprilysin Inhibhitors (NEPi)

The second strategy of NPS modulation was to inhibit the breakdown of NPs by using Neprilysin inhibitors.

A. INITIAL NEPRILYSIN INHIBITORS

Initial studies with Candoxatrilat , an intravenous NEPi were encouraging , with promising natriuresis and urinary ANP excretion[18]. However studies with candoxatril – the oral prodrug of Candoxatrilat, was disappointing in patients with hypertension. Candoxatrilat could not sustain the initial reduction in blood pressure and therefore further development came to a halt. Neprilysin also breaks down angiotensin II, vasopressin and endothelin and inhibiting neprilysin alone, increases the levels of these vasoconstrictors, nullifying its favourable effects[19].

B. DUAL NEPRILYSIN AND ACE INHIBITION

Since lone neprilysin inhibition resulted in increase in the detrimental AT II levels, the next logical step was to combine RAAS and NPS blockade . Since ACE inhibitors had the most robust data in HFrEF, it was combined with a neprilysin inhibitor. The combined ACE and neprilysin inhibitor, Omapatrilat (combination enalapril and the NEPI sacubitril), had encouraging results in the initial studies[20,21]. Omapratrilat was compared with enalapril in the large **O**mapatrilat **V**ersus **E**nalapril **R**andomized **T**rial of **U**tility in **R**educing **E**vents (OVERTURE) trial involving 5770 NYHA class II to Class IV heart failure patients. The primary end point, death from any cause or HF hospitalisations was not reduced by Omapatrilat. Although other secondary end points suggested a benefit with Omapatrilat, the rate of angioedema was much higher in the Omapatrilat group[22]. Both ACE and neprilysin break down bradykinin, and Omapatrilat, in addition inhibits aminopeptidase P, which also catabolises bradykinin. Bradykinin enhances prostaglandin concentrations and increases vascular permeability and fluid extravasation. Therefore, unintended excessive potentiation of bradykinin resulted in high rates of serious angioedema and led to the discontinuation of the clinical development of this drug.

C. ANGIOTENSIN RECEPTOR BLOCKER NEPRILYSIN INHIBITORS (ARNI)

The potential solution to the problem encountered with omapatrilat, was to combine an ARB and a neprilysin inhibitor. The angiotensin receptor neprilysin inhibitor (ARNI) sacubitril/valsartan (formerly known as LCZ696) was designed with the aim of inhibiting neprilysin while blocking the adverse effects of RAAS but without causing bradykinin potentiation. LCZ696 is a supramolecular complex of 6 molecules of the ARB Valsartan with 6 molecules of the NEPi prodrug, Sacubitril (AHU377). The mechanism of action of Sacubitril-Valsartan complex is summarised in Fig 2.

As the active metabolite of sacubitril, sacubitrilat (LBQ657), does not inhibit aminopeptidase P, the risk of angioedema was expected to be lower than with Omapatrilat. Given twice daily, Sacubitril/Valsartan leads to sustained neprilysin and RAAS inhibition over a 24 h period addressing one limitation of the OVERTURE trial in which Omapatrilat was given as a single large dose, once daily. That approach may have contributed to the significant early post dose hypotension seen with omapatrilat,at the same time not providing sustained inhibition of ACE and neprilysin over 24 h.

Initial trials of LCZ696 in hypertensive patients showed impressive results with greater fall in systolic, diastolic, and pulse pressures with LCZ696 than with either Valsartan or the NEPi prodrug (AHU377) administered separately[23].

TRIALS OF ARNI IN HF

A. HFrEF

The landmark PARADIGM-HF (**P**rospective Comparison of **ARN**I With **A**CEI to **D**etermine **I**mpact on **G**lobal **M**ortality and Morbidity in **H**eart **F**ailure) compared Sacubitril/Valsartan 97 mg/103 mg twice daily with Enalapril 10 mg twice daily in 8,442 patients with HFrEF [24,25].

Eligible patients had NYHA functional class II-IV symptoms and LVEF <40% (which was changed to <35% by protocol amendment), were taking an ACEi or ARB, beta-blocker (if tolerated), and mineralocorti- coid receptor antagonist (if indicated), and had a plasma

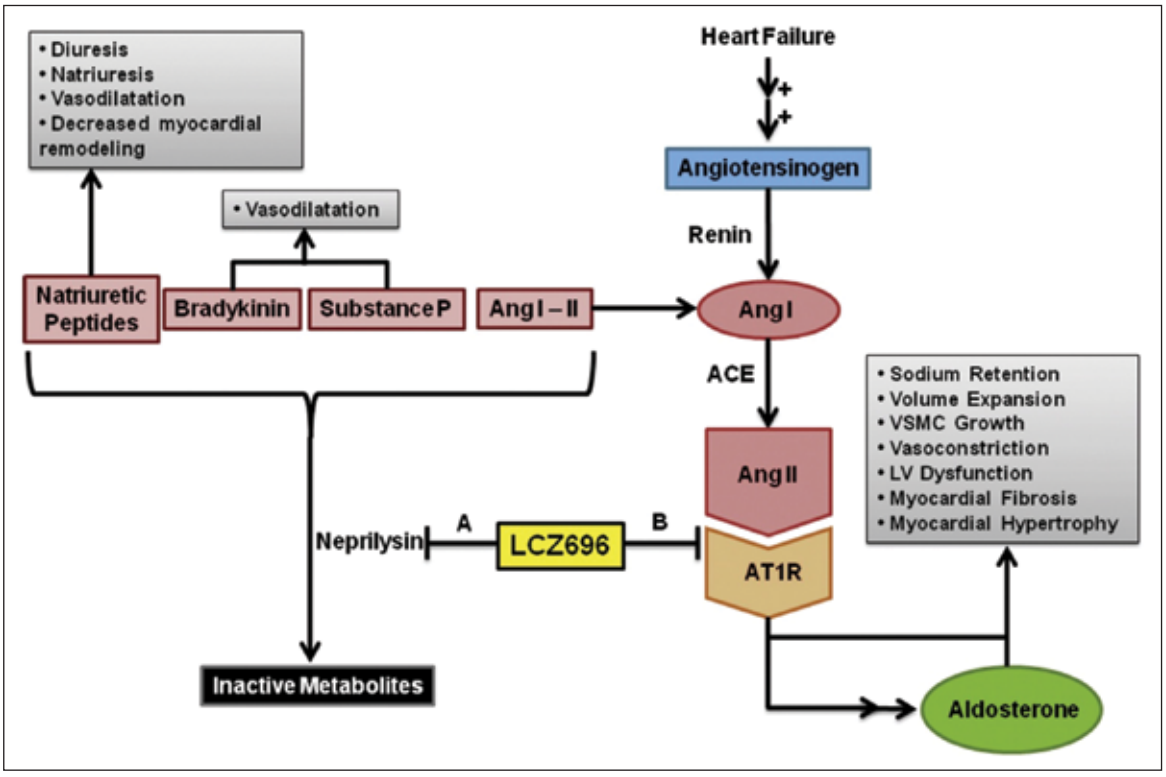

Fig. 2.LCZ696 prevents the degradation of several vasoactive substrates, including natriuretic peptides, bradykinin, substance P, and Ang I and II, as well as inhibiting the downstream effects of Ang II. This mechanism counteracts states of volume overload and the activated RAAS via increased diuresis, natriuresis, vasodilatation, and inhibition of downstream Ang II and aldosterone effects.

ACE, angiotensin-converting enzyme; AT1R, angiotensin II type 1 receptor; LV, left ventricular; VSMC, vascular smooth muscle cell.

BNP >/= 150 pg/mL or NT-proBNP >/= 600 pg/mL. (In patients hospitalized for HF in the past 12 months, the BNP cutoff levels were reduced by one-third).

Patients were excluded if they had symptomatic hypotension or systolic BP $\leq$ 95 mm Hg, decreased eGFR (< 30 mL min^{-1} 1.73 m^{-2}), Serum Potassium >/= 5.4 mEq/L , or history of angioedema or unacceptable side effects to ACE inhibitors or ARBs .

All randomized patients completed a run-in period of 6–8 weeks during which it was required that target dose of both drugs were tolerated prior to randomization. Each treatment period included a washout period to avoid simultaneous neprilysin and ACE inhibition and the potential risk of angioedema.

The trial was terminated early, due to a sustained and highly significant reduction in the risk of the primary composite end point (CV death or HF hospitalization) by 20% (hazard ratio [HR]: 0.80; 95% confidence interval [CI]: 0.73 to 0.87; p = 0.0000004) . Similar reduction was observed for individual end points of cardiovascular death (HR: 0.80; 95% CI: 0.71 to 0.89; p = 0.00008) and hospitalization for HF (HR: 0.79; 95% CI: 0.71 to 0.89; p = 0.00008). All-cause mortality was reduced by 16% (HR: 0.84; 95% CI: 0.76 to 0.93; p < 0.0002). These findings were consistent across all pre specified subgroups.

For every 1000 patients switched from enalapril to sacubitril/valsartan, over a median of 27 months, there was : 47 less primary end points (CV death or HF hospitalisations), 33 less CV deaths, 28 less first hospitalisations for HF (53 less total hospitalisations for HF) and 32 less deaths from any cause. There was also reduced need for intensification of the treatment for HF, fewer visits to an emergency department for worsening HF, a lower requirement for intensive care or need for intravenous inotropic agents and HF device implantation or cardiac transplantation.

There was no statistically significant difference in the rate of angio-oedema with Sacubitril/Valsartan although numerically more cases were observed than in the Enalapril group (19 patients in the Sacubitril/Valsartan group and 10 cases in the Enalapril group, p=0.13). Hypotension was significantly more common with Sacubitril/Valsartan than with Enalapril (14% vs 9% in the in the Sacubitril/Valsartan and Enalapril groups respectively, p<0.001), although this rarely led to study drug discontinuation (0.9% and 0.7% in the Sacubitril/

Valsartan and Enalapril groups respectively, p=0.38). Conversely, renal dysfunction, hyperkalaemia and cough were less common with Sacubitril/Valsartan than with Enalapril.

Based on the results of this study, the European Medicines Agency (EMA) and the United States Food and Drug Administration (FDA) approved Sacubitril/Valsartan for the treatment of symptomatic chronic HFrEF patients in November 2015 and July 2015, respectively[26, 27].

Heart Failure with preserved Ejection Fraction (HFpEF)

PARAMOUNT (**P**rospective comparison of **AR**Ni with **A**RB on **M**anagement **O**f heart fail**U**re with preserved ejectio**N** frac**T**ion) trial, a double blind randomized trial compared LCZ696 200 mg BD with Valsartan 160 mg BD in 301 patients with HFpEF[28]. The primary endpoint, the decline in NT-proBNP at 12 weeks , was significantly greater in the LCZ696 group than in the Valsartan group and there was greater improvement in the NYHA functional class with LCZ696 than with Valsartan. NT-proBNP reduction was sustained in the LCZ696 arm through 36 weeks, though by 36 weeks, NT-proBNP had declined in the Valsartan arm also, so that the difference was no longer statistically significant. LCZ696 was well tolerated in these patients, with no significant differences in adverse events between groups.

These hypothesis generating findings have provided the rationale for a large outcomes trial in HFpEF. PARAGON-HF (**P**rospective Comparison of **AR**NI With **A**RB **G**lobal **O**utcomes i**NH**eart **F**ailure With Preserved Ejection Fraction) will enroll 4,300 patients with HFpEF, and will answer the question, whether Sacubitril-Valsartan can reduce cardiovascular death or total HF hospitalizations in patients with HFpEF.

Who should/should not receive Sacubitril/Valsartan?

The only evidence as of now for the use of Sacubitril/Valsartan is in ambulatory patients with HFrEF and the drug is not indicated at present for HFpEF patients .We also do not have robust data on the use of Sacubitril-Valsartan in hospitalized patients with decompensated HF , those with HF complicating acute myocardial infarction and newly diagnosed HFrEF patients who are ACEi/ARB naive .

ESC guidelines 2016 for HF recommend Sacubitril/Valsartan as a replacement for an ACEi in ambulatory HFrEF patients, who remain symptomatic with NYHA class II to IV symptoms despite optimal treatment with an ACEi, a beta-blocker and a MRA. In addition, the ESC guidelines also require that candidate patients are able to tolerate ACEi or ARB at doses equivalent to enalapril 10 mg twice daily and have increased levels of natriuretic peptides , as in PARADIGM trial[29].

The ACC/AHA /HFSA 2016 focussed update on New Pharmacological Therapy for Heart Failure recommend Sacubitril/Valsartan for symptomatic chronic HFrEF patients with NYHA II or III symptoms, as a replacement for ACEi or ARB. ACC/AHA recommendation is more relaxed as it does not clearly state the need for beta-blockers and MRA pretreatment or the need for increased levels of natriuretic peptides, but, on the other hand, excludes patients with NYHA IV symptoms[30].

The best way to ensure translation of positive results reported by trials into clinical benefit is to treat as similar patients as possible to those studied in trials. Based on the PARADIGM HF trial , the ideal patient for Sacubitril/Valsartan seems to be an ambulatory symptomatic HFrEF patient on optimal treatment with an ACEi or ARB (at a dose equivalent to at least enalapril 10 mg twice daily), a beta blocker and a MRA, unless contraindicated, for at least 4 weeks, with a systolic blood pressure ≥ 95 mmHg, a serum potassium ≤ 5.4 mmol/L, an eGFR ≥ 30 mL/min/1.73m^2 and increased levels of natriuretic peptides, without a history of angioedema or other serious side effects associated with ACEi or ARB therapy.

If the patient is receiving an ACEi or an ARB at a dose lower than that equivalent to Enalapril 10 mg twice daily, the treating physician should ideally consider trying a 2-week testing period of Enalapril at 10 mg twice daily before starting Sacubitril/Valsartan at 100 mg twice daily.

A more conservative initiation and titration scheme can also be attempted in these patients (rather than the two week testing period) with a starting dose of 50 (24/26) mg twice daily for 2 weeks, followed by 100 mg twice daily for 3 weeks and then 200 mg twice daily .This more conservative approach has also been proposed for elderly patients as well as patients with moderate hepatic disease (Child-Pugh class B)[32].

If we go strictly by the PARADIGM HF criteria, Sacubitril/Valsartan should be used in patients who are on ACE inhibitor or ARB for at least one month as we are lacking evidence for patients with newly diagnosed HFrEF. Should they be established on an ACEi/ARB for at least 1 month before switching over to Sacubitril-Valsartan ?. In the Safety and Tolerability of Initiating LCZ696 in Heart Failure Patients (TITRATION) study of

dose escalation strategies of Sacubitril/Valsartan which included 498) patients, 7 % were ACE inhibitor or ARB-naïve and the rates of adverse events were similar to those reported inPARADIGM-HF. Hence FDA labelling is flexible and allow starting Sacubitril/Valsartan in ACE inhibitor/ARB-naïve patients at a lower dose with gradual up titration[26].

HOW SHOULD SACUBITRIL/VALSARTAN BE PRESCRIBED?

Sacubitril/Valsartan should not be given in conjunction with another ARB or ACE inhibitor. Due to the potential risk of angio-oedema when used concurrently with an ACE inhibitor, Sacubitril/Valsartan must not be started for at least 36 h after discontinuing an ACE inhibitor. This washout period is not necessary if the patient is receiving an ARB.

The starting dose of Sacubitril/Valsartan is 49 mg/51 mg twice daily. This should be reduced in certain groups (Table 1) . The dose should be doubled every 2–4 weeks as tolerated by the patient to the maximum dose of 97 mg/103 mg twice daily[32].

Table 1. Starting dose and dose titration for Sacubitril/Valsartan in a variety of patient populations with heart failure and reduced ejection fraction (HF-REF)

Population with HFrEF	Starting dose of Sacubitril/ Valsartan
No patient characteristics requiring caution or dose reduction	49 mg/51 mg twice daily
Currently only taking a low target dose of ACE inhibitor or ARB†	24 mg/26 mg twice daily
No ACE inhibitor or ARB in the past	24 mg/26 mg twice daily
GFR <30 mL/min/m^2†	24 mg/26 mg twice daily
Moderate hepatic impairment (Child–Pugh class B)	24 mg/26 mg twice daily
Elderly	24 mg/26 mg twice daily

Uptitration to be done by doubling of dose every 2–4 weeks until a target dose of 97 mg/103 mg twice daily is reached.

SIDE EFFECTS AND CAUTIONS

Renal function, potassium and blood pressure should be monitored as for any other RAAS blocker.

The development of angioedema should lead to immediate discontinuation and treatment with appropriate therapy until it has resolved.

Concern has been raised that neprilysin inhibition might lead to accumulation of amyloid beta peptides in the brain, implicated in the development of Alzheimer's disease, as neprilysin is one of the clearance mechanisms for these neurotoxins[33]. As multiple other enzymatic pathways and transport proteins are involved in the clearance of amyloid beta peptides in the brain, it is not known whether long term neprilysin inhibition might have a significant effect on accumulation of these peptides[34]. Dementia and cognition related adverse effects were not increased by LCZ696 in PARADIGM-HF trial. Howeve, serial cognitive function testing is planned in the PARAGON-HF trial in HFpEF patients and will hopefully allay this safety concern.

MONITORING TREATMENT

Sacubitril/Valsartan increases levels of circulating BNP therefore BNP is not useful for monitoring the prognosis of these patients[35]. NT-proBNP is still useful as a prognostic marker since it is not a substrate for Sacubitril.

CONCLUSION

Neurohormonal inhibition of RAAS by ACEI/ARB, MRA and that of SNS by betabockers were the cornerstones in the management of HFrEF for decades. The superiority of Sacubitril-Valsartan over enalapril in the PARADIGM HF trial in patients with HFrEF may herald a new era of HFrEF management, in which the focus will be shifting from neurohormonal inhibition to neurohormonal modulation. Based upon the robust data of PARADIGM-HF trial, Sacubitril-Valsartan may replace conventional ACEis or ARBs in many patients with chronic HFrEF. However, the potential value of Sacubitril-Valsartan in HFpEF, acute decompensated HF, post MI HF, and in newly diagnosed HFrEF patients who are ACEi/ARB naive, and of course the long term safety, needs to be convincingly demonstrated in future studies.

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Clinical Sign :The Hepatojugular Reflux

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WHAT IS IT?

Hepatojugular reflux (HJR) , more appropriately termed as Abdominojugular test or reflux (AJR) is a clinical sign implying incipient or latent right ventricular (RV) failure[1]. It is also known as the Pasteur-Rondot sign after William Pasteur who described it first as a sign of tricuspid regurgitation (TR) in 1885 and Edouard Rondot who named it 'HJR', but clarified subsequently in 1898 that it was not pathognomonic of TR[2].

WHAT IS THE MECHANISM?

When there is an increase in the pressure in the intraabdominal compartment followingsustained gentle, but firm compression over the abdomen for 15 seconds, this elevation in pressure and increased venous return from the splanchnic circulation gets transmitted through the inferior vena cava (IVC) to the right atrium (RA). This results in an elevation of the height of the jugular venous column[3]. Normally, this elevation of height of the jugular venous pulse (JVP) does not last for longer than a few cardiac cycles as the healthy right ventricle has enough compliance and contractile reserve to accommodate and handle this extra load. Hence the height of the venous column drops back to baseline in a normal person in a few cardiac cycles. However, in case of a right ventricle that is failing and is non-compliant resulting in increased RV end diastolic (and RA) pressure, the elevation of > 3cm in height of the JVP is sustained throughout the period of compression, and is denoted as a 'positive AJR'. In the absence of left heart failure, this suggests one or more of the following abnormalities of the right ventricle: a decreased RV compliance, RV systolic dysfunction or increased RV afterload[4].

HOW IS IT ACTUALLY DONE?

The patient should be in a position where the jugular venous pulsations can be properly observed (eg: supine with 45 degree angle). Ask the patient to breathe normally; normal breathing with the mouth open can help to avoid a Valsalva response during the abdominal compression[1]. The pressure applied should be progressive and then sustained for atleast 15 seconds at a level corresponding to approximately 20 – 35 mm Hg or upto a maximum 'weight' of 8 kg[2,5]. The venous column should be observed before, during and after the compression. The sudden fall in venous column may sometimes be more easily appreciated.

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SHOULD IT BE HJR OR AJR?

It is not necessary to compress over the liver. In fact, to avoid patient discomfort, it is preferable to avoid pressure on the right hypochondrium or directly over an enlarged tender liver in a patient with heart failure. Moroever, pain produced by the stretching of the hepatic Glisson's capsule may also inadvertently lead to a Valsalva response. Hence, pressure over the periumbilical area may be the ideal method.

WHAT ARE THE HEMODYNAMIC CORRELATES OF A POSITIVE AJR?

A positive AJR predicts an RA pressure > 9 mm Hg, RV EDP > 12 mm Hg and a PCWP > 15 mm Hg[6,7].

DOES IT HELP IN ANY OTHER WAY?

In case of doubt whether a neck pulsation is venous or arterial, the AJR can be used to confirm a venous pulsation if it becomes more prominent on doing the maneuver. AJR can also be used to augment or unmask the murmur of TR.

CAN IT BE ABSENT DESPITE RV FAILURE?

Yes, if there is concomitant hepatic vein thrombosis, as in Budd-Chiari syndrome, the increased venous return and elevated intra-abdominal pressure will not be transmitted to the RA and hence AJR may be 'false negative'[7]. Vigorous diuretic therapy can also mask a positive AJR. In a patient with Fontan circulation, AJR will classically be absent.

CAN THERE BE FALSE POSITIVE AJR IN ANY SITUATION?

Hypervolemia or fluid overload may give rise to a positive test. The increased work of breathing in chronic obstructive lung disease has also been mentioned in literature as a cause of false positive AJR due to the effect of altered intrathoracic pressure relationships[1].

WHAT CAN HAPPEN TO THE FIRST HEART SOUND DURING PERFORMANCE OF ABDOMINOJUGULARTEST?

Rondot originally made the astute observation that the first heart sound (S1) becomes softer during AJR. The increase in RA pressure reduces the early systolic pressure gradient between RV and RA and makes the T1 (tricuspid) component of S1 to become softer[3].

SHOULD AJR BE PERFORMED IN A PATIENT WITH CLEARLY ELEVATED JVP?

No. Routine examination for AJR does not add much in a patient with overt heart failure and an unmistakeably elevated JVP. On the other hand, it should be routinely checked in patients with a 'borderline' or doubtful JVP elevation[1].

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KJC Pearls

The Editorial Board of KJC invites teaching articles (Original Research Articles, Case Reports, ECG, X ray, Echo or Angiogram of academic value) to this section from all readers. Review articles unrelated to the topic of **"KJC Diamonds"** also invited.

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