THE UNIVERSITY OF NEW MEXICO HEALTH SCIENCES CENTER
CHILDREN'S HOSPITAL
OF NEW MEXICO

A PRACTICAL GUIDE TO

PEDIATRIC CARDIOLOGY

THE UNIVERSITY OF NEW MEXICO ✦ HEALTH SCIENCES CENTER
CHILDREN'S HOSPITAL
HEART CENTER

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17 October 1997

Dear Colleague,

It is our pleasure to provide you with *A Practical Guide to Pediatric Cardiology* from the Children's Hospital Heart Center at Children's Hospital of New Mexico, located witn the UNM Health Sciences Center. This is intended to encompass clinically relevant information about heart disease in children--both congenital and acquired--for the primary care giver: physician, nurse, technician. It has been organized for easy reference and will be updated as needed. Although initially planned for the pediatric residents, many other individuals (attending pediatricians, family practitioners, adult cardiologists, surgeons, nurses, etc.) have found it useful and requested copies. Therefore, we are providing this compendium as a service to the medical community and hope you will refer to it whenever you have a patient with possible heart disease or in follow-up.

If you have any questions or suggestions about the Guide, please feel free to contact us.

Sincerely yours,

J D Waldman
G. Holmes
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Children's Hospital Heart Center
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KEY CARDIAC INFORMATION

Adenosine (FOR SVT):

0.1 mg/kg IV ***RAPID*** push (up to 0.3mg/kg)
Continuous ECG monitoring

Prostaglandin E_1 (alprostadil)

To maintain or re-establish ductal patency
0.1 µg/kg/min IV (can be peripheral)
Watch for apnea; usually needs intubation

SBE Prophylaxis

All are: 1hr before op and **no second dose**.

Dental/Upper respiratory:
Amoxicillin 50mg/kg PO (max=2 grms)
PLUS
Clindamycin 10mg/kg

G-I/G-U : Ampicillin 50mg/kg IV or IM
PLUS
-Gentamicin 2 mg/kg (or vanco)

Emergency Cardiac Medications

- Dopamine drip: 5µg/kg/min IV (may increase as needed or **ADD**
- Dobutamine: 5-10µg/kg/min
- Atropine: 0.01-0.02mg/kg IV; MINIMUM dose=0.1 mg

New Mexico Poison Control = **800-432-6866**

Contents
A Practical Guide to Pediatric Cardiology

Abbreviations used in Congenital Heart Disease

AS = aortic stenosis.
ASD = atrial septal defect.
BD = balloon dilation.
CHF = congestive heart failure.
Coa = coarctation of the aorta.
CO = cardiac output.
CXR = chest X-ray
HLHS = hypoplastic left heart syndrome.
HPV = hypoxic pulmonary vasoconstriction
HR = heart rate.
IAA = interrupted aortic arch;
mVO_2 = myocardial oxygen consumption.
L→R = left-to-right; R→L=right-to-left.
LVOT = left ventricular outflow tract.
PAH = pulmonary artery hypertension.
PAP = pulmonary artery pressure.
PAcIVS = pulmonary atresia with intact ventricular septum.
PDA = patent ductus arteriosus.
PS = pulmonary stenosis
PGE_1 = prostaglandin E_1 (alprostadil).
pt = patient.
Pulm = pulmonary.
PVOD = pulmonary vascular obstructive disease. [NOT the same as PAH.]
PVR = pulmonary vascular resistance.
Qp = PBF = pulmonary blood flow.
Qs = systemic blood flow
RVOTO = right ventricular outflow tract obstruction.
TA = **not used**, as it might mean tricuspid atresia OR truncus arteriosus.
TAPVC = total anomalous pulmonary venous connection.
ToF = tetralogy of Fallot. ToF/PA = ToF with pulmonary atresia.
TGA = transposition of the great arteries
Truncus = truncus arteriosus
SV = stroke volume; *BEWARE*: also used for single ventricle.
SVR = systemic vascular resistance.
SVT = supraventricular tachycardia
Ventr = ventricle (ular).
VO_2 = oxygen consumption.
VSD = ventricular septal defect.

General review

1. Embryology

In the earliest stages of fetal development, nourishment of cells and disposition of wastes is handled by cell-to-cell diffusion; this quickly becomes inadequate for the number of cells and a more efficient method must be developed. The result is the cardiovascular system. Shortly before the body somites form, angiogenetic cells coalesce to form symmetrical endocardial tubes which subsequently fuse to form a single primitive heart tube (≈19 days of gestation). At this stage of embryogenesis, there are still two dorsal aortae which are connected to the heart tube by the early aortic arches.

Bringing blood to the heart are bilaterally symmetrical pairs of vitelline, umbilical and cardinal veins which drain (respectively) the yolk sac, the placenta and the body wall. Prior to segmentation of the heart tube, blood is propelled to the aortic arches and onward to the body by simple peristalsis of the muscular tube. The heart tube begins to separate into endo and epi-myocardial layers, after which indentations and outpouchings develop which divide the tube into five segments like hot dogs on a string. The Table below names the parts of the heart tube (numbers 1-5 below) from venous to aortic ends and shows what these parts ultimately become:

Early embryologic structure	Final (adult) structure
1. Sinus venosus	Great systemic veins; part of RA
2. Atrium	Right and left atria
3. Ventricle	Left ventricle
4. Conus	Right ventricle
5. Truncus arteriosus	Aorta and pulmonary artery

During the third week of embryogenesis, the heart tube begins a period of rapid growth. Being anchored at its ends by the veins and aortic arches, expansion is restricted to the central part of the tube which is forced to fold or loop. The direction of looping is not random, as chemical markers encourage the heart tube to bend anteriorly (ventrally) and to the right. By the end of the first month of embryogenesis, the external subdivisions (listed above) of the heart tube are evident, the tube itself is curved, and a contraction/relaxation sequence of the cells (similar to peristalsis) has commenced. At this point, septation of components of the tube begins. It is critical to remember that multiple changes occur concurrently: while the

atrial septae are growing, the ventricular wall is developing, the myocardium is excavating to form valves, the truncus is subdividing, and the aortic arches are forming, remodeling and resorbing. At no time is right heart blood completely separated from left heart blood.

The right side of the sinus venosus experiences differential growth forcing the sinus horns (with their accompanying great veins) to relocate to the right side of the developing atrium. After, and only after, the sinus venosus has moved to the right can septation of the atrium begin. A first wall (septum primum) grows towards the atrio-ventricular orifice and concurrently, in a plane *perpendicular* to the septum primum, the endocardial cushions grow towards each other dividing the [single] atrio-ventricular canal into two orifices: a right side, which will connect with the conus, and left side which leads to the primitive ventricle (ultimately to become the left ventricle). A subsequent wall, the septum secundum, begins to form to the right of the origin of the septum primum. The resultant arrangement of walls achieves a flap-valve opening. This allows right-to-left flow (in utero) but with the potential to close when left atrial pressure exceeds right atrial, as occurs after birth. [Were the atrial septum to close well before birth, the left heart structures would be underdeveloped because of lack of intra-uterine flow.] The final opening between the atria is called the foramen secundum or foramen ovale because of its oval shape; in the adult, this opening is sealed shut and is called the fossa ovalis or oval indentation. The atrio-ventricular canal is the orifice connecting the atrium to the primitive ventricle. Three processes occur concurrently to change the anatomy of this area: 1) the atrio-ventricular canal subdivides into two orifices, 2) the canal shifts rightward making connection with the conus, and 3) valves are formed within each orifice, all without stopping the circulation at any time. Undermining of the ventricular myocardium causes formation of papillary muscles to which the developing chordae of the a-v valves attach; the number and location of papillary muscles is dependent morphology of the undermining myocardium (two on the LV free-wall and one on the RV [conus-derived] free-wall).

During the fourth week of embryogenesis, an invagination from the 'floor' of the primitive ventricle near the ventriculo-conal fold begins to grow towards the atrio-ventricular canal; this will be the muscular portion of the interventricular septum. The orifice between this growing muscular septum and the endocardial cushions is called the interventricular foramen. Until the aortic part of the truncus opens a direct communication with the atrio-ventricular canal, the only way for blood to exit the primitive ventricle is through the interventricular foramen. Over time, the interventricular

foramen closes by centripetal growth of the: 1) muscular interventricular septum, 2) endocardial cushion tissue, and 3) conal septum. Closure is complete by the end of the second month of gestation (17-19 mm long embryo). Both the ventricle and the conus begin aggressive cell growth to become the left and right ventricles respectively. They have similar volumes but are anatomically different structure both grossly and in myocardial ultrastructure.

The right ventricle shows coarse, parallel-oriented trabeculae with the cristal system of muscle bars and a diminutive papillary muscle seen on the RV side of the muscular septum. The left ventricle has fine, obliquely running trabeculae and neither muscle bars nor papillary muscles on its septal surface. Viewed in cross-section, the LV has myocardial cells which form a complete circle of contractile elements while the RV contracts ON the LV. When evaluated functionally, the LV has greater capability for pressure work while the RV has a wider range of volume. Even the conduction system is asymmetric with the RV bundle having a single branch but the LV bundle branch subdivided into anterior and posterior divisions.

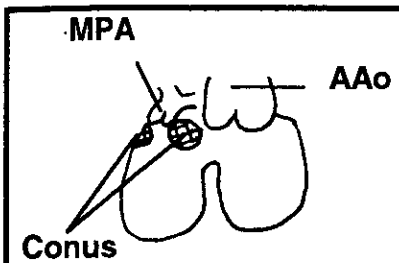
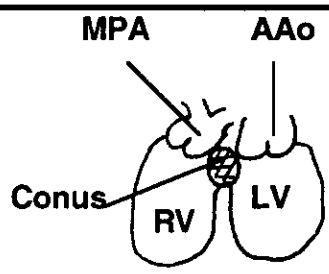
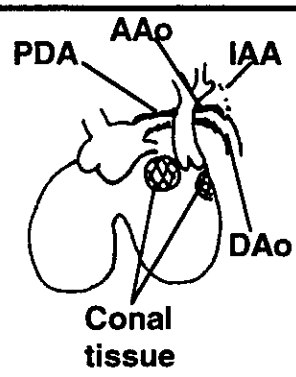
The truncus arteriosus, connecting the conus with the aortic arches, has truncal ridges in its lumen which commence growth from distalward towards the conus; they grow towards each other in a spiral fashion, ultimately making two channels (aorta and pulmonary artery) which spiral around each other. At the proximal end of the septated truncus, intercalated valve swellings develop which, in association with the truncal ridges, form the completely symmetrical semi-lunar valves.

One of the most complex movements during cardiogenesis is the truncal-ventricular union. If one approaches these events teleologically, it may be more comprehensible. The aortic channel of the truncus 'wants' to connect with the developing left ventricle. When it does so, the interventricular foramen will be able to close, separating cardiac flow into two circulations. The pulmonary channel of the truncus 'wants' to connect with the right ventricle and therefore can retain its normal luminal connection with the conus which will become the right ventricle. The two arterial channels-aortic and pulmonic, initally sharing a common exterior wall, separate. The pulmonary artery remains connected to the conus which becomes the right ventricle. Conus under the aorta reabsorbs, the aortic channel moves postero-inferiorly making contact with the atrio-ventricular canal part of the heart and opens a direct connection with the postero/inferior chamber, which is the primitive ventricle but which is becoming the morphologic left ventricle. Concluding the septation of the truncus and of the conus/ventricle, the truncal septum is seeking to fuse

with the point of union of the muscular interventricular septum, the conal septum and the endocardial cushions.

An example is given below to demonstrate the interaction of morphogenesis with flow effects resulting in the mature heart or maldeveloped heart. Orient yourself first on the middle panel. The side panels assume that the conal septum has migrated abnormally, too little in the left panel and too much on the right. Note the results of this single event.

EFFECT OF CONAL SHIFT ON CARDIAC MORPHOGENESIS

		
In the above drawing, the conal septum has not migrated (normally) posteriorly; this leaves a defect in the inter-ventricular septum and obstructs the RV outflow tract. The obstruction decreases intra-uterine flow which reduces the normal flow-stimulus to PA growth making the PA system hypoplastic. The above drawing depicts tetralogy of Fallot.	The line drawing above shows a normal lateral view of the conal septum (cross-hatched) and the remainder of the ventricular septum as well as the great arteries. Note that the conal septum (normally) is separated from both outflow tracts.	If the conal septum migrates too posterior, it again leaves a VSD (mal-alignment type) and now obstructs the LV outflow tract causing hypo-plasia of the AAo and loss of flow-stimulus for growth to distal aorta resulting in interrupted aortic arch (IAA) or severe coarctation.

Development (and resorption) of the aortic arches is summarized in the Table on page 6.

Adult Structure	Fetal Structure	Adult Structure
Main Pulm Art	TRUNCUS	Proximal AAo
	AORTIC SAC	AAo thru Brachiocephalic Art

AORTIC ARCHES

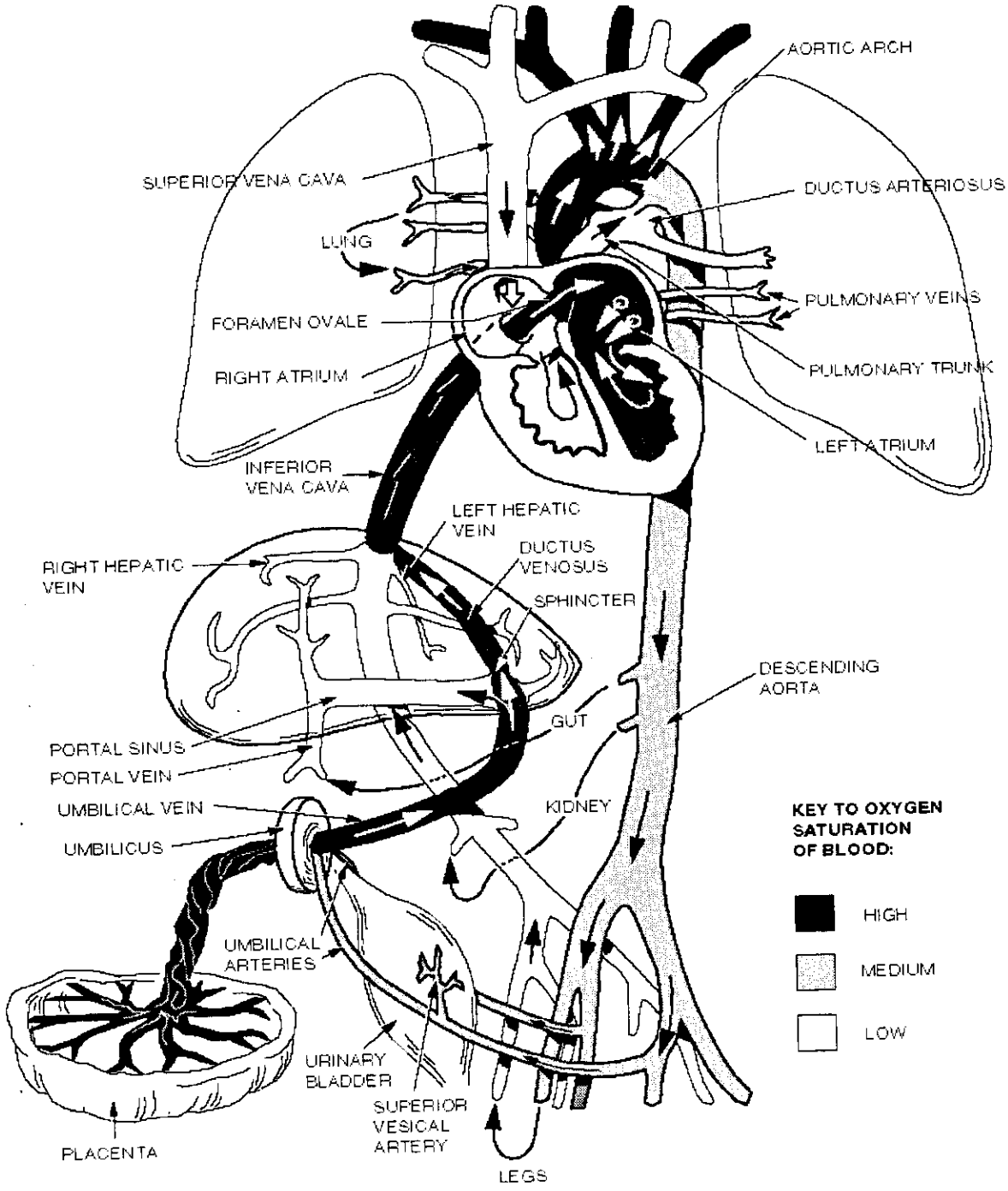
Right	Left
0 - - - - - - - - - - - 1	1 - - - - - - - - - - - - - - - 0
0 - - - - - - - - - - - 2	2 - - - - - - - - - - - - - - - 0
Rt Common Carotid Art--3	3---------Left Common Carotid Art
Rt Subclavian Art-------4	4------------Aortic Arch
0 - - - - - - - - - - - 5	5 - - - - - - - - - - - - - - - 0
Rt Pulm Art-------6	6----------Left Pulm Art + Ductus Arteriosus
	"7" (see text)--Left Subclavian Art

O = no known residua in the mature circulatory system.
Pulm=pulmonary. Art=artery. AAo=ascending aorta. Rt=right.

In utero, the organ of respiration for the fetus is the placenta. Although the fetal lungs move, they play no role in gas exchange. Average pO_2 in utero is ≈21-25 torr. [Consider this in context with the section on Pathophysiology of Cyanosis.] In utero, the right ventricle (RV) does more work than the left ventricle (LV): >55% of the combined ventricular output is pumped by the RV. By pumping blood through the ductus arteriosus, the RV supports the entire lower half of the body. [Remember the flow of blood in the normal fetal heart: IVC-to-RA-to-LA-to-LV-to-AAo and SVC-to-RV-to-MPA-to-DAo; see Figure below]

Note these differences between intra-uterine flow (see following Figure) and post-natal cardiovascular physiology.

- Flow in a large VEIN (the umbilical) is oxygenated and in the corresponding artery, the blood is de-oxygenated.
- IVC blood is oxygenated (coming from the placenta via the umbilical vein.)
- There is a streaming pattern in the RA such that SVC blood preferentially goes to the tricuspid valve while IVC [oxygenated] blood goes to the foramen ovale.
- Blood coming into the LA from the pulmonary veins is de-oxygenated and blood going into the blood (in the MPA) is also de-oxygenated.
- Flow through the ductus arteriosus is from MPA to DAO.
  Blood in the DAO is partly oxygenated (that component derived from the AAO and LV) and partly de-oxygenated (the fraction derived from the SVC-RA-RV-MPA).


AORTIC ARCH
SUPERIOR VENA CAVA
DUCTUS ARTERIOSUS
LUNG
PULMONARY VEINS
FORAMEN OVALE
PULMONARY TRUNK
RIGHT ATRIUM
LEFT ATRIUM
INFERIOR VENA CAVA
LEFT HEPATIC VEIN
RIGHT HEPATIC VEIN
DUCTUS VENOSUS
SPHINCTER
DESCENDING AORTA
GUT
PORTAL SINUS
PORTAL VEIN
UMBILICAL VEIN
KIDNEY
UMBILICUS
KEY TO OXYGEN SATURATION OF BLOOD:
HIGH
MEDIUM
LOW
UMBILICAL ARTERIES
URINARY BLADDER
SUPERIOR VESICAL ARTERY
PLACENTA
LEGS

Elements not covered in this abbreviated review include development of the coronary arteries, the pulmonary veins and the conduction system; excellent monographs are available in these subjects as is a complete chapter on Cardiac Morphogenesis. Ask Dr. Waldman for this information if you are interested.

2. Anatomy: ask Dr. Waldman to view the training video entitled "Basic Cardiac Anatomy - The Examination of Congenital Heart Specimens".

3. Physiology:

a) Shunt = diversion of blood flow to a pathway alternative to the normal flow sequence. Left-to-right (L→R) and right-to-left (R→L) apply only to the normal state where there are two circulations in series; when there is TGA or TAPVC, L→R and R→L are ambiguous, meaningless, and **should not be used**.

b) R = P ÷ F : resistance = pressure ÷ flow, loosely translated as 'blood flows downhill'. Remember, R = P ÷ F also means F = P ÷ R.

Clincal examples:

Condition	Pressure	Flow	Resistance
Large VSD at 3 mo	RV=LV=PA=Ao	L→R, ↑ PBF	PVR << SVR
Large VSD at 3 yrs	RV=LV=PA=Ao	No shunts	PVR = SVR
Large VSD at 10 yrs	RV=LV=PA=Ao	R→L, ↓ PBF	PVR > SVR
ToF c mild RVOTO	RV=LV=Ao	L→R, ↑ PBF	sl ↑ at RVOT
ToF c pulm atresia	RV=LV=Ao	R→L,ductal-dep	∞ at RVOT
AS, mild	LV > Ao	normal	sl ↑ at LVOT
AS, severe s CHF	LV >> Ao	normal	↑ ↑ at LVOT
AS, severe c CHF	LV > Ao	low C.O.	small LVOT
gradient			

d) Obstruction

1) Means abnormal resistance to forward flow causing part of the heart to do excessive work.
2) Gradient means pressure difference across the obstruction. One can have obstruction without a demonstrable gradient.
3) Venting means there is a defect which gives blood a pathway for flow other than through the obstruction. Example: AS + VSD. When the VSD is smaller than the aortic anulus, there is a 'partial' vent; some blood will be shunted L→R and there will be a gradient from LV to Ao; when the VSD is larger than the aortic orifice, there will be a large L→R shunt, full venting of

the LV and no LV-Ao gradient despite the AS.

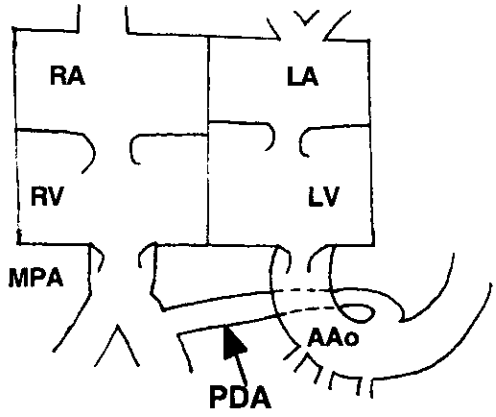
4) *Fixed* or *dynamic* [obstruction] refers to acute variability in degree of obstruction and generally is applied as a physiologic term; *discrete* vs *long-segment* refers more to anatomic appearance.

e) 'Common mixing lesion'

infers that at some point in the circulation oxygenated and de-oxygenated blood join, mix completely and proceed onward as a uniform concentration. Such a phenomenon is considered present in conditions such as complete atrio-ventricular canal, single ventricle (mixing at the ventricular level), and total anomalous pulmonary venous drainage (TAPVC; mixing at the atrial level). However, streaming is often present, making blood NOT uniformly mixed. In fetal and neonatal hearts, superior vena caval blood preferentially flows toward the tricuspid valve while inferior vena caval blood is 'aimed' at the foramen ovale. If there is TAPVC to the innominate vein, blood from the head and from the lungs [with increased oxygen saturation] would flow through the tricuspid valvem RV , MPA and into the lungs, while IVC [de-oxygenated] blood would fill the left atrium and systemic arterial system. Thus, in this 'common mixing lesion', blood would be quite un-mixed; indeed, the patient would have so-called transposition physiology (higher saturation in the pulmonary artery than in the aorta).

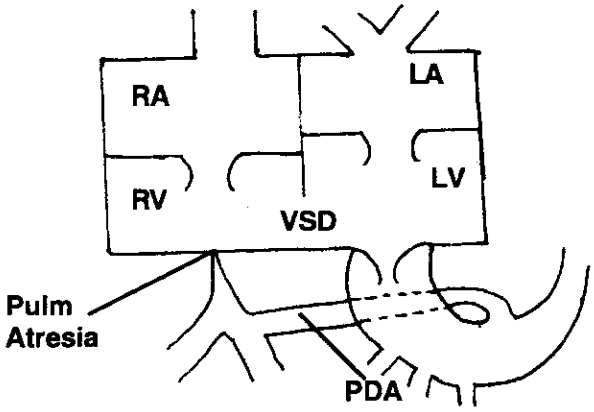
f) Ductal-Dependent Physiology

means that either pulmonary or systemic arterial blood flow is dependent on wide patency of the ductus arteriosus. Examples (as shown below): ToF with pulm atresia, Interrupted aortic arch (IAA), hypoplastic left heart syndrome (HLHS).



PDA without heart disease

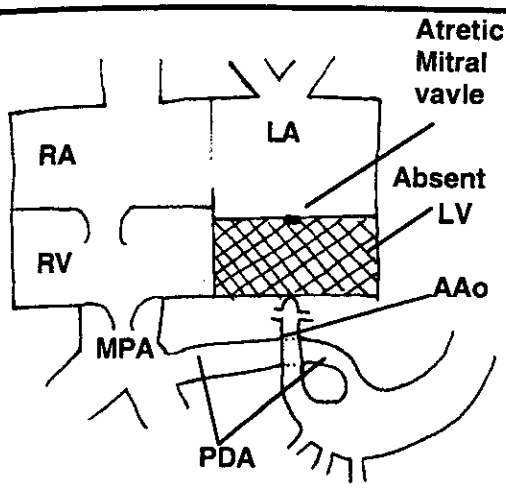
Volume and direction of flow are dependent on the resistance differential: Ao to PA, including PVR, SVR, and caliber + length of the ductus. Neither circulation is dependent on the ductus for flow.



Ductal-dependent Qp

Example: ToF with pulm atresia.

There is no route for direct flow from the heart to the lungs. Therefore, Qp is dependent on a L-R shunt through a widely PDA.



Ductal-dependent Systemic Blood Flow

Example: Hypoplastic LV syndrome.

There is no direct flow into the aorta and the ductus is necessary for both antegrade DAo flow as well as retrograde AAo flow to perfuse the coronary arteries. See HLHS in section on left heart obstruction for important additional physiologic information.

g) Timing of Presentation

When a patient has congenital heart disease, clinical manifestation of the pathology ("presentation") occurs when there is alteration from the neonatal physiologic state:

1) Ductal-dependent (presents at 1-3 weeks): when normal ductal narrowing occurs, patient exhibits symptoms, e.g., with IAA there is insufficient flow to the lower half of the body and in ToF/PA there is inadequate PBF.
2) PVR-dependent (presents at 1-3 months): shunt flow is dependent on level of PVR; patient develops symptoms when PVR << SVR resulting in a large L→R shunt, e.g., an isolated VSD.
3) When patient has both obstruction and shunting lesion (e.g., VSD + coarctation), the obstruction causes increased SVR which increases the tendency to shunt L→R. These patients present very early, usually within the first week of life.

Cyanosis and Congenital Heart Disease

1. Definitions:

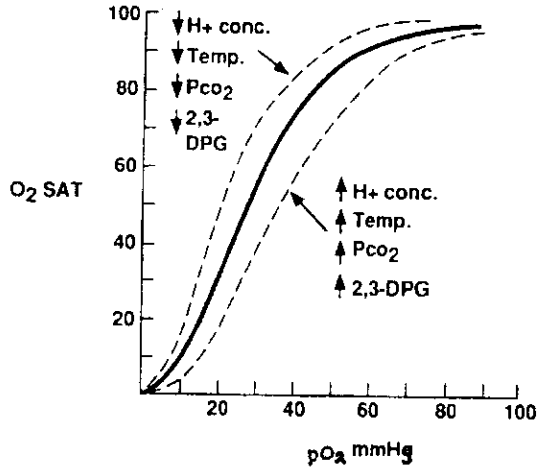
Cyanosis = the condition of appearing blue; (this is a perception, not a saturation value or a pO_2.)

Hypoxemia = reduced measurement of O_2 torr in systemic arterial system

2. Pathophysiology

O_2 transport: in blood, O_2 is mainly carried on Hb within RBCs; when oxygenated, HB is red and when deoxygenated (reduced), it is blue. BUT, to perceive cyanosis, the pt must have >4.5 gms of desaturated Hb. *O_2 saturation:* defined as the percentage of total hemoglobin molecules in the blood that are oxygenated. O_2 sat. is determined by:

a) intra-alveolar partial pressure of O_2
b) efficiency of O_2 transport from alveolus to capillary
c) the partial pressure (mm Hg) of O_2 in the serum
d) matching of ventilation and perfusion (V/Q)
e) the affinity of the molecule for O_2



O_2 dissociation curve (see Figure above): at high partial pressures there is little change in saturation despite big changes in pressure. In the middle range of O_2 pressures there is a marked increase in saturation for a given increment in O_2 tension.

Factors Affecting the Affinity of Hemoglobin for O_2:

a) ↑ Affinity (higher saturation at a given pressure of O_2) alkalosis, hypothermia, hypocapnea (low CO_2) , decreased 2,3 DPG, fetal hemoglobin

b) ↓ Affinity: acidosis, hyperthermia (fever), hypercapnea, increased 2,3 DPG, adult hemoglobin

c) Biochemical changes in Hb may make it incapable of carrying O_2: Carbon Monoxide: affinity of CO for O_2 binding sites on Hb is many-fold greater than O_2. This causes Hb to appear cherry red even though the pt's O_2 sat is ↓. Methemoglobinemia: methylation of Hb molecule, associated with nitrates, analine dyes, etc. Patient will be well saturated but have poor color, blood appears chocolate; check methemolobin level.

hydroxyurea for hypoxia?

O_2 content versus O_2 saturation: it is the arterial **O_2 content** that determines availability of oxygen to the tissues. This is calculated as: (Hb) x (1.39) x (Sat.) *Compare an adult and a neonate with the same oxygen tension:* a) adult with pO_2 of 40 mm Hg has a sat. of 70%; with normal Hb of 15 gm/dl, O_2 content = (15) x (1.39) x (.70) = 146 ml O_2/ L; b) A baby with a pO_2 of 40 mm Hg has a higher O_2 sat. of 75% because of fetal Hb. The infant also has more Hb (20 gm/dl) which results in an O_2 content calculation as follows: (20) x (1.39) x (.75) = 203 ml O_2/ L. *Conclusion:* A neonate is better able to tolerate lower pO_2 because of the increased Hb affinity for O_2 and higher Hb.

Difference between cyanosis and insufficient O_2 availability: the neonate with a pO_2 of 40 mm Hg and a Hb = 20 gm/dl will have a sat of 75% resulting in 5 gms/dl of desaturated Hb. He will appear blue yet his oxygen content will be the same as one of us "normal adults" with a Hb = 15 gm/dl and 100% saturation. Conclusion: a person can appear cyanotic, but be getting enough O_2 (not hypoxic). [The opposite is also true, especially in anemia.]

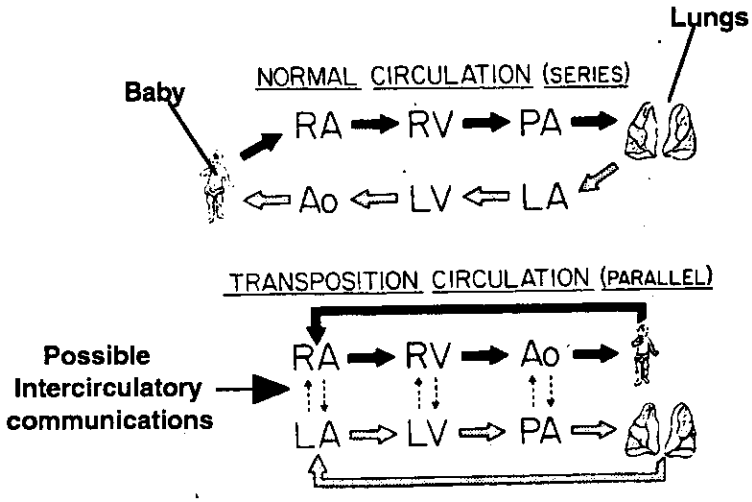
Importance of distinguishing central from peripheral cyanosis:

a) Acrocyanosis: slow blood flow allows greater removal of oxygen by the tissues, more desaturation and blueness in the hands and feet (acrocyansosis). This is common in babies with high

Hct.

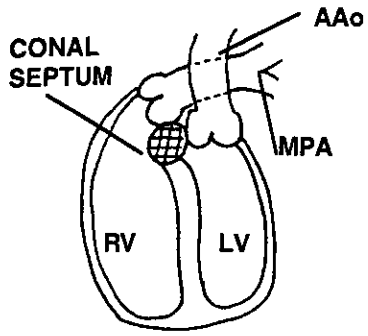
b) Central cyanosis (a more reliable indicator of desaturated arterial blood): systemic venous blood bypassing the pulmonary capillary system and entering the systemic arterial circulation deoxygenated.

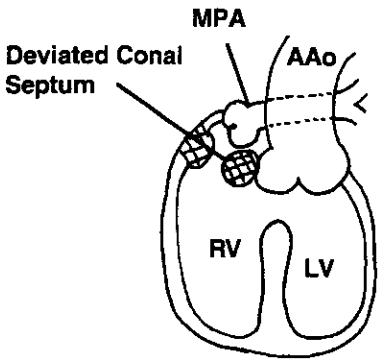
'Transposition physiology' refers to the condition where the saturation or pO_2 in the pulmonary artery is higher than in the aorta. This is only found in cyanotic heart defects such as TGA but can also be seen in double outlet situations where it is caused by streaming. Furthermore, transposition anatomy can often give equal saturations in the two great arteries and therefore anatomy must be distinguished from physiology. The drawing below summarizes the difference between normal *serial* circulation and *parallel* circulations found in TGA.
[Without an ASD/PFO or VSD, all children with TGA would die immediately after the cord was clamped (even with a PDA).]

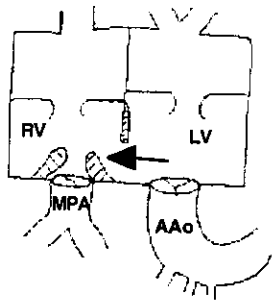


3. Differential Diagnosis of Cyanotic Congenital Heart Disease

a) *Anatomic* Differential Diagnosis ("Five Ts"):

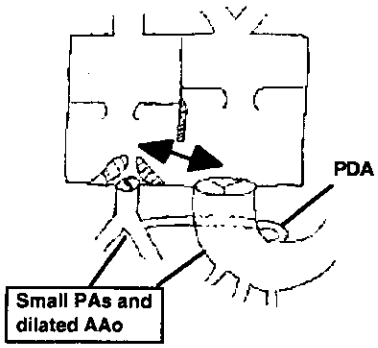
<table>
<tr>
<td>Normal heart
 
</td>
<td>Normal heart from lateral viewpoint.

Note the position of the conal septum in relation to the great arteries and the interventricular septum. The AAo is more cephalad than the MPA by the subpulmonary conus. Note that the AAo and MPA 'cross' in space and that the normal ascending aorta over-rides the interventricular septum by ≈15-20%.</td>
</tr>
<tr>
<td>Tetralogy of Fallot
 
</td>
<td>1) Tetralogy of Fallot (ToF) = under-development of subpulmonary conus causing subpulmonary obstruction and a large mal-alignment VSD. Note that the conal septum is deviated antero-superiorly. As a result of the subpulmonary obstruction, the MPA grows poorly in utero and the AAo is correspondingly large because of the greater in utero blood flow.</td>
</tr>
</table>



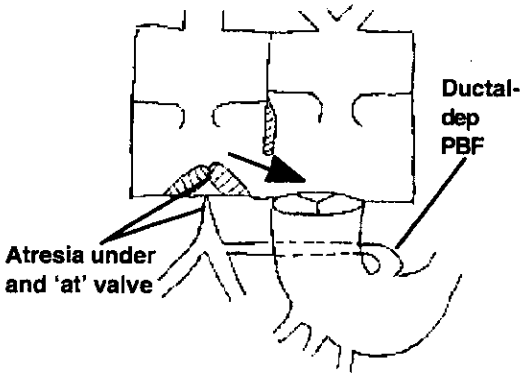
1a) 'Mild' Tetralogy of Fallot

Though there is subvalvar muscular (dynamic) PS, the total resistance to flow from RV to lungs is less than the SVR and therefore, the shunt is L→R and the pulmonary arteries are good-sized. This pt is not cyanotic at rest but is a good candidate for ToF spells.



1b) 'Moderate/Severe' Tetralogy of Fallot

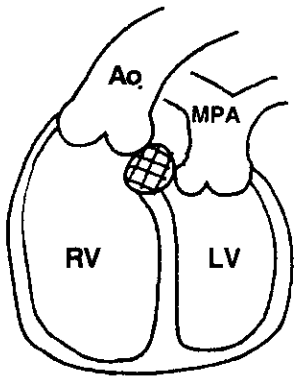
Major obstruction is seen at the subvalvar level making resistance to RF outflow and SVR similar; therefore, the shunt is bidirectional. The pt is cyanotic at rest from the R→L part of the ventricular shunt. PA size is likely to be < normal. Pt can 'spell' but less likely to do so than pt 1a.



1c) Tetralogy of Fallot with Pulmonary atresia

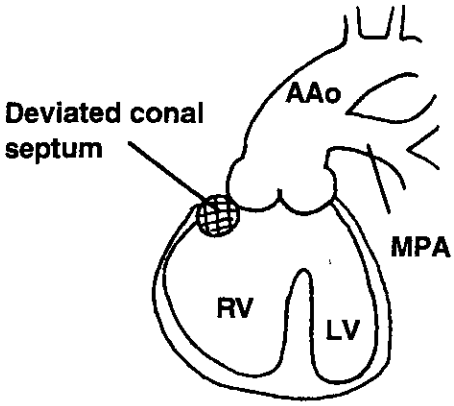
Complete obstruction (atresia) under the valve from non-expansion of the subpulmonary conus; therefore, there is no direct RV-to-PA flow. Ventricular shunt is solely R→L. Pulmonary artery system is always hypoplastic. PBF is ductal-dependent and patient's degree of cyanosis depends primarily on the volume of ductal flow.

Transposition of the Great Arteries



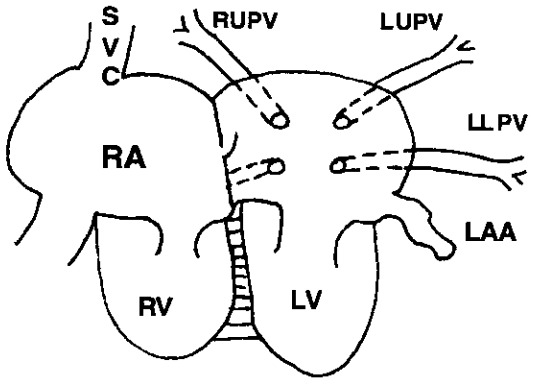
2) Transposition of the great arteries
(TGA) = AAo arising from morphologic RV and MPA arising from morphologic LV.
Note that the great arteries are parallel rather than crossing; this is easily seen on echo and is pathognomonic of TGA. Note also that without an associated defect (PDA, PS, VSD), there is no turbulence and therefore no murmur.

Truncus Arteriosus

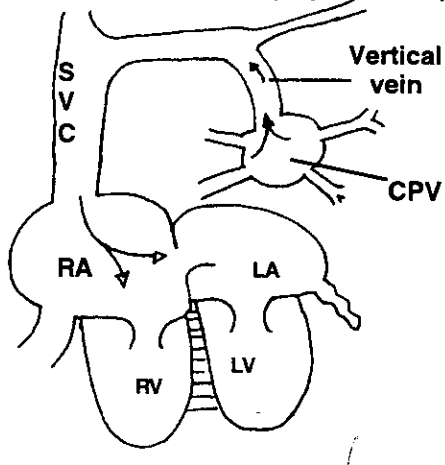


3) Truncus arteriosus = single arterial trunk arising from base of heart giving origin to the pulmonary arteries, the coronary arteries and the AAo.
Note the extreme deviation of the conal septum with (always) a large mal-alignment (ToF-like) VSD. Some times, the pulmonary arteries arise separately and sometimes there is interrupted aortic arch. Like ToF, a large percentage has right aortic arch.

Normal Pulmonary Venous Drainage



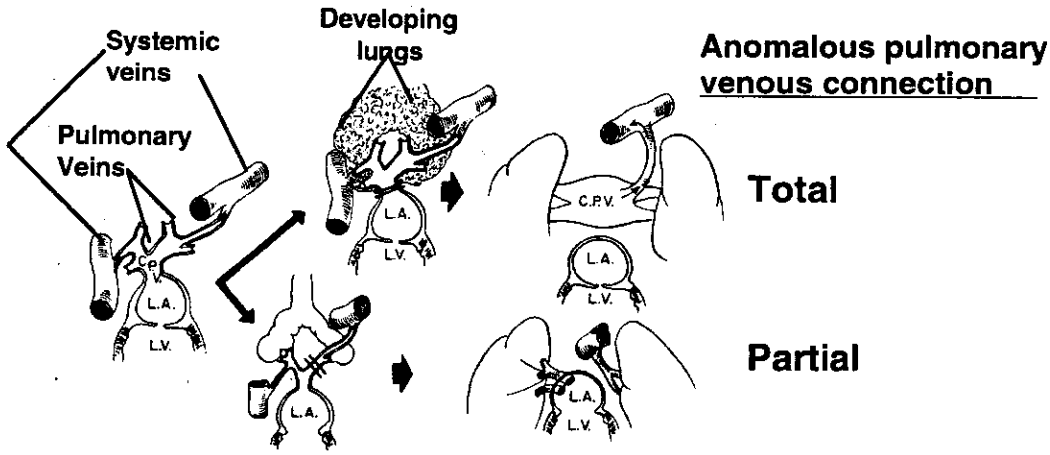
Total Anomalous Pulmonary Venous Connection (supracardiac)



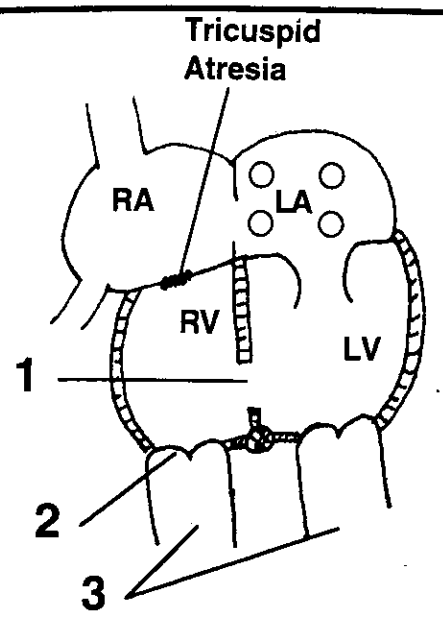
all babies should have S a O2?

4) TAPVC (total anomalous pulmonary venous connection): all pulmonary veins drain to point(s) in right heart or systemic veins. Left lower picture on page 17 shows complete (normal) incorporation of pulmonary veins (and therefore the common pulmonary vein, CPV) into the LA with normal flow pattern. Right lower picture (page 17) shows supracardiac TAPVC with the CPV draining to the ascending vertical vein which joins the innominate vein; follow the blood flow and note that the only way to fill the left heart and systemic circulation is by R→L shunt through an ASD. 'Clinical Pearl': the *only* condition in medicine where the umbilical venous pO_2 is higher than the umbilical arterial pO_2 is TAPVC to the portal vein. This finding is unqualifiedly diagnostic.

The drawing which follows summarizes the abnormal embryogenesis which results is non-communication of the CPV (common pulmonary vein) with the LA, called TAPVC versus incomplete incorporation of the CPV, called partial anomalous pulmonary venous connection.; the latter does not cause cyanosis.



5) Tricuspid atresia and other rt heart syndromes; to keep the mnemonic simple (e.g., five 'T's), most people lump pulmonary atresia with intact ventricular septum into this category of cyanotic congenital heart disease. On pages 19 and 20, there appear explanations of the anatomic factors which determine the pathophysiology and therefore the treatment for pts with tricuspid atresia. Drawings 2-4 are some examples of variations of these factors.



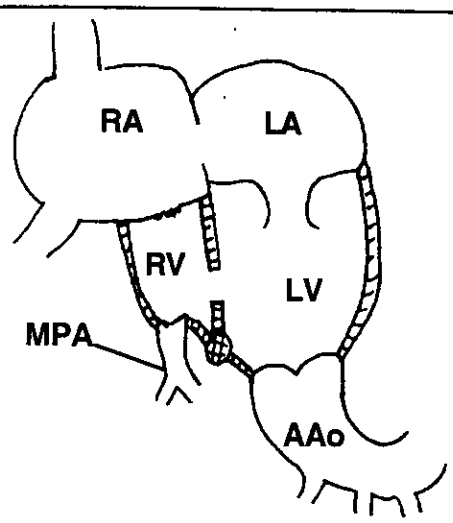
Tricuspid atresia: factors which determine the physiology:

1 = Size of VSD; if tiny, then RV is severely hypoplastic and RV-related great artery receives no direct flow. If large, then RV can even be of normal size.

2 = Stenosis of semilunar valve arising from the RV; determines vol of flow into its great artery.

3 = Great vessel relation: TGA or normally related.

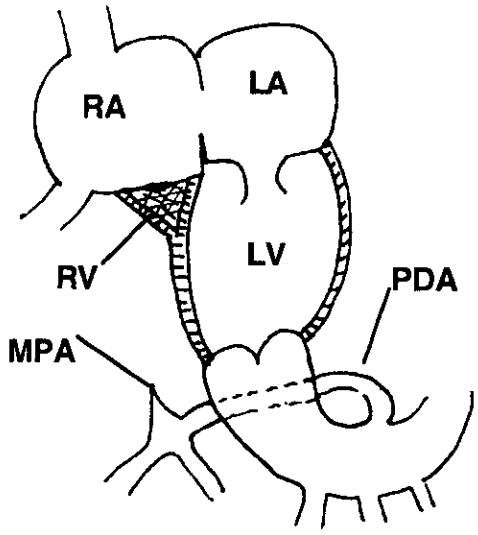
See examples below; consider some of the other potential variations and their physiologic effects.



Pt to left has: Tricuspid atresia + small/moderate VSD; PS; normally related great arteries.

Restrictive VSD makes RV small; Small RV and PS makes MPA small; Two above factors make the Qp inadequate.

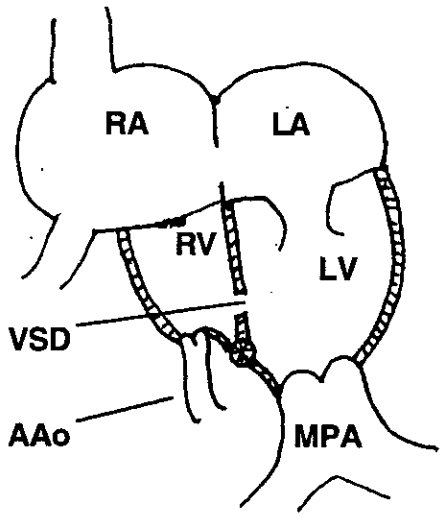
Pt needs more Qp, i.e., needs a shunt.



Pt to left has: Tricuspid atresia + Normally related great arteries; No VSD and therefore no RV; No trans-RV flow in utero and therefore Pulmonary atresia;

Qp is ductal-dependent and therefore, pt needs a shunt.

This is a fairly common form of Tricuspid atresia: absent RV syndrome.



Pt to left has: Tricuspid atresia + small/moderate VSD; AORTIC stenosis and TGA (Ao from RV and MPA from LV).

The small VSD has reduced flow in utero causing hypoplasia of the RV, aortic valve, and AAo.

FUNCTIONALLY, the pt has hypoplastic left heart syndrome and needs a Norwood operation.

b) *Pathophysiologic* Differential Diagnosis

1) Independent pulmonary and systemic circulations (circulations in parallel, not in series). This causes **severe** cyanosis, e.g., TGA.
2) Inadequate pulmonary blood flow: degree of cyanosis is variable, depending on degree of patency of the ductus arteriosus. Examples: ToF, tricuspid or pulmonary atresia
3) Admixture lesions (mild-to-moderate cyanosis): TAPVC

4. Evaluation of Cyanotic Infant:

a) determine adequacy of tissue oxygenation
b) determine the cause of the cyanosis

Methods:

a) Get an objective measurement to confirm your observation
   1) ABG
   2) transcutaneous oximetry (less invasive)
b) Brief Hx
   1) Maternal Illness
   2) Birth hx, APGARs
   3) Family hx
c) General physical exam
   1) Appearance: in distress?, central or acro-cyanosis
   2) Respiration: e.g., pulmonary disease is a more likely cause of cyanosis in presence of tachypnea, retractions, grunting. An infant, cyanotic with heart disease, either breathes normally or with mild tachypnea or hyperpnea but not with distress.
   3) CNS: periodic breathing, apneas suggest central hypoventilation as cause of cyanosis
d) C-V exam
   1) Pulses and capillary refill
   2) Precordial activity
   3) Thrills
   4) Murmurs
   5) Second Heart Sound
   6) Abdomen
e) Laboratory Studies
   1) O_2 Sat, ABG, CBC, glucose [If pO2 < 30, O_2 sat < 60, or there is poor perfusion, check blood lactic acid level.]
   2) ECG useful quick screening tool for heart disease
   3) When lung disease is in differential, get CXR, place baby in 100% O_2 hood and repeat ABG in 10-15 min (O_2 sat. determination is inadequate). Watch baby carefully for clinical deterioration as the extra O_2 may induce ductal constriction. Results: i) pO_2 > 300 mm Hg $\rightarrow$ neither significant heart or lung

disease. ii) pO_2 >150 mm Hg→sig hrt dis unlikely, problem is probably pulmonary

iii) *Exceptions to the rules*: Infants with no heart disease but persistent pulmonary hypertension of the newborn with a large ductal R-L shunt may have very low pO_2. Infants with supracardiac TAPVR can rarely have pO_2 up to ≈200 mm Hg.

g) Echocardiography-*when done by an experienced technician or pediatric cardiologist* is the definitive test for all forms of cyanotic heart disease.

CXR in Cyanosis: pay special attention to pulmonary vascular markings (Qp),

1) Qp ↑ usually = TGA but may be TAPVC or truncus
2) Qp ↓ usually = ToF or hypoplastic rt heart syndrome
3) Heart size and shape both important
4) Pay special attention to abdominal and thoracic SITUS.

EKG in Cyanosis

1) "Southwest" QRS axis suggests TGA, TOF, Ebsteins
2) "Northwest" QRS axis suggests Tricuspid Atresia, DORV
3) "Southeast" QRS axis suggests Pulmonary Atresia

5. Management

a) An infant with severe cyanosis of cardiac origin often needs to maintain ductal patency: i) to supply pulmonary blood flow (Tricuspid Atresia, Pulmonary Atresia, TOF etc.) or, ii) for mixing (TGA)

b) PGE_1 (alprostadil) is generally started at 0.1 µg/kg/min and can be reduced to 0.05 µg/kg/min when adequate ductal patency is demonstrated.

c) PGE_1 can cause apnea, hyperthermia, flushed appearance

d) If transport is necessary ON PGE_1, intubate electively before transport, to prevent an emergency procedure en route.

e) High PEEP should be avoided in cyanotic lesions in which there is insufficient PBF as this will further impede systemic venous return.

f) Administration of oxygen while on PGE_1 is safe. It will not cause ductal constriction.

g) Irradiate blood and blood products for transfusion until status of (e.g., possibility of Di George syndrome) is determined to avoid potential graft-vs-host reaction. [This is generally standard procedure in neonatal ICUs.]

Congestive Heart Failure

1. Definition(s)

Heart failure occurs when cardiac performance is inadequate to meet the body's need for blood flow. This can occur because: a) the heart muscle itself is weak (e.g., a myocarditis or a myopathy, or b) the workload of the heart is excessive (e.g., an excessive L-R shunt through a VSD causing a volume overload or excessively high blood pressure from renal dysfunction causing a pressure overload). What we recognize clinically as heart failure is really a summation of the underlying hemodynamic abnormalities that provoke the failure and the body's attempts to compensate for inadequate cardiac performance.

Qp),

2. Pathophysiology

To understand the pathophysiology of heart failure and how it can be treated, one must first understand the determinants of cardiac output.

a) Pre-load: Ventricular filling volume, determines initial stretch of sarcomeres, thereby affecting the number of interacting actin myosin elements which in turn generates force.

b) After-load: stress distributed in the ventricular wall which must be overcome by myocardial shortening and ejection.

c) Contractility: variable force of ejection independent of loading.

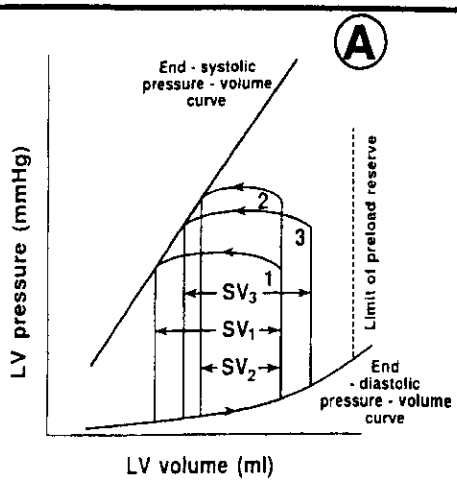
d) Heart rate. [Remember: CO = SV x HR.]

3. Mechanisms to compensate for low Cardiac Output

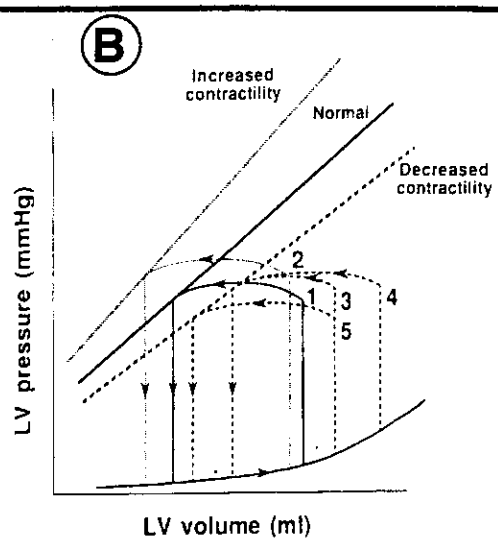
a) Frank-Starling

i) compensates for ↑ afterload (see Graph A, page 24)

ii) compensates for ↓ contractility (see Graph B, page 24)

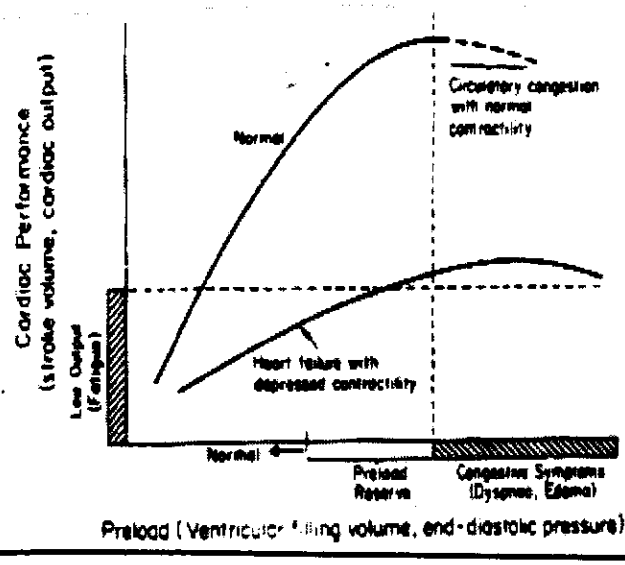


(A) Above: Response of normal hrt to increase in afterload. Loop 1 originates from normal end-diastolic volume and ejects normal quantity of blood. Loop 2 represents diminished stroke volume in response to acute increase in afterload. Loop 3 represents compensatory redistribution of total load to return stroke volume to normal; contraction begins at a sl. larger end-diastolic volume but with slightly less afterload and despite greater end-SYSTOLIC volume, stroke volume is comparable to original [normal] beat.



(B) Above: Effect of changing contractility on LV pressure-volume relation. Loop 1 represents normal contraction. Loop 2 shows effect of increase in contractility. In loop 3, with decreased contractility, stroke volume is diminished despite larger end-diastolic volume. At this same level of contractility, stroke volume may be restored with an increase in preload (loop 4) or a decrease in afterload (loop 5).

iii) *Drawbacks:* Moving up on the Starling curve increases the end-diastolic atrial pressure which in turn increases pulmonary and systemic venous pressures predisposing to pulmonary congestion and edema and hepatomegaly.



Frank-Starling Mechanism

Idealized ventricular function demonstrating Frank-Starling mechanism. Cardiac performance, represented by stroke volume or cardiac output, is related to some estimation of pre-load, ventricular end-diastolic volume, or pressure.

b) Myocardial hypertrophy: The thickness of the heart muscle itself is a determinant of wall stress and afterload such that thicker heart muscle:

i) Reduces mVO_2 by decreasing wall stress

ii) Maintains emptying of overloaded ventricle

iii) *Drawbacks:*

↓ vent compliance pre-disposing to diastolic dysfunction

may pre-dispose to subendocardial ischemia if myocardial hypertrophy outstrips vascular growth

c) Sympathomemetic secretion: When blood pressure falls, reflex activation of the sympathetic nervous system results. Through stimulation of cardiac and vascular adrenoreceptors this causes:

I) ↑ contractility

ii) ↑ heart rate

iii) ↑ vascular tone (↑ peripheral resistance)

iv) ↑ angiotensin II/aldosterone/NA^+/H_2O retention/volume activates Frank-Starling

v) *Drawbacks:* ventr end-diastolic pressure predisposes to pulm edema & ↑ mVO_2

d) Atrial naturetic protein(s)

i) Vasodilatation

ii) ↑ urinary NA^+ loss

iii) *Drawback:* Hyponatremia

e) ↑ 2,3-DPG (increases tissue ability to extract O_2 by shifting O_2 dissociation curve to the right).

Note: THE DELETERIOUS EFFECTS OF THE COMPENSATORY MECHANISMS CAN OUTWEIGH THEIR BENEFITS. HEART FAILURE CAN BE SELF-PERPETUATING IF NOT THERAPEUTICALLY INTERRUPTED.

4. Clinical Features of CHF

a) History

i) Neonate: may have acute presentation
Feeding difficulties; poor wgt gain
Diaphoresis; wheezing & non-productive cough

ii) Child: Decreased exercise tolerance
Decreased appetite
Respiratory difficulties, esp orthopnea
Onset can be slow/subtle or sudden

b) Physical Exam

i) Neonate/infant:
↑ HR and ↑ respiratory rate
Hepatomegaly & peri-orbital edema
Mottled, cool extremities
Gallop rhythm

ii) Child: similar to infant, plus-
Jugular venous distention
Rales; peripheral edema

c) Labs

i) CXR: Cardiomegaly +/- abnormal shape
↑ pulmonary vascularity
Atelectasis; fluid in fissures
Hyper-inflated lungs (air trapping)

ii) ECG: Chamber enlargement
Decreased voltage in myocarditis
ST segment elevation/PR segment depression in pericarditis

iii) Blood gases: Hypoxemia
metabolic acidosis
Respiratory compensation

iv) Normal calcium and glucose levels critical to neonates.

v) Anemia ↑'s requirement for CO and also ↑ L→R shunting

5. Age-specific Differential Diagnosis

Remember reasons for CHF:

a) Left Heart obstruction: usually ductal-dependent, NOT problem

when ductus open. Can acutely decompensate when ductus closes, usually within first 3-10 days of life.

b) L→R Shunt volume is dependent on PVR and therefore usually is NOT manifest till pt older (4-8 weeks old).

c) When have both (e.g., Coa + VSD), pt presents very early because obstruction exacerbates the shunt, and the ↑'d shunt is tolerated less well because of the obstruction.

d) In the uterus, left heart obstruction is not manifest because of PDA and L→R shunt not relevant because lungs are collapsed (making PVR ⇑⇑). Therefore, to have fetal CHF, something must effect the myocardium in utero.

FETUS: i) Volume overload (e.g., Erythroblastosis fetalis; systemic arterio-venous fistula)
ii) Atrio-ventricular valve regurgitation (e.g., severe A-V canal defect)
iii) Rhythm disturbance (e.g., SVT or heart block)

First week: i) Left heart obstruction (e.g., HLHS, Coa, IAA, AS)
ii) Sepsis
iii) *Obstructed* total anomalous pulmonary venous connection
iv) Systemic arterio-venous malformation
v) SVT
vi) Myocardial dysfunction 'syndrome' (may be secondary to intra-uterine [?viral] myocardial infection

'Older': i) Left heart obstruction (less severe than those presenting in first week of life; usually only one level of obstruction.)
ii) L→R shunts (PDA; VSD; A-V canal)
iii) Complex shunts (single ventricle without PS; TGA with VSD; truncus arteriosus, total anomalous pulmonary venous connection *without* obstruction)
iv) Primary myocardial dysfunction.

6. Drug Treatment of CHF: Pressors

a) Digoxin: i) increases available intracellular Ca^{++} by 'poisoning' the Na^{+}/K^{+} ATPase system.
ii) has anti-sympathetic effect through CNS → ↑ HR and vasodilatation.
iii) Beware in myocarditis and in left heart obstruction: myocardium may be very sensitive and digoxin may build up because of ↓ renal clearance.
iv) Digoxin is excreted ≈85% by the kidney
v) Dosage notes (see Table below)

-Digitalize as fast (or slow) as pt went into CHF.
-Digoxin levels used only in case of possible intoxication
-Parenteral dosage is 2/3 of the oral dose.
-The only liquid form should be 50µg/cc; do not even stock any other concentration.

Patient's Age:	Total Dig'ing Dose	Maint. Dose (daily)
Premature (µg)	20 (/kg)	5 (/kg)
Full term (µg)	30 (/kg)	8-10 (/kg)
< 2 years (µg)	40-50 (/kg)	10-12 (/kg)
2-10 years (µg)	30-40 (/kg)	8-10 (/kg)
> 10 years (µg)	75-250 (**total**)	125-250 (**/day**)

b) Dopamine
   i) Catecholamine precursor of epinephrine
   ii) In *low dose* acts on dopaminergic receptors renal blood flow resulting in urinary loss of NA^+ and H_2O
   iii) In *medium doses*, it has inotropic effect through β_1 and β_2 adrenergic receptors
   iv) In *high doses*, dopamine acts on α adrenergic receptors causing vasoconstriction.
   v) Propensity to tachycardia, especially in higher dosage range
   vi) Drug effect may attenuate due to catecholamine depletion
   vii) DOSAGE: 3-30 µg/kg/min
   viii) Physiologic effects of low, medium, high doses are age dependent
c) Dobutamine
   i) synthetic sympathomimetic agent
   ii) Inotropic effect with less tachycardia than dopamine
   iii) Decreases SVR (in contrast to high dose dopamine)
   iv) High dose dobutamine OR high dose dopamine causes greater ↑ in mVO_2 than combination of BOTH together in medium dosage.
   v) DOSAGE: 5-20 µg/kg/min
d) Amrinone
   i) phosphodiesterase inhibitor which ↑ cAMP → ↑ Intracellular Ca^{++}
   ii) ↑ contractility
   iii) ↓ afterload
   iv) → ↓ PVR
   v) may cause thrombocytopenia

vi) DOSAGE: 3-10 μg/kg/min

6. Drug Treatment of CHF: Vasodilators

Reduce afterload or pre-load or both

a) *ACE inhibitors* (inhibit formation of angiotensin II and promote formation of bradykinin--a potent vasodilator) such as:
Captopril- may cause: proteinuria/glomerulonephritis; neutropenia.
Enalapril- similar but fewer complications than captopril; can be given once daily and can be given orally.

b) *Ca^{++} channel blockers* reduce contraction. Examples: nifedipine, diltiazem, verapamil.

c) Prazozin (Minipress): oral α antagonist with no α_2 receptor blockade and therefore causes less ↑ HR.

Agents below can only be given intravenously:

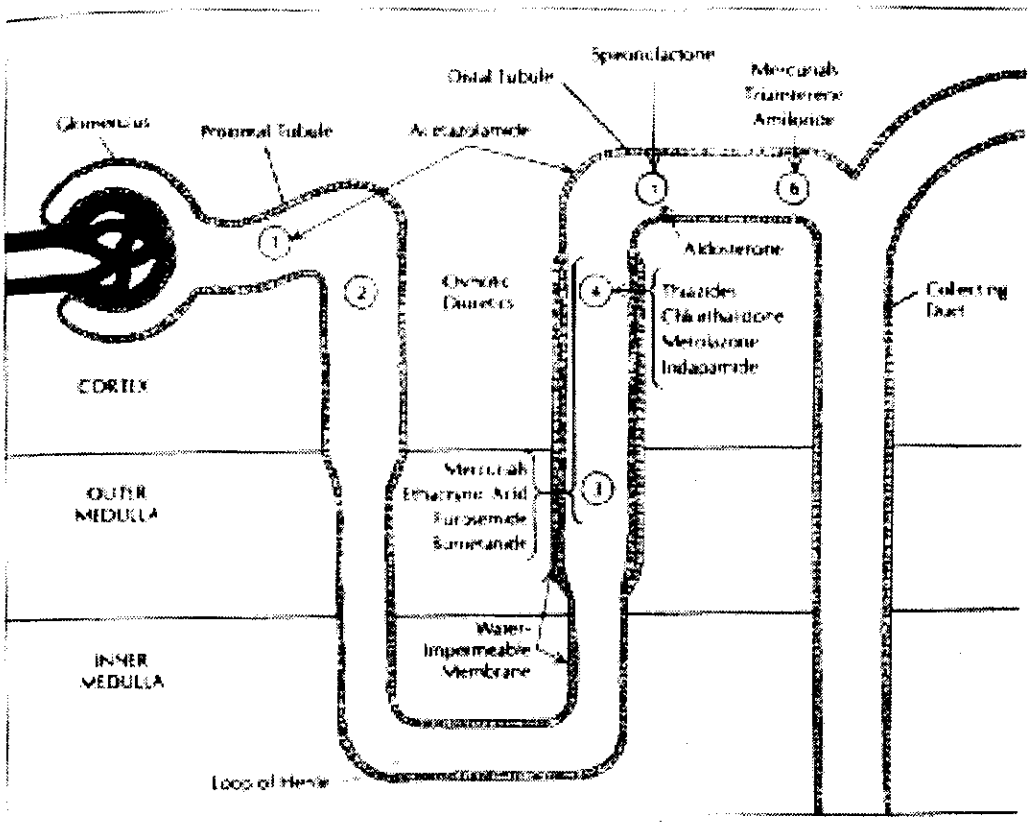
d) *Nitrates:* Nitroprusside is Nitric Oxide donor and affects arterioles > veins; be careful re: CNS and thiocyanate toxicity. Nitroglycerin affects veins > arteries and may cause methemoglobinemia.

e) *Phentolamine:* α antagonist with α_2 receptor blockade; may cause tachycardia due to norepinephrine release.

6. Drug Treatment of CHF: Diuretics

General effect: reduce intra- or extra-vascular volume by causing inhibition of Na^+ reabsorption causing negative Na^+ balance. Because Na^+ reabsorption is coupled to other tubular functions at various locations within the kidney, one must consider the *site* of action of a potential diuretic to assess the clinical implications its corollary effect(s) on electrolyte, fluid and acid/base balance.

The proximal tubule is sensitive to diuretics inhibiting carbonic anhydrase and hydrogen ion secretion (1). Proximal-acting diuretics increase delivery of sodium and water to the ascending limb of Henle and more distal nephron and, ultimately, increase free water reabsorption or production, depending on ADH activity or its absence. An osmotic diuretic (e.g., mannitol) acting in the proximal tubule (2) also would enhance free-water reabsorption at a site where major free-water generation would also be inhibited. At the same time, such an agent impedes delivery of osmotically active material into the medullary interstitium, impairing its ability to reabsorb free water. A diuretic acting solely in the cortical diluting segment (4) affects free water production but not reabsorption. Diuretics that enhance sodium passage proximal to the distal nephron will enhance K^+ secretion, thereby increasing K^+ loss. Diuretics acting in the distal tubule conserve K^+ either by inhibiting aldosterone's action (5) or independently of aldosterone (6).


Distal Tubule
Spironolactone
Glomerulus
Proximal Tubule
Aldosterone
Osmotic Diuretics
Thiazides
Chlorthalidone
Indapamide
Collecting Duct
CORTEX
OUTER MEDULLA
Ethacrynic Acid
Furosemide
Bumetanide
Water-Impermeable Membrane
INNER MEDULLA
Loop of Henle

Left-to-right Shunts

I. Introduction

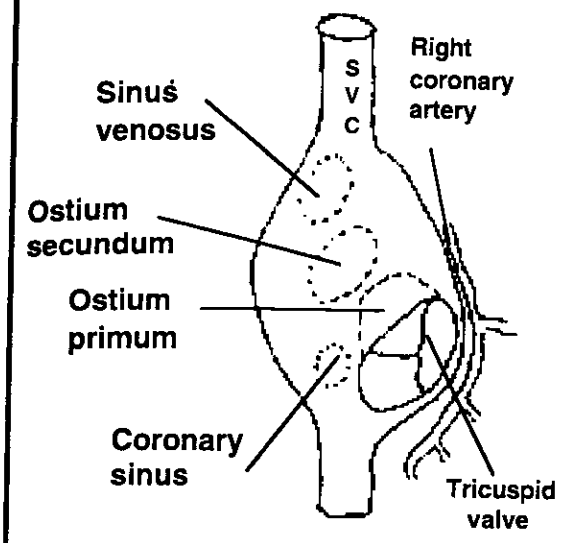
"Left-to-right" (L→R) only has meaning when the circulation has the potential for a normal flow pattern. When the connections are fundamentally wrong, e.g., transposition of the great arteries or total anomalous pulmonary venous connection, "left" and "right" are ambiguous, confusing and should be avoided. For example, in TGA, the usual shunt direction through the ductus arteriosus is from aorta to pulmonary artery; while one might be tempted to call this 'left-to-right', it is *de-oxygenated* blood flowing into *oxygenated* blood (hardly what one usually implies with "left-to-right"). This flow pattern should be called what it is: an aorta-to-pulmonary artery shunt.

There are three levels at which one can have a left-to-right shunt: atrial, ventricular, and great artery. [A connection between artery and vein within the lungs would produce cyanosis, not 'left-to-right' shunting in the typical meaning.] The discussion below will be divided into these three anatomic variants.

II. Atrial Septal Defects

A. Anatomic types (See Figure on page 33)

1. High (cephalad) ASD: located supero-posterior, near the SVC-RA junction, often is associated with anomalous insertion of upper pulmonary veins (esp the RUPV) and sometimes is associated with sinus node abnormalities. Also called sinus venosus ASD.
2. Mid atrial ASD: most common defect, found in fossa ovalis, and called ostium secundum ASD.
3. Low atrial ASD: just above atrio-ventricular valve, called ostium primum ASD; a form of endocardial cushion defects, usually associated with a cleft in the mitral valve.
4. Coronary sinus ASD: where the 'roof' of the coronary sinus is missing, there is a communication between LA and RA which can flow in *either* direction and can produce cyanosis by coronary sinus blood entering the systemic circulation.



Types of Atrial Septal Defects

The left Figure is a view from the surgeon's perspective with the right/lateral atrial wall 'cut-away'. The right coronary artery runs in the atrio-ventricular groove. Most are closed by direct suture technique, even large ones; only occasionally is a patch required.

B. Pathophysiology of atrial left-to-right shunts

1. Magnitude of shunt volume is dependent on size of hole and relative compliances of LA and RA (indirectly LV and RV).
2. Usually produces volume overload of right heart structures (RA, RV, MPA) plus engorged pulmonary arteries.
3. Despite excessive pulmonary blood flow, which must return to the LA, the LA does not enlarge because it is 'vented' into the RA.
4. Dilated RA produces peaked P wave often with short PR interval in lead II on ECG.
5. Volume overloaded RV requires more time to empty; seen as rsR' in anterior ECG leads and manifest as prolonged RV systolic time interval on Echo.
6. When there is an ectopic atrial pacemaker on ECG, consider sinus venosus ASD.
7. It requires decades of shunt flow to cause pulmonary vascular damage and PAH in patients with ASD, but eventually, there will be pulmonary vascular obstructive disease.

C. Physical findings in hemodynamically significant ASD

1. Normal pulses, +/- RV lift, no thrill
2. The flow through the ASD does NOT cause a murmur. [How much turbulence can be caused by a 1 mm Hg pressure difference?]
3. The second heart sound (A_2--P_2) is *widely split* and the splitting interval *does not change with respiration.* To correlate pathology with physiology, remember that a volume overloaded RV takes more time to

eject completely, which results in a delayed P_2 The lack of splitting requires understanding of normal splitting. Normally, during inspiration, the negative intrathoracic pressure 'sucks' blood into the RA while the same negative pressure keeps blood within the pulmonary veins. This increases right heart volume and decreases left heart volume. Result: earlier aortic valve closure and later pulmonary valve closure, causing a wide time interval between A_2 and P_2 The reverse is true during expiration causing a narrow splitting interval. This physiologic sequence requires differences in atrial volume coincident with phases of respiration. But in a large ASD, there is volume equilibration across the atrial septum precluding respiratory effects on the splitting interval. Thus a 'fixed', widely split second heart sound.

4. Extra volume passing across the (usually normal) pulmonary valve produces a soft (often non-specific) 'PS' murmur and the same volume traversing the normal tricuspid valve may cause a rumble during the period of rapid filling (mid-diastole).

D. Natural History

1. Atrial level L→R shunt is rarely (<10%) associated with CHF
2. Pulmonary artery pressure remains normal for decades, but eventually, the pt WILL develop irreversible pulmonary vascular changes.
3. Prolonged right atrial dilatation predisposes to atrial tachydysrhythmias.
4. Secundum (but not other) ASDs may spontaneously close, usually in the first two years of life. Many of those that close were stretched foramena ovale.
5. Infective endocarditis does not occur in ASD (not enough turbulence).
6. The 'PS' murmur in a large ASD may be confused with:
   i) innocent murmur (normal S_2, clear diastole)
   ii) partial anomalous pulmonary venous connection (wide S_2 with variable split and no diastolic murmur)
   iii) mild valvar PS (ejection click, wide S_2 with variable split, no diastolic murmur, and normal Qp on chest X-ray).

E. Management

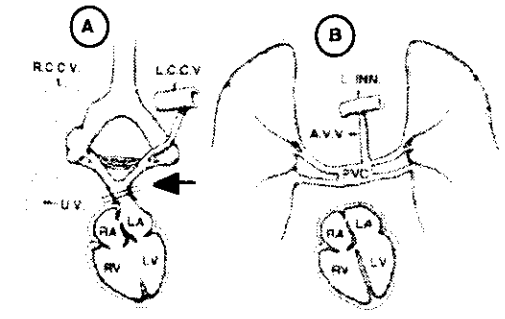
1. Anti-CHF Rx's almost never needed.
2. Exercise tolerance is usually normal until 2^{nd} or 3^{rd} decade of life.
3. SBE prophylaxis not necessary.
4. Indications for closure:
   i) CHF or FTT (both rare)
   ii) ASD still hemodynamically significant over two years of age

iii) defect >3mm in adolescent female (danger of paradoxical emboli during pregnancy); this is hotly debated at present.

5. Surgical closure: generally after two years of age or 10 kg as that size allows 'bloodless' surgery. Mortality = <<<1%. [JP, GH and JDW together have never seen a child die from ASD surgery.] Usually can be done with just sutures; some require a patch.
6. Per-catheter closure now available at experimental centers around the country, including UNM.

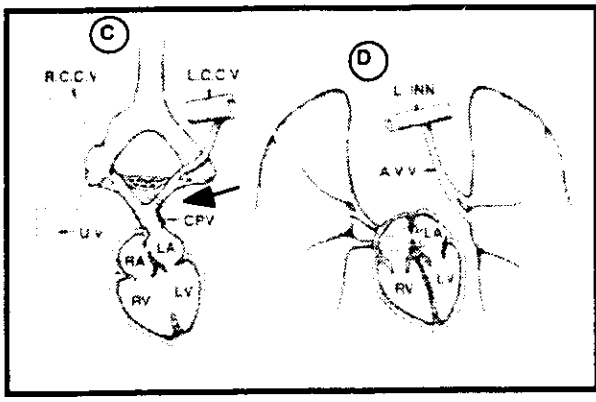
III. Partial Anomalous Pulmonary Venous Connection (PAPVC), including Scimitar Syndrome

Total anomalous pulmonary venous connection is a cyanotic defect because there is always mixing of de-oxygenated and oxygenated blood (see section on cyanotic heart disease). In partial anomalous pulmonary venous connection (PAPVC), at least one (usually most) pulmonary vein(s) connect to the LA and only one pulmonary vein, usually the right upper connects to the right heart at the RSVC; therefore, there is no de-oxygenated blood entering the systemic circuit. These patients have the effects of L→R shunting at the atrial level but may not have an atrial septal defect and therefore may not have fixed splitting of S_2. On CXR there is pulmonary overcirculation and on echo there is volume overload of the right heart. Such children often need diagnostic cardiac catheterization for selective angiography in order to guide the reparative operation. Surgery usually consists of a baffling procedure within the atrium rather than simple re-attachment of the anomalous vein.



Development of TOTAL anomalous pulmonary venous connection- for comparison with figure below.

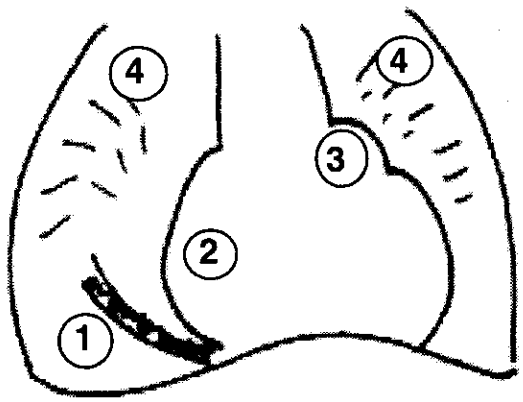
If the pulmonary venous confluence (PVC) fails to fuse with the LA (Panel A, at arrow) all pulmonary veins will drain to a persistent systemic venous connection (AVV= ascending vertical vein, Panel B) which drains to the left innominate vein.



Development of PARTIAL anomalous pulmonary venous connection (PAPVC).

If only the pulmonary veins from one side, e.g., the left, fail to maintain connection with the CPV (common pulmonary vein; arrow in Panel C), then one has PAPVC, as shown in Panel D. As oxygenated blood enters the LA from the right pulmonary veins, the child is not cyanotic.

Scimitar syndrome refers to a specific form of PAPVC in which the right lower pulmonary vein drains into the IVC-RA junction, causing a curvilinear opacity on chest X-ray in the right cardiophrenic area which looks like a scimitar sword. This is usually associated with hypoplasia (sometimes severe) of the right lung and collateral vessels from the descending aorta into the right lung, increasing the L→R shunt effect.



CXR in Scimitar syndrome

Cardiomegaly plus:

1 = Curvilinear structure in RLL
2 = Right atrial enlargement
3 = Dilatation of MPA
4 = Increased pulmonary vascular markings.

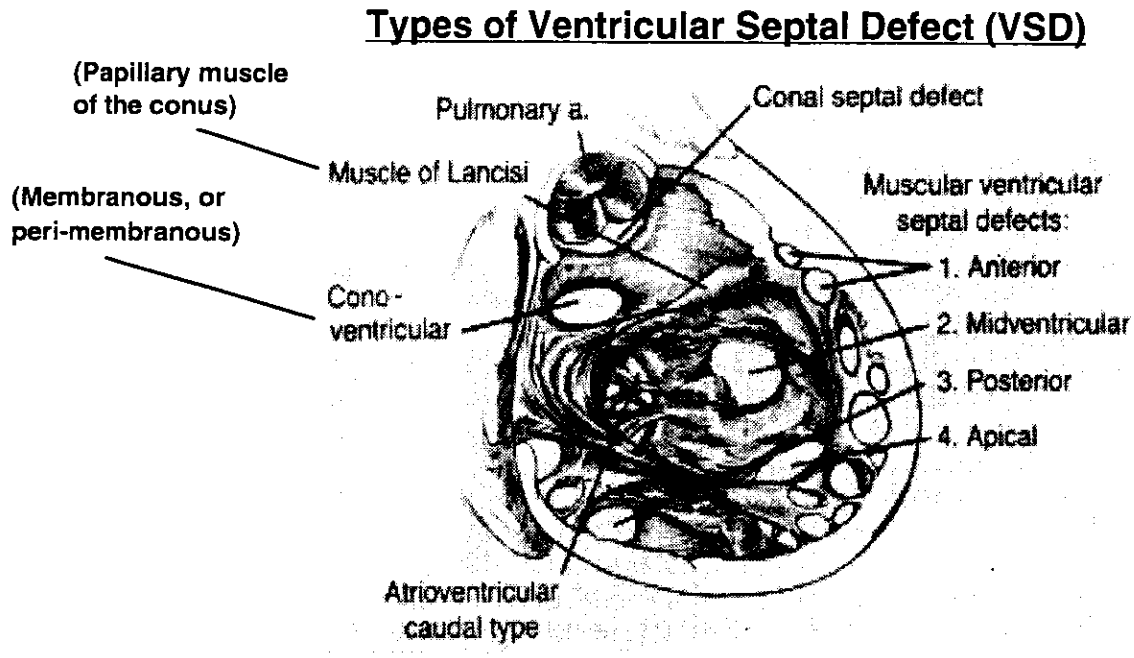
IV. Ventricular septal defects

A. Anatomy: the position of the defect in the ventricular wall has implications for both natural history and therapy. There are five types of VSD (by location). [There is ongoing debate as to classification and even nomenclature of VSDs.]

1. *Membranous:* thin part of ventr septum at its cephalad end next to the tricuspid valve. Most common type of VSD and has high incidence (50-80%) of spontaneous closure.
2. *Muscular:* in the trabecular portion of the septum; may be multiple. These too may close spontaneously.
3. *Cristal:* in or above the crista supraventricularis which puts the defect immediately adjacent to the aortic valve. This hole (regardless of size) predisposes to aortic regurgitation. When it 'closes', it does so by prolapse of an aortic leaflet over/into the defect [not the best way to close a VSD] resulting in progressive aortic regurgitation.
4. *A-V canal* (endocardial cushion): posterior in the septum, adjacent to the atrio-ventricular valve, a defect OF/IN the inlet septum. These do not close or narrow spontaneously nor does #5 below. These may be associated with a primum ASD and cleft mitral valve ("complete" a-v canal) or just an isolated VSD.
5. *Mal-alignment*: in contrast to the others above, nothing is *missing*; this is an abnormality of relative positioning between the muscular and the conal septae leaving a gap. This is the type of VSD found in tetralogy of Fallot, truncus arteriosus, and IAA. It is always large and never undergoes spontaneous closure. The malalignment often leads to obstruction of an outflow tract (right in ToF, left in IAA). These never close.

Figure: Types of VSD **(by location on the RV side of the interventricular septum)**

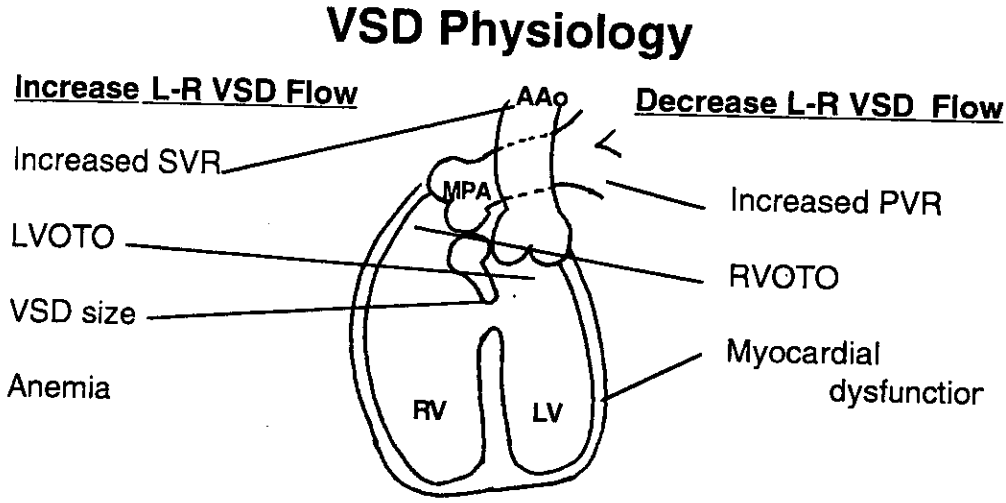
Note: All membranous (cono-ventricular) and muscular VSDs have the *potential* to undergo spontaneous closure; the others do not.



B. Pathophysiology

1. Magnitude and direction of the L→R shunt is dependent on size of defect and relative resistances: systemic versus pulmonary.
2. In a small VSD, the hole itself is the major determinant of resistance and PVR has little effect.
3. In a large defect (= to or > than aortic anulus), net resistance (from LV to pulmonary capillaries) determines shunt flow. Increased PVR or valvar PS or subpulmonary obstruction (as in ToF) all will decrease the volume of L-R shunting by increasing resistance to flow in that direction.
4. Corollary to #3, increased systemic resistance will increase the L→R shunting, e.g., aortic stenosis or coarctation of the aorta plus VSD has much greater and earlier L→R shunt than same VSD without the AS or coa.
5. PVR usually takes weeks to reduce to point where volume of shunt can cause CHF; therefore, even large VSDs generally present at 4-8 weeks of age. However, premies have less medial musculature in the pulmonary arteries; therefore, their PVR can drop faster and they can have CHF with a VSD earlier than term babies.

6. L→R ventr shunt causes enlargement of LA, LV and MPA. CXR shows this along with ↑ Qp. Echo can quantify the enlargement, which correlates closely with the volume of shunting.



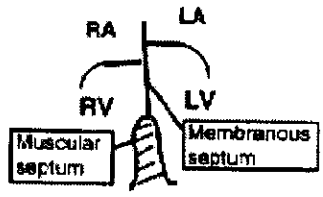
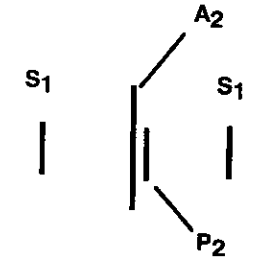
C. Clinical correlations

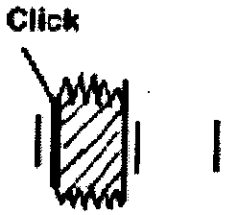
1. "Small/moderate/large" refer to size of hole in relation to the aortic anulus. Small would be >2-15%, moderate >15-60%, large >60-150%.
2. *Small VSDs* transmit a small volume of blood resulting in no volume overload. They generally cause no change in CXR or ECG. The murmur starts at S_1, can be quite loud [big pressure difference from LV to RV], and can abruptly stop just before S_2 if the defect is muscular. S_2 is normal as there is no PAH.
3. *Moderate VSDs* allow hemodynamically significant L→R shunt, enlarging the MPA, LA and LV. The RV may not be enlarged as the shunt is systolic and often flows directly into MPA without dilating the RV body. Without PAH, there may not be RVH. Harsh systolic murmur coincident with S_1 normal P_2 (no PAH), and the excess volume passing across the normal mitral valve causes a diastolic murmur of 'mitral stenosis'; gallop sound of filling the dilated LV is common. Precordial LV activity is ↑. CXR often shows cardiomegaly with ↑ Qp.
4. *Large VSDs* greater chamber dilation than moderate VSDs. Direct transmission of LV pressure into MPA causes PAH. RV must pump into the hypertensive system, therefore RVH on ECG (in addition to LVH). CXR shows considerable cardiomegaly and Qp; without an ASD to vent the LA, carinal angle is widened and posterior bulging on lateral film

indicating LA enlargement. Many have overt CHF with Kerley B lines on CXR. May have a harsh murmur commencing with S_1, sometimes a thrill but with a large enough defect, there may be no turbulence and therefore no murmur! P_2 is always loud and essentially single due to PAH. Mid-diastolic rumble and gallop are common along with precordial overactivity.

D. Natural History

1. Membranous and muscular VSDs can close spontaneously, as high as 80% (depending on study). Complete closure is not necessary to avoid surgery, just reduction in size to become hemodynamically insignificant (see indications for op, below). Closure/narrowing has been reported as late as 10 years old.
2. A-V canal, cristal and mal-alignment VSDs do not close.
3. Large size of defect does NOT preclude closure or narrowing.
4. Onset of symptoms is generally ≈4-8 weeks old.
5. High pressure, high flow VSDs promote pulmonary obstructive vascular disease (PVOD) which become irreversible over time; this is called **Eisenmenger's physiology** (or reaction), at which time PVR = or > SVR, the shunt becomes R→L and the child is cyanotic. The rate at which this occurs is related to the complexity of the congenital heart disease, i.e., more complex → earlier PVOD. PVOD does not occur < 2 yrs old in simple VSD, may occur between 1 and 2 yrs with A-V canal, and is likely before first birthday in TGA+VSD.
6. Evolution of spontaneous closure of a membranous VSD:

Explanation	Anatomy	Phonocardiogram
Normal =		
Early Phase of VSD: VSD is membranous and unrestrictive. Auscultation: soft systolic murmur and mid-diastolic rumble from excessive flow across mitral valve.		

Early VSD Closure: Redundant tissue ("accessory endocardial cushion tissue": AECT) reduces VSD orifice. Mid-diastolic rumble gone; systolic murmur louder, higher-pitched and longer.		
Late Phase of Closure: AECT now resembles a wind-sock with small holes providing the only LV-to-RV communications. Systolic murmur louder & higher-pitched. Early systolic click or 'snap' from systolic expansion of the wind-sock formed by the AECT.		
VSD totally closed: The AECT has completely closed the interventricular communication and retracted. There is no murmur or click.		

E. Management of patients with VSD

1. If suspect VSD, determine if it is hemodynamically important clinical signs, cardiomegaly on CXR, F.T.T., etc.
2. ALL neonates with Down syndrome should have pediatric cardiology consultation (and probably an echo) as a-v canal can be present with no murmur and no symptoms.
3. Small VSD: can be followed by pediatrician even without referral to pediatric cardiologist. If murmur still present at 2 yrs old, should get consult and echo as murmur of subaortic stenosis can sound exactly like a VSD.
4. Moderate/large VSD-if membranous or muscular, seek to defer intervention waiting for spontaneous narrowing/closure. If other types, surgery will be necessary and only question is when. All pts with hemodynamically important VSD need referral to pediatric cardiology. Medical treatment includes: digoxin, diuretics, and sometimes after-load reduction, plus high caloric regimen.
5. Always encourage good dental hygiene and SBE prophylaxis.

6. Indications for intervention (closure):
   i) CHF refractory to medical management
   ii) Growth failure or recurrent pneumonias
   iii) Evidence of PAH beyond 6 months of age
   iv) Cardiomegaly beyond 1 year of age
   v) VSD in immediate proximity to aortic valve (risk of aortic regurgitation).
7. Closure is done surgically by suture-placement of a patch; this requires cardio-pulmonary bypass. Over 2.5 kg, there is no reduction in the (very low) mortality risk with increase in wgt. Per-catheter technique is not available at present and unlikely to be safer than surgery in foreseeable future.
8. Indication(s) for pre-operative diagnostic cardiac catheterization vary with institution, surgeon and associated defects. When PVR needs be known before surgery, only cardiac cath can define it accurately; when PVR>50% SVR, surgery is contra-indicated.
9. Pulmonary artery band has essentially been abandoned except for: multiple VSDs, single ventricle, and infants under 2 kg.

V. Great Artery L→R Shunts

A. Patent ductus arteriosus (PDA)

1. Not 'congenital heart disease' but rather a holdover from in utero life; in Europe, they use the term "persistent arterial duct".
2. In term infant, usually physiologically closed in 1-2d but not sealed for weeks.
3. In pre-term, persistent PDA is common, and also it may *re-open* after spontaneous or pharmacological closure.
4. Magnitude of shunt determined by:
   i) relative resistances- PVR versus SVR,
   ii) resistance offered by the ductus (length, shape, caliber)
5. Physiology similar to VSD
6. Physical exam:
   i) Small PDA with normal PVR: continuous murmur, normal P_2, normal precordium
   ii) Moderate PDA: continuous murmur, apical filling [diastolic] murmur, loud P_2, bounding pulses, over-active precordium.
   iii) Large PDA: may have no! murmur with equalization of pressures; may have continuous murmur but not high-pitched [as velocity cannot be high without a large gradient]; loud/single P_2, over-active precordium,

prominent pulses.

7. Natural history:
   i) In a term baby, an arterial duct that is patent after 1 week is unlikely to close.
   ii) In pre-term neonates, especially after surfactant treatment, PDA can cause *early* CHF
   iii) PDA will cause more CHF than same size VSD (as a PDA flows through systole AND diastole.)
   iv) Large PDA can cause Eisenmenger's reaction.
   v) The smaller the PDA, the higher the risk of SBE.

8. Treatment
   i) SBE prophylaxis
   ii) No exercise restrictions unless pt has PAH
   iii) Indication for closure is the presence of the PDA.
   iv) Most PDAs can be closed in cath lab; short, large ones still require surgery [at present].
   v) Timing for closure: after 1 year old, before entrance to school, or anytime when there is CHF or PAH.

B. Less common Ao→PA shunts

1. *Coronary artery fistula*

Fistulous connection of either right or left coronary artery to RV, RA or central PA system; even reported connected to LA and LV. Involved coronary is usually very large and tortuous; receptacle chamber is dilated. Usually does not cause symptoms in childhood; if present, CHF. Commonly detected by continuous murmur suggestive of but not typical for PDA. Diagnosis is by echo; angiography is usually needed for surgical repair. The presence of such a communication is an indication for intervention; some can be closed by per-catheter techniques.

2. *Systemic arterio-venous fistula*

Connections between systemic arteries and veins can be single, multiple, cavernous and when the fistula allows a large volume of L→R flow, it will cause CHF. The two sites for occult fistulae are intra-cerebral and intra-hepatic; other locations include the limbs and chest-both obvious on physical exam. They generally require angiography for pre-operative delineation and many can be closed without surgery (per-catheter approach).

3. *Collaterals in pulmonary atresia*

Some children with pulmonary atresia (especially ToF pts) can have large vessels connecting the DAo with the PAs; these function like multiple PDAs and can cause CHF due to a very large volume of L→R shunting. The

approach to these is complex and sometimes, they are used as pulmonary arteries in a staged reparative approach rather than simply ligated or closed per-catheter.

4. *Ruptured aneurysm of the aortic sinus of Valsalva*

Rare, often fatal but potentially reparable condition. Weakness in one of three aortic sinuses of Valsalva, usually congenital but may be secondary to infection. Bulges and ultimately ruptures into RA or RV. Not seen in small children, usually adolescents. Usually a murmur is present before rupture, but rupture is very dramatic with abrupt CHF/collapse. Immediate surgery is necessary, usually with echo diagnosis only.

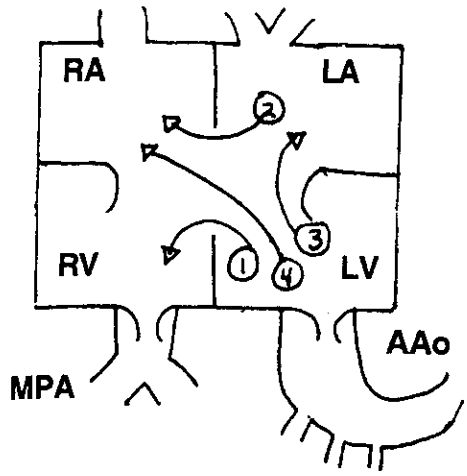
VI. Multiple Levels of L→R Shunt

1. *Multiple Defects*

One can have any combination of ASD/VSD/PDA with resultant additive effects. Many children with large VSD or PDA have enough stretching of the LA to have a stretched-open foramen ovale but often not a true ASD. When there is a large VSD, one must always rule out a PDA by echo or angio as the latter can be masked by the former. An isolated PDA is operated from a lateral thoracotomy but it can be closed through a median sternotomy concurrent with VSD surgery.

2. *Endocardial cushion defect ('complete' A-V canal)*

When there is the 'complete' form of a-v canal, one has a single central defect in the region of the central fibrous body/lower atrial septum/upper ventricular septum which includes incomplete separation of the a-v canal into mitral and tricuspid valves. This single hole is subdivided physiologically by the closed atrio-ventricular valve leaflets [during systole] into an atrial component (ASD) and ventricular component (VSD); during diastole, there is one hole. Such children have the potential for the following shunts, depending on their specific anatomy and physiology: LV→RV (VSD L→R flow), LA→RA, (ASD L→R flow) LV→LA (mitral regurgitation), LV→RA. This condition is common (≈30%) in Down syndrome but can be seen in children with normal chromosomes. Treatment is repair before 6 months of age to prevent the development of PVOD.



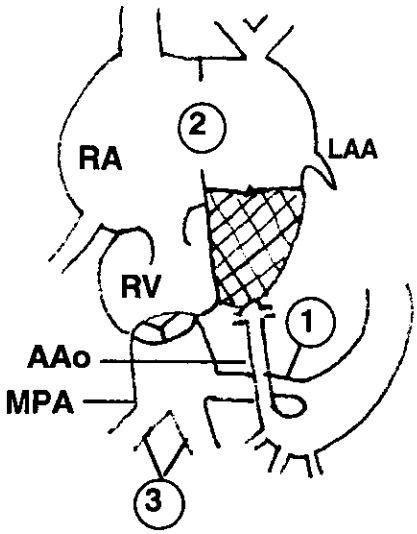
Potential Shunt Flow Patterns in Complete A-V Canal

1.= 'VSD flow' (LV → RV)
2 = 'ASD flow' (LA → RA)
3 = Mitral regurgitation (LV → LA)
4 = LV - RA communis

Complete A-V canal is a single central hole which is divided into 'ASD' and 'VSD' by the coapted a-v valve leaflets in systole. With a cleft in the mitral side and even without it during diastole, there is the potential for shunting from LV → RA as well as LV → LA.

Left heart obstructions

1. *Aortic Atresia ↔ Hypoplastic Left Heart Syndrome (HLHS)* .



Hypoplastic Left Heart Syndrome

Note atresia of the mitral valve, non-development of the LV and atresia of the aortic valve. The AAo is the size of the combined coronary arteries as that is the only volume of blood which is transmitted through the AAo.

Aortic atresia includes imperforate aortic valve + hypoplastic AAo.
Usually part of hypoplastic left heart syndrome (HLHS), which includes hypoplasia/atresia of LV cavity and mitral valve.
In utero: ductus arteriosus (normally) supplies lower half of body and in aortic atresia, ductus also supplies AAo + coronary arteries by *retrograde flow* through transverse and ascending aorta
After delivery, baby does well until that ductus narrows, at which time the constriction reduces systemic blood flow, especially to the coronaries and the child develops acute circulatory collapse. The ductus can generally be re-opened with PGE_1 but some children do not return to good/normal cardiac function.
After PGE_1 is started, the problem is generally pulmonary overcirculation and heart failure.
Remember: the three key physiologic factors to survival in HLHS (see Figure above) are:
1) Widely patent ductus arteriosus (to provide systemic flow);
2) Open atrial septum (to allow pulmonary venous egress out of the obstructed left heart); and
3) ***HIGH*** PVR to <u>discourage</u> Qp because more blood into the lungs means less blood out to the body.

Therefore, children with aortic atresia/HLHS should breathe the LOWEST O_2 concentration compatible with life, certainly no higher FiO_2 than 0.21 [lower if available], and use the lowest concentration of PGE_1 which maintains ductal patency (usually 0.02-0.03μg/kg/min).

Treatment options for children with HLHS include:

i) Non-heroic approach (no ventilator, withdraw PGE_1, etc.)

ii) Norwood operation: make main pulmonary artery into a neo-aorta, create large ASD and insert systemic-pulmonary shunt.

iii) Neonatal transplant; problems of non-availability of donor hearts, chronic rejection, and accelerated atherosclerosis (especially coronary arteries).

2. *Interrupted aortic arch*

Generally two types: those with large mal-alignment VSD and those with no VSD. Most commonly used classification is based on where the interruption is in relation to the brachiocephalic arteries.

Pathophysiology: blood flow to the DAo and body is dependent on ductal patency; ductal narrowing causes hypoperfusion of lower body but not the coronary circulation (as is seen in HLHS).

Initial management is similar to HLHS.

Definitive therapy is correction: restore AAo-DAo continuity and close VSD if present. This is usually done as a single stage repair in the neonate. For those who develop recurrent aortic obstruction later in childhood, balloon dilation is the preferred approach.

3. *Coarctation of the Aorta* (Coa)

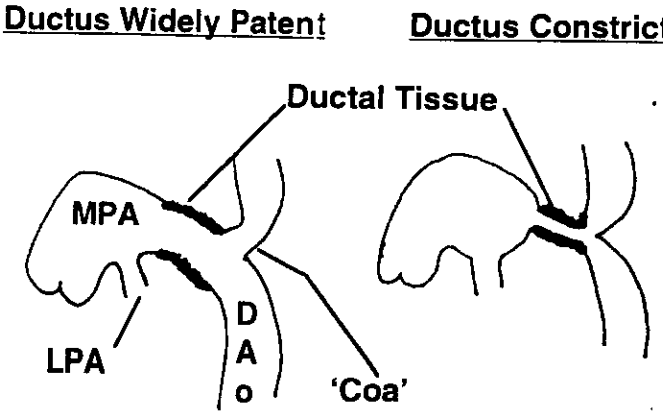
a) Anatomy

Spectrum ranges from discrete juxtaductal shelf to hypoplasia of the transverse aorta. Extension of ductal tissue *into* the aortic wall is often found.

b) Pathophysiology

i) In utero there is no effect because wide PDA supplies the DAo.

ii) Coa becomes manifest when ductus narrows See Figure on page 48 showing how the obstruction is 'circumvented' by wide patency of the aortic end of the ductus; this becomes manifest when the ductus constricts.



iii) Obstruction causes DAo hypotension and hypoperfusion as well as cerebrovascular and LV hypertension. Hypertension in the cerebral vessels may be especially damaging as the germinal matrix and vessels themselves are in a formative stage.

c) Clinical
   i) May be discharged from birth admission looking normal if ductus is still widely patent.
   ii) Can present acutely, in CHF, or even shock when the ductus narrows.
   iii) Often pulseless on presentation because of low CO.
   iv) After Rx improves cardiac output, arm BP rises but femoral pulses remain absent or reduced.
   v) CXR: cardiomegaly and pulmonary venous congestion
   vi) Echo usually diagnostic; ECG is of little help; diagnostic cath generally not needed.

d) Initial treatment:
   i) If young enough, try PGE_1 to restore ductal patency.
   ii) Lasix and fluid restriction
   iii) Oxygen; ventilatory assistance often is very helpful.
   iv) Dopamine if severe CHF; may use digoxin but IV pressors preferable.

e) See Surgery section for repairs.

4. *Aortic stenosis* (AS)

a) Valvar AS:

Anatomy: AS is congenital but there are degrees of severity: as leaflets and commissures are increasingly primitive, the obstruction is worse and less amenable to surgery or balloon dilation. In older children, AS can be rheumatic in origin, especially if the child has immigrated from

Mexico or USSR.

Pathophysiology: [Remember congenital AS is UNVENTED obstruction and therefore, the ventricle you see at birth has been damaged for >7 months, not acutely.] In utero and after birth, AS causes:

i) ↓ LV output
ii) ↓ coronary filling
iii) ⇑ myocardial O_2 demand
iv) ↓ LV compliance → ↑ LA pressure
v) ↓ or ⇓ systemic output

In neonates, systemic blood flow can be ductal-dependent and therefore, some will respond to PGE_1 even though it does not vent the obstructed LV.

Physical: valvar AS always has a click (unless the valve is unicuspid). When the gradient exceeds ≈40 mm Hg, there is a thrill. Remember: when there is CHF and low output, there may not be much gradient or murmur despite severe obstruction. Such patients will be acidotic and poorly perfused.

Treatment: both surgical valvotomy and balloon dilation are options. All approaches are palliative and ultimately, most pts who need intervention within the first year of life will require valve replacement [which is a new 'disease' itself.]

b) Subvalvar AS

Anatomy: can range from discrete thin membrane to fibrous tunnel to dynamic muscular obstruction (IHSS; see hypertrophic cardiomyopathy in Acquired...section). Many children with interrupted aortic arch + VSD *develop* subAS when older.

Pathophysiology: is similar to valvar AS when the obstruction is 'fixed' (i.e., non-dynamic). When it is dynamic, exercise and digoxin are contra-indicated.

c) Supravalvar AS

Anatomy: tubular narrowing at crest of aortic sinuses of valsalva with intimal proliferation in this area. Often associated with multiple additional areas of obstruction and generalized hypoplasia of the aorta.

Commonly found in William's syndrome (see section on Syndromes).

Pathophysiology: obstructs LV, ↑ mVO_2, causes *hypertension* in coronary arteries and hypotension downstream.

Treatment is surgical: placement of a complex patch to enlarge the ascending aorta.

Pulmonary artery hypertension

1. **Definition:** elevated systolic pressure (> 30 mm Hg) in the MPA
2. **Pulmonary microvascular anatomy**
   a) From hilum to periphery, pulm arteries are: elastic, muscular, partly muscular, non-muscular, capillary.
   b) Arterial wall layers:
      i) Intima-endothelial cells, pericytes and intermediate cells (latter two have contractile elements, first is metabolic powerhouse; see below)
      ii) Media: smooth muscle cells, arranged is spiral pattern.
      iii) Adventitia: connective tissue + fibroblasts.
   c) Pulmonary capillaries-extensive network within alveolar septae. At thinnest point--best for gas exchange--the alveolar capillary wall is essentially one cell layer thick, a composite of one endothelial cell, one epithelial cell and the basal lamina.
3. **Lung functions:**
   a) General: i) Gas exchange
      ii) Filtration
      iii) Immune responses
      iv) Secretions of vaso-active substances (mostly active within lungs but activities outside lungs unknown.)
   b) Of Pulm vasc endothelium: (NOT simply an inert lining)
      i) Metabolism of circulating hormones and vaso-active substances;
      ii) Modulation of pulm vasc Tone (in part BY #i)
      iii) Regulation of hemostasis/thrombosis
      iv) Participation in inflammatory and local vessel wall functions.
      NOTE: Vasc endothelium throughout body is metabolically active, but pulm circ has much more endothelium because of its huge surface area.
4. **Hydraulic relations of PAP, Qp, and PVR**

PAP varies with the logarithm of Qp.

Increases in Qp have three phases of pressure response:

   a) Initial increment of increased flow causes rapid increase in PAP. This is needed to overcome *critical opening pressure* of

vessels being recruited.

b) Slower rise in pressure as flow increases due to distention of elastic vessel walls and relaxation of wall musculature.

c) When all vessels are maximally dilated and all potential channels are recruited, then increase in Qp causes corresponding linear increase in PAP.

At constant flow, change in total cross-sectional area changes the PVR.

a) Constriction of muscularis causes reduction in lumen caliber which reduces area and increases resistance.[This is 'active', and generally reversible.] Increased amount of muscle in arterial walls (increased thickness and extension to more peripheral arteries) logarithmically increases this effect

b) Intimal hyperplasia and fibrosis of distal arteries narrows and obliterates the lumen which decreases total cross-sectional area which increases PVR.

c) Recruitment of un- or under-perfused vessels increases the surface area which decreases PVR.

5. PVR decreases from fetus to neonate *because*:

a) Lungs are much more efficient oxygenator than placenta. Therefore, post-birth pO_2 is much higher than intra-uterine, and increased pO_2 causes drop in PVR.

b) Alveolar expansion directly causes drop in PVR.

c) Secretion of vaso-dilatory substances (prostaglandin, prostacyclin, leukotrienes).

6. Hypoxia and the Pulmonary Vasculature

HPV=hypoxic pulmonary vasoconstriction; a commonly used term which describes the pulmonary arteriolar vasoconstrictor response to hypoxia. HPV is unique to pulm vasculature; systemic circ either doesn't respond or vasodilates. Current thinking suggests that the function of HPV is to reduce V/Q mismatch by selectively reducing perfusion to underventilated areas. The location of critical O_2 sensors (pre-capillary; intra-alveolar?) is still under investigation. The mechanism is also poorly understood: direct effect (O_2--to--muscularis) versus indirect using vaso-active substances as blood-born(?) mediators.

7. "Pulmonary Vascular Obstructive Disease"

Used to describe occlusion of distal pulmonary vessels with rise in PVR. [The abbreviations PH (pulmonary hypertension) and even PAH are often mistakenly used synonymously with PVOD; PVOD describes an physical

phenomenon in the pulm vasculature and PH or PAH mean elevated pressure (not necessarily resistance) in the pulmonary arteries.]

Several classifications have been used to grade PVOD based on findings at microscopy of pulmonary vessels: Heath & Edwards is the best known (Grades 1-6), Wagenvoort and Reid/Rabinovitch also have made substantive contributions to understanding the grades and phases of PVOD.

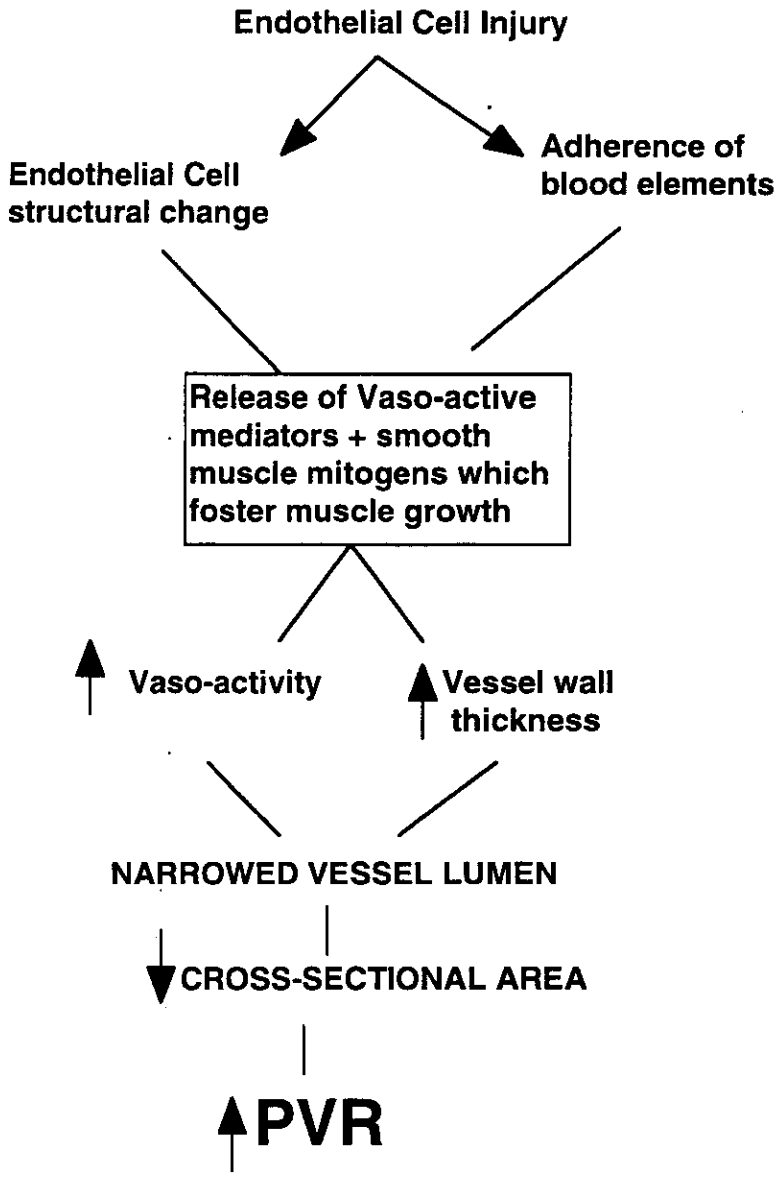
Most pediatric cardiologists reserve the term PVOD for an irreversible condition resulting from unrepaired congenital heart disease, e.g. truncus, transposition, a-v canal after one year of age.

The mechanisms of development of PVOD are not well understood. Factors associated with PVOD include:

1. Increased flow
2. Increased pO2 in the pulmonary arterial blood
3. Transposed great arteries
4. (?) Increased pressure in the MPA (?even without flow?)
5. (?) Trisomy 21

NB: Increased pulmonary VENOUS pressure (e.g., with mitral stenosis) is generally <u>not</u> associated with irreversible changes in the pulmonary vasculature unless very long-standing, i.e., for several decades.

Endothelial injury is considered a primary event in PAH, an important factor in the abnormal hemodynamics and the subsequent structural changes in the pulmonary artery wall. A preliminary and incomplete schema for this interaction is shown below.



8. Differential diagnosis of PAH

a) LV stiffness, e.g., from cardiomyopathy or LVOTO
b) LA hypertension, e.g., from mitral stenosis or regurgitation
c) Pulmonary venous stenosis
d) Pulmonary arteriolar obstruction:
    1-Reduced cross-sectional area: congenital or thrombo-embolic
    2-Constriction [*potentially relaxable, e.g., NO therapy*]
    3-Pulmonary vascular obstructive disease
e) Branch pulmonary artery stenosis

9. Bronchopulmonary dysplasia and PAH

Bronchopulmonary dysplasia (BPD) is a syndrome diagnosed no earlier than one month of age with the following clinical hallmarks: chronic respiratory distress, need for oxygen to maintain normal saturation in room air, and abnormal chest x-ray; there is no 'definitive' test. It is known that hypoxemia, especially the normal nocturnal condition, exacerbates BPD and oxygen administration is the foundation of therapy, seeking to maintain arterial saturation over 90%. Steroids are commonly employed to treat an inflammatory component of the pathogenesis. Chronic diuretic therapy is also considered helpful.

Pulmonary artery hypertension has been associated with BPD, initially reported from UNM in 1982. At present, echocardiography is the primary means by which pulmonary vascular status is assessed including RV wall thickness; RV systolic time intervals; pulmonary artery flow velocity and acceleration time; and the most reliable indicator *when available*, velocity of tricuspid regurgitant jet. In addition to oxygen, drugs which induce pulmonary vasodilatation are currently in use such as nifedipine and dipyridamole. However, it is likely that additional agents will be identified in the near future with greater efficacy to treat the PAH associated with BPD.

10. Use and limitations of echo, cath

Echocardiography, including doppler flow studies, can provide valuable information in evaluating patients with PAH. Two-dimensional images can assess anatomic causes of PAH (such as a ,b, c, e from above list). Physiologic factors assessed in evaluating PAH include RV systolic time intervals, pulmonary artery acceleration times, RV wall thickness, and tricuspid regurgitant jet, when TR can be found. The last is the most accurate measurement. When two dimensional studies confirm the absence of RV outflow tract obstruction, then RV systolic pressure should equal PAP (systolic). The velocity in the TR jet estimates the RV to RA gradient. As the RA pressure can be assumed to be ≈8 mm Hg, then subtracting this from the velocity (i.e., gradient) yields to RV systolic pressure, in turn inferring the PA systolic pressure. Similarly, the pulmonary artery diastolic pressure can be inferred from the pulmonary insufficiency gradient (when there is pulmonary regurgitation). Unfortunately, patients can have clinically significant (even severe) PAH without tricuspid or pulmonary regurgitation. In large populations, pulmonary acceleration times (corrected for heart rate) and RV systolic time intervals do correlate reasonably well with PAP, but

for the individual patient, the wide range of variability in these measurements makes them of limited use in both identifying and quantifying PAH.

Pressure measurements through a fluid-filled catheter in the cardiac cath lab are the 'gold standard' in evaluating PAH. One can determine PAP, PA wedge pressure [to estimate pulmonary venous pressure] and assess the reactivity of the PAH with exercise, high O_2, low O_2, and medications. By measuring cardiac output or pulmonary and systemic flows (in patients with shunts), one can reliably calculate PVR under various conditions. For patients in whom transplantation is a consideration (heart, lung, or heart-lung), pulmonary vaso-reactivity is a key determinant of operability and a guide to post-operative management. Selective pulmonary arteriography can help assess possible sites of obstruction (which side?, which segment or branch artery?) and the appearance of small distal pulmonary arteries grossly correlates with level of PAH. There are some limitations in the use of the catheter. Such studies require detailed, precise and bilateral measurements of pressures and blood gases under multiple conditions, as well as direct determination of cardiac output. These are invasive, time-consuming, uncomfortable, expensive and not easily done serially. Pulmonary angiography in those with elevated PVR, especially primary PAH, carries some risk; it is generally avoided particularly since essentially all surgically remediable causes of PAH can be evaluated by ultrasound. In those with primary PAH, pulmonary vaso-reactivity in response to various drugs is best done in the ICU (rather than the cath lab) with a Swan-Ganz catheter in place; this can be done over several days without the need for sedation, NPO status, time constraints and immobility imposed by the cath lab.

11. Lung Biopsy

In children with elevated PVR, reversibility of PAH (and PVR) is a critical factor in determining need for surgery, timing and choice of operation and suitability for transplantation. Though echo is useful, it provides indirect assessment of physiology, and even direct pressure/resistance measurements still only provide information about the physiology, not the anatomy or pathology. Lung biopsy is the definitive test to assess (and 'grade') changes in pulmonary vasculature. This is only used occasionally because: a) it is truly invasive, requiring thoracotomy and general anesthesia, and b) more importantly, changes in pulmonary vessels has been shown NOT to be uniform. Therefore, one might have grade 2 changes in one area (indicating reversibility) while grade 4 (irreversible) in another.

Thus, a single or even two lung biopsies may not reflect the totality of the patient's condition.

12. Pharmacology of the Pulmonary Circulation

The list below simply summarizes the effect on pulm artery pressure. Full understanding is much more complex as these substance also effect CO, SVR, flow through holes and shunts, pulmonary VENOUS resistance, etc.

Increase PAP

- α-adrenergic agonists (NEpi, phenylephrine)
- β-adrenergic antagonists (propranolol, esmolol)
- Vaso-active peptides (angiotensin I & II; vasopressin, bradykinin)
- PGE_2, $PGF_{2\alpha}$

Decrease PAP

- α-adrenergic antagonists (tolazoline, phentolamine)
- β-adrenergic agonists (isuprel)
- Dobutamine
- Histamine
- PGE, PGI
- Calcium channel blockers (nifedipine, verapamil)

There is considerable variability between species regarding pulm vascular responses to various drugs and substances, as well as general and age-specific responses within the same species.

13. Treatment

Children with PAH, especially those with Down syndrome, often have hypercarbia secondary to upper airway obstruction due to hypertrophied tonsils and adenoids. The elevated CO_2 in turn exacerbates PAH and further increases PVR. This possibility should always be considered in children with congenital heart disease (e.g., in A-V canal defects) because we have all seen children declared "inoperable" from irreversible PVOD who were clearly operable after a T&A. This procedure should be done before repair of the congenital heart defect to optimize the child's status both with respect to risk stratification and post-operative management.

As alvelaor hypoxia is known to cause pulmonary vasoconstriction (HPV), so ambient low oxygen tension--found as altitudes such as Albuquerque, NM; Leadville, CO; La Paz, Bolivia--exacerbates PAH. Patients with PAH should be encouraged to move from residence at high altitude to <1000 meters or sea level if possible.

Though factors such as pressure transmission, flow volume, shear stress rate, pO2 in the MPA are loosely associated with elevation of PVR, *duration* of the vascular derangement is directly related to the progression

to PVOD and irreversibility. Therefore, AGE is a key risk factor and most centers seek to normalize PAP before one year of age, usually before six months. The preferred method is reparative surgery such as VSD closure, repair of A-V canal or truncus where possible; when this is not an option or the risk is high, palliative pulmonary artery banding is done as early as possible.

Lung transplantation, usually unilateral, has been used with short-term success in patients with PVOD (usually primary PAH). Though this often dramatically reduces PAP, optimal anti-rejection regimen (infection or rejection) has been a major problem. Unfortunately, the statistics are less successful than in heart transplantation (probably because the lungs are more active metabolically).

Numerous drugs have been tested empirically in the past 10-15 years with inconsistent success rates. A list of such drugs includes:

Nifedipine	Captopril	Diazoxide	Dopamine
Verapamil	Tolazoline	Hydralazine	Isuprel.

Prostacycline is currently under investigation and preliminary results are encouraging; this drug requires continuous IV administration. As research has progressed, a simple but unstable molecule-nitric oxide (NO)-has been confirmed to be A (not necessarily THE) mediator of pulmonary vascular tone, causing relaxation of pulmonary arteriolar smooth muscles. NO has a very short half-life and at present can only be given by inhalation. It is likely that a more basic understanding of control of pulmonary vascular tone will be forthcoming, allowing more efficacious treatment of PAH.

Acquired heart disease

1. Kawasaki disease (KD)

Diagnosis requires Fever for > 5 days + (4 of 5 below):

a) changes in extremities, especially palmar erythema;
b) polymorphous truncal exanthem;
c) bilateral conjunctivitis;
d) oromucosal involvement;
e) cervical adenopathy (>1.5 cm).

Course is often triphasic: acute, subacute, convalescent; may present as sudden death (Cardiol Young 1992; 2: 73-77)

Often have hydrops of the gallbladder

May resemble meningitis or acute abdomen; prominent irritability.

Younger children have more severe involvement, esp males.

Laboratory data-nothing specific. ESR usually very high, platelet count elevated well into the disease, and may be > 1 million.

Echo: 1) Myocardial dysfunction is common, and therefore is NOT necessarily a sign of coronary artery involvement;
2) Pericardial effusion often seen;
3) coronary artery dilatation-generalized vs segmental, rarely leading to late thrombosis or stenosis.

Pathophysiology

Fundamental problem is angiitis, preceding in retrograde fashion from smallest arterioles to major (muscular) arteries

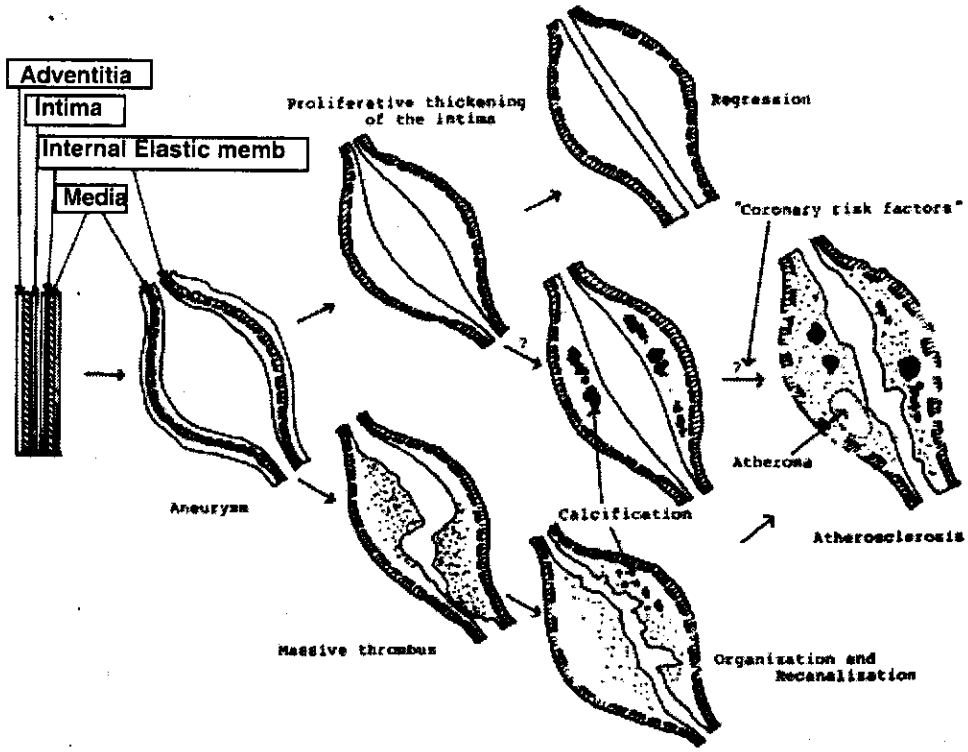
Weeks 1-2 (of disease): microvascular vasculitis and perivasculitis-inflammation of intima and perivascular areas with edema and cellular infiltration.

Weeks 2-4: inflammatory process more prominent in medium-sized arteries, including aneurysms, thrombi and stenoses, esp. coronaries.

Weeks 4-7: inflammation subsides and granulation in progress.

After 7 weeks: scar formation, intimal thickening, old thrombi, aneurysms, focal scars/fibrosis in myocardium.

Sasaguri's summary of the pathophysiology and potential outcomes is summarized in the Figure below.



Debate currently on-going as to whether these children may be more prone to atherosclerotic coronary artery disease in later life (see above).

Remember: other arteries than coronary can be involved, e.g. renal, mesenteric, cerebral not reported.

Natural history is benign in >95% of cases. Severe coronary artery involvement occurs in 1-3% (depending on ethnic mix). In those with aneurysms, a large number will develop coronary artery stenosis if: a) the aneurysm is initially large (>9mm) and b) the patient is followed long enough, i.e., > 8 years. Smaller aneurysms seem tolerated well for long periods.

Treatment

1) Steroids have been reported to exacerbate the coronary involvement but this is now debated by many cardiologists.
2) ASA helps symptoms and *may* help prevent arterial involvement
3) IGG effective (>90%) in preventing arterial complications

IF GIVEN BEFORE DAY 10 OF DISEASE. Since the diagnosis cannot be made until day 5, one has only 5 days in which to begin treatment.

IGG treatment also reduces severity and duration of symptoms.

Surgery: bypass grafting has been successfully done using internal mammary artery in small children. Indications still unclear.

Differential Diagnosis: JRA. Serum sickness. Rheumatic fever. Viral exanthem. Meningitis/osteomyolitis/sepsis.

2. Cardiomyopathy/Myocarditis

Cardiomyopathy means (by definition): Abnormal myocardial performance characterized by:

1. decreased contractility with secondary ventricular dilatation;
2. hypertrophy causing intra-cavitary obstruction;
3. hypertrophy impairing ventricular filling.

The relationship of myocarditis to cardiomyopathy (CM) is unclear. Some myocarditis cases are thought to progress to CM and some CM are suspected of having previously been myocarditis. However, the pathogenetic links are unknown.

a) Myocarditis

May be fulminant; many spontaneously and completely recover

Characterized by myocardial lymphocytic infiltration.

Though Coxsackie virus has been definitely implicated, in most cases of myocarditis, an infectious etiology is not found.

Debate continues whether immunosuppressive therapy (steroids, immuran, cyclosporin, IGG) helps.

Complex ventricular dysrhythmias may persist even after 'complete' resolution [JACC 1994; 24:780-783]

Cardiac biopsy in children:

Safe, can be done at any age over 5 kg.

Poor correlation between clinical and histologic diagnosis (e.g. 11% of dilated CM pts had myocarditis on biopsy, and only 27% of those with clin dx of myocarditis had it on biopsy.)

ONLY definitive way to diagnose myocarditis is by biopsy.

Biopsy procedure samples the RV trabeculae and (hopefully) not the free-wall because of the danger of perforation. In the lower portion of the RV, there is little danger to the conduction system.

Debate continues over utility of biopsy as there is insufficient data on the effect of treatment regimens in children.

b) Carnitine deficiency cardiomyopathy

1. Important NOT because of its frequency [very rare] but because it is one medically correctable form of cardiomyopathy.

2. May be primary or secondary. Often familial.
3. Carnitine palmitoyltransferase is an important enzyme for transfer of fatty acids into mitochondria for oxidation
4. Usually presents as dilated cardiomyopathy
5. Histology: focal myocyte hypertrophy (light microscopy); Electron microscopy shows extensive cytoplasmic lipid deposits
6. Diagnosis made by measurement of plasma carnitine and fatty acid metabolic by-products
6. Treatment: Oral L-carnitene

c) Hypertrophic cardiomyopathy

Many, many names (e.g., ASH, IHSS, Teare's disease, etc.)
60% show autosomal dominant genetics; 40% unclear
Wall hypertrophy: LV and esp. septum
Classic histol picture is cellular disorganization, non-uniformity of myocyte size and increased transverse diameter ("hypertrophy").
Extensive fibrosis seen at autopsy but unclear whether this is ischemia secondary to massive thickness or to abnormal intramural coronary arteries.
When disease manifest in younger children, RV often involved and may have greater obstruction than LV.
Natural history: highly variable but earlier onset of symptoms presages earlier demise. Death usually sudden (probably arrhythmia), often during athletics. (VT on a holter study is ominous sign.)

Treatment, medical:

1) beta-blockade (e.g. propranolol)-reduces HR and thereby increases time for diastolic filling; reduces contractility and thereby reduces gradient.
2) calcium channel blockers (e.g. verapamil) relaxes myocardium during diastole
3) anti-arrhythmics (e.g. amiodarone) are controversial

Treatment, surgical:

Currently used only when symptoms not relieved by medical Rx.
Myotomy/myectomy: small risk of both death and heart block
Surgery does not appear to reduce the mortality rate.

d) Dilated ("congestive") cardiomyopathy

Defined as: diminished myocardial contractility and LV dilatation; when increased stroke volume cannot compensate for the decreased contractility, pulmonary congestion occurs.

Genetically determined immune response; factors associated with HLA loci may play a role in pathogenesis of dilated cardiomyopathy. Extensive studies seeking viral etiology have been unrewarding.

Pathology: Grossly normal wall thickness but more of it (therefore increased heart weight). Histology: non-specific; inflammatory cells usually absent; patchy fibrosis; myocardial cell degeneration which corresponds to duration of the process.

Clinical picture:

Physical: signs of CHF; failure-to-thrive.

CXR: cardiomegaly, increased pulm venous markings, enlarged LA

ECG: LAE, LVH, ST segment abnormalities.

Echo: LV dilatation and poor contractility; mitral regurgitation; thickening of endocardium

Clinical course: difficult to predict, partly because "dilated CM" encompasses several different diseases. Generally, 1/3 die, 1/3 recover completely (probably acute myocarditis), and 1/3 recover with impaired cardiac function.

Treatment-palliative; symptomatic:

(See section on CHF re: details regarding drugs)

1. enhance contraction (digitalis)
2. reduce contraction (propranolol)
3. reduce pre-load (lasix; captopril*)
4. reduce after-load (hydralazine; captopril*)
5. improve diastolic filling (verapamil)

* NB: captopril (an angiotensin-converting enzyme [ACE] inhibitor) affects both *pre-load* by reducing water retention and *after-load* by reducing or preventing peripheral vasoconstriction.

Treatment-'corrective':

1. change metabolic status (give carnitine or thiamine; stop adriamycin)
2. Ablate arrhythmogenic focus
3. immunosuppressive Rx: Prednisone +/- cyclosporine
4. remove tumor
5. transplant

Differential Diagnosis (dilated cardiomyopathy) :

Myocarditis (?viral). Toxic/ingestion. Chronic dysrhythmia. Infiltrative (e.g. mucopolysaccharidosis)

Metabolic (e.g. ↓ glucose; ↓ or ↑ T_4; ↓ carnitene; ↓ Ca^{++} or K^+ ; etc.)

3. Rheumatic fever (RF) +/- carditis

General/Miscellaneous Clinical Info

1. Causative agent: Group A Streptococcus, sp. *Pyogenes*
   a. >20 sero-types of ß-hemolytic strep
   b. "Hemolytic"= causes hemolysis when grown on sheep's blood agar
2. Even during epidemic of strep infections, ≈3% of infected pts get RF
3. RF does not occur in children under 2 years of age.
4. Increased incidence of RF in adults highly exposed to strep, e.g., military recruits, teachers and parents of elementary school age children.
5. Strep infections *other than pharyngitis* (e.g. impetigo) do NOT lead to RF.
6. During RF (after latent period), fever is only moderately high [contrast to Kawasaki disease].
7. Dramatic improvement with steroid Rx.

Current Considered Pathophysiology

1. Genetically susceptible individual (supported by HLA typing studies), probably a single recessive gene.
2. Repeated, untreated (often unrecognized) infections with Group A, ß-streptococcus infections sensitize pt
3. After 2 years of age, a repeat strep infection causes marked antibody response including sharp rise in anti-streptolysin O (ASO)
4. Approximately 10 day-to-3 week 'latency' period where pt feels/appears well.
5. 'Antigenic mimicry': in response to the prior strep infection, antibodies are produced against bacterial antigens which cross-react with host tissues causing the damage.
6. Auto-immune response/reaction causes the clinical picture
7. Recurrent infections re-activate RF

Similarities of RF to Kawasaki Disease

1. Many (mild) cases go unrecognized
2. No definitive test; clinical diagnosis
3. Population studies suggest a familial (viz. genetic) factor or predisposition
4. Other than cardio-vascular involvement, disease is essentially benign.
5. Auto-immune system clearly involved although precise mechanism is unknown.
6. ? Small vessel vasculitis

Histopathology

1. Pathognomonic histopatholgy: Aschoff body = granuloma consisting of perivascular infiltrate of large cells with polymorphous nuclei and

basophilic protoplasm arranged in a rosette around an avascular fibrinoid center.

2. Fibrinoid = eosinophilic substance of fibrin, globulin, etc., with interspersed collagen fibers plus granular material derived from degenerating collagen.
3. Aschoff bodies can be found anywhere but are most common in the left atrial appendage.
4. Degree of histologic abnormality does not correlate with clinical severity.

MAJOR Criteria leading to Diagnosis

1. Polyarthritis:
   - Multiple joints, migratory; if only one joint, prob not RF.
   - Pain at rest, accentuated by both active and passive movement; generally tender to touch
   - Remember: this is arthritis, not just arthralgia
   - Large joints (hips, knees, ankles, etc.) involved in contrast to small joint involvement in JRA).
   - Generally responds well to salicylates
   - Polyarthritis never occurs with chorea [reason unknown]
2. Carditis:
   - Most with RF who have carditis get it on the FIRST attack.
   - Murmur (>50%) of mitral regurgitation, occ. add'l AR (≈20%); Carey-Coombs murmur of 'relative MS'
   - Usually a pancarditis but layer involvement 'prioritized', e.g. ALWAYS endocardial (mitral regurgitation), often myocardial (poor contractility), sometimes pericardial (rub; fluid). [Contrast to JRA where prioritization is pericardial, myocardial, rarely endocardial.]
   - Occasionally there is first or even second-degree heart block.
3. Erythema marginatum:
   - ≈10% occurrence, but when present, virtually certain RF
   - Irregular, geometric, marginate, evanescent red truncal rash.
   - Not pruritic. Brought out by a hot bath.
4. Subcutaneous nodules:
   - Small, non-tender, nodules of central fibrinoid necrosis surrounded by epithelial and mononuclear cells over bony surfaces: elbows, knees, spine, occiput, etc.
   - Over-lying skin is not discolored
   - Usually a late finding, but when present, pt has active RF.
5. Syndenham's Chorea: (St. Vitus' dance)

Usually young adolescent female; does not occur in adults.
Choreiform movements, aggravated by emotional stress.
Slurred speech, 'spooning' of outstretched hand, darting of extruded tongue, 'Milk-maid's grip', characteristic mood lability; Findings disappear during sleep.
May present as decreased school performance or teenage behavior problem!
Reflects CNS involvement (basal ganglia +/or caudate nucleus)
There is NO differential diagnosis; Chorea = RF.
Latency is longer than other manifestations, often > 3 months.
Can produce late valvar damage just like 'full-blown' RF.

MINOR Criteria/Lab Tests

1. Throat culture-generally positive (unless partially treated)
2. Enzyme tests:
   Group A streptococcus produces extracellular enzymes:
   a. hyaluronidase;
   b. streptolysin* S (oxygen stable);
   c. streptolysin* O (oxygen labile); *=causes hemolysis on agar.
   d. erythrogenic toxins (cause skin rash)
   e. streptokinase (which activates fibrinolytic system)
   f. Deoxyribonclease isoenzymes
   g. Misc-NADase, esterase, amylase, etc.
   Release of above enzymes induces formation of antibodies, e.g., anti-streptolysin O (ASO), which can be tested.
   Each enzyme test is ≈80-85% accurate and therefore, to exceed 90% reliability, should test for more than one enzyme.
   Remember positive tests (enzymes present) only means antecedent strep infection; it does not 'prove' RF.
3. ESR very elevated (must correct for anemia); may be normal when congestive heart failure (CHF) is present.
4. CRP: elevated like other acute phase reactants (e.g., platelets, but not as high as in Kawasaki disease). CRP not affected by CHF.
5. ECG is of limited usefulness; ≈20% have increased PR interval.
6. CXR shows cardiomegaly because of: 1) MR, 2) myocardial dysfunction 3) pericardial thickening or fluid.
7. Echo is diagnostic of presence and degree of carditis.
8. Cardiac cath essentially unnecessary.

Diagnosis of RF

1. Requires two major criteria OR One major + two minor
2. Should have labs of precedent strep infection. With (occasional) long

latent period, enzyme tests may be negative.

3. Common diagnostic challenge: pt with fever, arthralgia/?itis and prior strep infection. Though often labeled RF (and probably NOT), pt be followed to assure absence of later valve disease.

Treatment and Prevention

1. Acute attack:
   - Benzathine PCN IM: 1.2 million units for >27 kg, 600,000 units <27 kg OR PCN 125-250 mg PO QID x 10 days
   - After 10 days, PCN 200,000 U PO BID for prevention
   - Absence of positive throat culture should not defer antibiotic RX if diagnosis likely on clinical grounds.
   - **Antibiotic Rx stops the infection but not the auto-immune reaction.**
   - Salicylates for symptomatic Rx (80-100mg/kg/day, QID); when using steroids, add ASA in third week.
   - With carditis and certainly with CHF, steroids indicated: Prednisone 2 mg/kg/day X 2 weeks then taper. May need to restart or increase dose if symptoms return or ESR rises.
   - Treat CHF with lasix
   - Myocardium may be very sensitive to digoxin (pro-arrhythmic) and caution must be used in giving cardiac glycosides.
   - Choreiform movements (with attendant emotional stress) can be treated with phenobarbital or valium.
2. Recurrent Rheumatic fever:
   - Usually failure of compliance with prophylactic program; very rarely a failure of *oral* PCN to prevent strep infection.
   - May prefer (IM) benzathine PCN if oral compliance is a problem.
   - Clinically resembles first attack though carditis may be more severe and/or longer in duration.
   - Surgery might be necessary and cardiac cath might be required.
3. Prevention/Follow-up:
   - No vaccine currently available.
   - "Once a rheumatic, always a rheumatic."
   - Recurrences more likely and more severe in children and with shorter interval since last attack.
   - Compliance a concern esp with BID oral Rx.
   - Pt with RF without carditis: follow for at least five years.
   - Pt with RF + carditis: follow indefinitely.

Differential diagnosis: Auto-immune disease (e.g. JRA).
Bacterial endocarditis.Kawasaki disease.

4. Bacterial endocarditis (BE)

Definition/Description

1. = Inflammation resulting from bacterial infection of a cardiac valve, mural endocardium or vascular endothelium
2. Acute vs subacute distinction now blurred; generally 'define' BE by the infecting organism

Epidemiology

1. Data unclear as to whether incidence has changed in past 25 yrs.
2. 5-15% of BE occurs in pts with no heart disease
3. 25-40% occurs in post-surgical pts
4. Most BE in children is related to a valve or a surgical shunt
5. ≈80% of BE is due to strep or staph

Pathophysiology:

1. Hemodynamic condition causing turbulence (jet &/or 'sink")
2. exposed intrasvascular collagen
3. sterile platelet-fibrin thrombus
4. high titer of agglutinating antibodies
5. Gram positive organisms more 'adherent' than gram neg and therefore more involved in BE
6. Bacteremia can occur spontaneously but initiation of BE is partly related to volume of bacterial inoculum; therefore, BE more likely after surgical instrumentation than a bowel movement.

Clinical features:

1. Fever; new or changing murmur; petechiae.
2. Splenomegaly; embolic phenomena; hematuria.
3. Positive blood culture; (5-8% of BE is culture-negative); NOT necessary to wait for temp spikes but get from mult sites.
4. Anemia; elevated acute phase reactants (including platelet ct)

Treatment principles:

1. Decision to treat BE is clinical, not solely dep on positive culture.
2. Parenteral antibiotics are mandatory; high blood levels often necessary.
3. √ blood levels against specific agent (in vitro) to assure killing.
4. Frequent repeat cultures & echoes are necessary to assure adequacy of Rx
5. Sometimes need to operate even during active BE, e.g. to remove infected valve (esp artificial) which cannot be sterilized.

Antibiotic prophylaxis:

1. Not conclusively proven that it is necess or that it works; strong inferential data supporting its use.

2. Given for all cong heart lesions; some (minority) do not give for ASD and PS.
3. In repaired cong heart disease with no residual condition causing turbulence, no need for prophylaxis, e.g. surgically closed VSD with no residual murmur. All repaired ToF or Coa pts need prophylaxis.
4. Standard regimen: amoxicillin 50 mg/kg 1 hour before procedure to maximum of 2 grams; NO SECOND DOSE.
5. For G-I or G-U procedures, use ampicillin plus gentamicin or vancomycin before op and NO SECOND DOSE.
6. For details, see JAMA 1997;277:1794-1801

5. Auto-immune diseases which affect the heart

1. Rheumatic fever and Kawasaki disease covered above.
2. JRA

During acute attacks, JRA and similar auto-immune disorders often affect the epicardium, causing effusion and occasionally pain. Endo- and myocardial involvement rarely occurs. Usually the treatment directed at the generalized inflammation will help the pericardial disease. Very rarely, pericardiocentesis is necessary. Constrictive pericarditis has not been reported as a late consequence.

3. Maternal SLE

Active, dormant and even undiagnosed SLE in a pregnant woman can induce SS-A/Ro and SS-B/La antibodies which cross the placenta and cause highly selective damage to the fetus, specifically destroying the His bundle, resulting in heart block. The mothers of all children with congenital heart block should be tested for SLE. Pregnancy in women known to SLE or prior children with congenital heart block should be followed carefully as steroid therapy during gestation may prevent damage to the fetal heart.

6. Mitral valve prolapse (MVP)

Definition is controversial: some say that typical auscultation *means* MVP with or without echo confirmation; others say MVP is an echo dx, even without click or murmur. There is a spectrum of: normal--to--click +/- murmur--to--MVP. Several studies show significant (?high) incidence of MVP on echo in otherwise (presumed to be) normal children. Often familial occurrence (Circ 1969; 39:327 & Circ 1973; 48:1128) Several authors raise the possibility of a primary autonomic disorder (note: repolarization abnormalities, tachycardia, G-I motility problems, etc.) as the etiology of MVP.

Pathology

Limited pathologic information since death is very rare in children

Myxomatous matrix of leaflets and of collagen within chordae seen in adults with history of MVP

Redundant valve tissue, lengthening of chordae

Clinical

Theory of "clinical/pathologic stages"

Stage 1: Click with grossly normal MV

Stage 2: Click + late systolic murmur but normal anulus

Stage 3: Holosystolic murmur, no click, stretching of leaflets and dilatation of the anulus.

Mean age of presentation (pediatric series) = 9.9 years

Female:male = 2:1

Usually referred for murmur or 'unusual' auscultatory findings

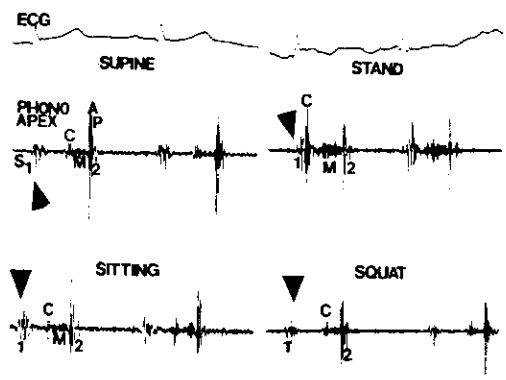
Symptoms are uncommon: Chest pain (nonexertional) ≈ 18%; dysrhythmia ≈ 3% though palpitations common in adults

Physical findings:

-Click at LLSB, midsystolic, which changes with body position

-Things which decrease ventricular volume make click earlier in systole; converse also true.

-Murmur follows the click and (like click) decreasing ventricular volume makes murmur earlier, louder and longer.



Phonocardiogram of postural interventions in an 8 year old with mitral valve prolapse. Arrows indicate the first heart sound (onset of systole) as a timing marker.
Supine: a non-ejection click (C) is followed by the murmur.
Sitting: the click and murmur occur earlier in systole and the murmur intensity is increased.
Standing: click and murmur occur very early, intensity is maximum.
Squatting: the heart rate slows, click and murmur occur later and intensity is less.

-Other findings related to the associated syndromes when present (scoliosis in Marfan's; lax skin in Ehlers-Danlos)

Echo shows posterior displacement on M-mode echo. On two-dimensional echo, there is superior systolic displacement of the anterior leaflet

proximal to the plane of the anulus. Mitral regurgitation can usually be found with extensive study and changes in body position.

Natural history:

Generally benign in children. Though some have dysrhythmias, malignant dysrhythmias are very rare. In contrast to adults, sudden death or chordal rupture have not been reported. Endocarditis has been reported.

Treatment:

SBE prophylaxis is indicated [JDW] though AHA guidelines do no mandate prophylaxis unless there is MR (JAMA 1990;264:2920.)

Propranolol may help the chest pain.

Many have esophagitis and may respond to antacids.

Counsel family and pt on benign nature of condition in children; *Avoid creating a 'cardiac cripple'.*

When part of a syndrome, surgical criteria relate to the degree and speed of progression of the MR. MV replacement may be necessary but valvuloplasty alone may suffice.

Differential Diagnosis (of ejection systolic click +/- murmur):

Valvar AS (or PS). VSD, partly closed by extra tissue.

Connective tissue disorder (e.g., Marfan's).

7. Cardiac Trauma

Statistics indicate that cardiovascular trauma is increasing tremendously in children: gunshot and stabbing wounds, motor vehicle accidents (as *children* can now drive in all states), as well as ingestions in infants and drugs/poisonings/overdoses in teenagers. The section below is intended only to acquaint the primary care physician with some of the concerns and thought processes that face the emergency room physician when faced with a traumatized child.

Pediatric cardiovascular trauma can be divided into:

- Blunt trauma
- Penetrating cardiac injury
- Electrical injury
- Ingestion/illicit drugs/poisonings

Blunt injury is commonly secondary to a motor vehicle accident or a fall. The physical factors causing the damage include: 1) impact, 2) shear stress from deceleration, 3) compression, contusion and concussion, and 4) the hydraulic ram effect. Impact

can often cause damage to the pericardium including tears through which the heart can herniate. Shear stress causes tearing at the fixed points in the vascular system such as the ligamentum arteriosum causing transection of the aorta. Compression can cause cardiac rupture especially if the heart is in diastole during the impact. Contusion can cause infarcts and arrhythmias and can be very subtle in presentation. When the abdomen or lower extremities are compressed (as in an acute crush injury) the systemic blood-both venous and arterial-is forced suddenly towards the heart somewhat analogous to a tidal wave; this can over-strain closed valves or distended chambers causing tears or even rupture. Lack of obvious signs of *external* chest trauma in no way excludes life-threatening *internal* cardiac injury. Do not let a traumatized child leave the ER, e.g., for an MRI, without first confirming cardiopulmonary stability.

The two most common penetrating cardiac injuries are bullet wounds and stabbings. Considerations in a gunshot wound of the thorax include: the bullet track (entrance and exit wounds), energy transfer from the bullet (bullet kinetic energy, bullet yaw or wobble, bullet and tissue character), and the temporary cavity created by the bullet passage. As a general rule, a bullet that crosses the midline should be considered always to have damaged a cardiovascular structure. In a stabbing injury, one must first consider the wall(s) effected, as the rate of bleeding is related to the wall thickness and the intracavitary pressure. Cardiac rupture is generally fatal but if there is tamponade rather than exsanguination, pericardiocentesis can be life-saving. Remember also that both broken ribs as well pericardiocentesis needles can lacerate the heart.

Electrocution can be either by lightening or man-made current. The mechanism of injury by electric shock is not defined: direct damage, coronary spasm, coronary endarteritis, reduced coronary flow due to decreased cardiac output in turn because of arrhythmia. A critical element in extent of injury is the resistance to electrical flow, the prime determinant of resistance being skin *moisture*. Use of the CPK-MB fraction is of little help in estimating the extent of damage as skeletal muscle are also injured and it too releases CPK-MB. In man-made shocks, alternating current (AC) is generally more damaging than direct current (DC) because AC causes muscle tetany which makes it harder to release the live wire, which in turn

prolongs the contact and current flow. The pathway often is readily apparent as both the entrance locus and exit (ground) cite are visible by heat damage. Lightening is different from man-made electric shock because lightening is: a) unidirectional; b) very brief, massive and much higher temperature; c) is associated with a shock wave from air displacement; d) of much higher voltage, from 1-30 million volts. Measurement of electricity is identical to blood flow: one usually knows the pressure (volts) but not the resistance, and therefore not the flow (amperage).

The 'top ten' list of ingestions from the New Mexico Poison Control Center are:

1. Cosmetics/personal hygiene products
2. Cleaning agents
3. Analgesics
4. Plants (note that oleander and foxglove are cardiotoxic)
5. Cold medications
6. Foreign bodies
7. Topical compounds
8. Antibiotics
9. Gastro-intestinal preparations
10. Vitamins

It is important to have the number of the local poison control center (800-432-6822 for New Mexico; also written on the first page of this book) readily available. In the last several years, the only child to die from cardiac complications of an ingestion was a hungry 18 month old who was fed a white material by his well-meaning 4 year old brother; the substance turned out to be cocaine. Always remember that children can get anywhere (even via a larger surrogate) and will eat anything.

Digoxin intoxication can occur commonly from pills and rarely from the liquid preparation. The child usually presents to the ER either asymptomatic with a possible history of ingesting an unknown amount of grandma's medicine or with a rhythm problem, usually atrio-ventricular block. Serum levels of digoxin must be monitored; a temporary pacemaker may be required to prevent life-threatening bradycardia. As digoxin 'poisons' the sodium-ATPase pump, causing serum K^+ to rise, this too must be closely monitored. Digoxin ingestion cannot be safely handled in a local hospital; the child should immediately be transferred to a center capable of inserting a pacemaker and having digoxin antibodies (brand

name=digibind) available. The usual criteria for use of digibind (Fab antibodies) are: 1) ingestion > 300 µg/kg; 2) underlying heart disease; 3) >25 ng/cc serum level; 4) life-threatening rhythm problems, including failure to capture by a pacemaker. Response is generally rapid (30-45 minutes).

A host of illicit drugs are, unfortunately, available to the pediatric population today and discussion of specific drugs is beyond the scope of this syllabus. However, many have cardiac effects, usually stimulation-both rate and contractility. For each drug, sometimes taken in combination, detailed information should be obtained from Poison Control.

Vascular Compression of the Upper Airway

1. Clinical picture

A common problem in the care of children is respiratory distress. When it becomes a chronic problem, reactive airway disease is the more likely diagnosis but one should always consider extrinsic causes of airway obstruction, including masses, tumors and vascular compression. These can present at any age in childhood and are not limited to the neonatal period. Children with this problem can grow well but may have difficulty feeding. Pulmonary problems are common such as repeated pneumonias, 'classic' asthma or episodes of 'croup-like' syndrome.

2. Differential Diagnosis

A. Aortic causes
   1. Double aortic arch
   2. Right aortic arch with left ductus or ligamentum
   3. Innominate artery syndrome (posterior origin of the innominate artery causing compression of the trachea).

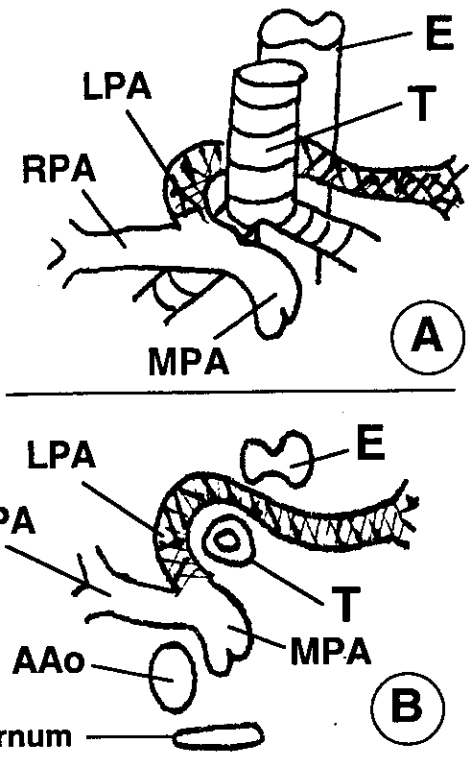
B. Pulmonary artery causes (both described below)
   1. Pulmonary artery sling
   2. ToF with Absent pulmonary valve syndrome

c. Left atrium (compressing the left mainstem bronchus from below)
   1. Large left-to-right shunt with no ASD
   2. Stenosis or regurgitation of the left atrio-ventricular valve

3. Pulmonary artery 'Sling'

A rare anomaly of pulmonary artery development causes the left pulmonary artery (LPA) to arise from the right pulmonary artery (RPA) rather than the main. This anomalous LPA courses over the right mainstem bronchus, executes a hairpin turn, crosses the midline between the trachea and esophagus to reach the left lung hilum where it ramifies normally (see Figure following). Blood flow to either lung is generally not a problem. However, there is airway obstruction on the right or bilaterally (from tracheal compression). Frontal chest x-ray may show asymmetric changes but may only demonstrate air-trapping; the lateral may be helpful by showing a 'mass' between the trachea and esophagus. Bronchoscopy confirms the pulsatile extrinsic compression and location of the compression may suggest the diagnosis. The definitive test is cardiac catheterization with pulmonary arteriography, however, in expert hands echocardiography can define the anatomy and obviate the need for invasive study. Treatment is surgical re-

positioning of the LPA from the right side to the normal position; this requires cardiopulmonary bypass. Recent results are excellent.



Pulmonary Artery Sling
E=esophagus; T=trachea.

Panel A: Frontal view shows the LPA arising from the RPA and coursing between the trachea and esophagus to enter the left hilum. Both the right mainstem bronchus and the trachea may be compressed by this vascular anomaly.

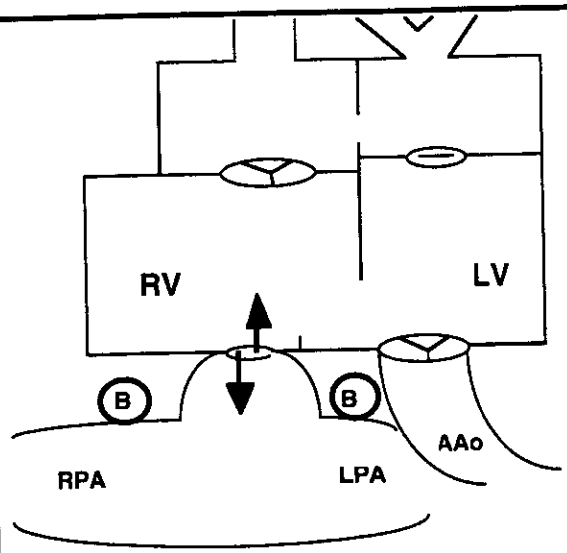
Panel B: is a coronal view of a pulmonary artery sling. Notice that the LPA between the esophagus and trachea may be seen as a 'mass' on a lateral chest-x-ray.

4. Tetralogy of Fallot with Absent Pulmonary Valve

This is a specific condition whose name has caused much confusion because the pathophysiology is NOT similar to other forms of tetralogy of Fallot.

The pathologic anatomy is that of a large VSD (usually mal-alignment as in ToF), without subvalvar pulmonary obstruction, but with a moderately hypoplastic pulmonary valve anulus on which are nubbins of tissue in place of valve leaflets. There is both obstruction (from the narrowed anulus) and regurgitation (from the lack of leaflets). Most of these children have no PDA and therefore, no vent for blood which enters the MPA in utero. This blood must go forward--into the high resistance (unexpanded) lungs or regurgitate backwards into the RV from whence it came; on the next contraction, the RV will eject the blood which entered from the tricuspid valve PLUS the volume which came back from the MPA. Thus, in utero,

there is progressive RV enlargement and massive dilatation of the pulmonary arteries: branch pulmonary arteries in a normal neonate measure ≈5-7 mm each but in ToF s PV, they often measure 25-40 mm! This results in compression of the bronchi and cyanosis due more to airway obstruction than to intra-cardiac shunting.



Pathophysiology of **ToF s PV**

1. Stenotic PV anulus
2. No pulm valve, therefore complete pulm regurgitation
3. Large mal-alignment VSD, [usually with L→R shunt rather than R→L].
4. Massive dilatation of RV secondary to #2 and #3
5. Massive dilatation of pulm arteries secondary to #1-4.
6. Compression of bronchi (**B**) from huge pulm arteries
7. Cyanosis & distress from airway obstruction

Clinically, these children generally fall into two groups: those with severe respiratory distress as neonates in whom the only option is reparative surgery (with significant risk of demise), and those who, though tachypneic and hyperpneic, tolerate the pulmonary conditions well enough to grow, in whom repair is deferred until 9-12 months of age when the risk is low. ToF s PV can be diagnosed by physical exam: there is cyanosis of varying degree in a neonate with respiratory distress and a loud (often grade IV-V) to-and-fro murmur (contrast to a continuous murmur). The chest X-ray shows hyperinflation and evidence of huge pulmonary arteries. The diagnosis is confirmed by echocardiography. Cardiac catheterization is usually necessary only for delineation of the coronary arteries in preparation for surgical repair.

Common tests

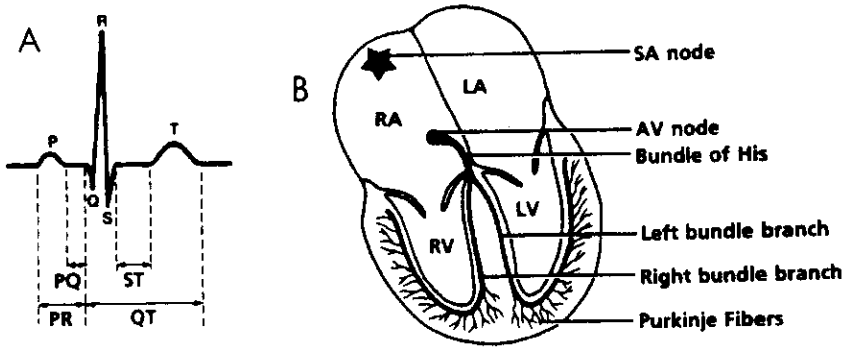
1. ECG

Introduction

An electrocardiogram is a recording of the electrical activity of the heart. Most frequently, a twelve lead recording is obtained, consisting of one electrode on each of the four extremities and six electrodes on the chest. There is a vast amount of information which can be obtained on an ECG, including heart rate, rhythm, axis of atrial and ventricular depolarization and ventricular repolarization, determination of chamber hypertrophy and/or enlargement, and conduction times through the atria, AV node and ventricles. Conduction disturbances can be evaluated as well. Below is a brief description of some of the basics of ECG interpretation.

Review of cardiac electrical events in sinus rhythm:

Cardiac tissue has the property of spontaneous depolarization. Myocardium is much slower than specialized conducting tissue but does have its own intrinsic rate (~30 BPM in adults). Conducting tissue depolarizes and recovers much faster than myocardium and this occurs in a prioritized system so that (normally) the SA node recovers first making IT the pacemaker of the heart. Then the right and left atria are depolarized as the electrical impulse spreads through the atria, producing what we see on the ECG as the **P wave**. When this atrial impulse arrives at the atrioventricular (AV) node, it passes through the node at a much slower velocity, resulting in the **PR interval**. The electrical impulse then passes through the AV node to the bundle of His, where it conducts rapidly down the left and right bundle branches, through the Purkinje fibers and on to the ventricular myocardium, producing the **QRS complex**. As the ventricles repolarize, the **T wave** is produced. Atrial repolarization normally is not seen since it is a low voltage event and typically occurs during ventricular depolarization (QRS complex.)

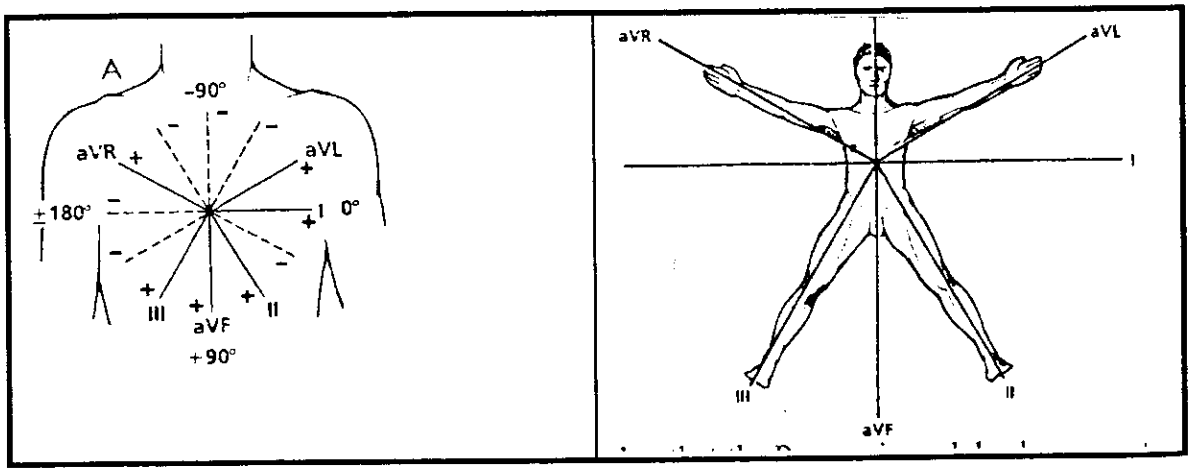


The QT interval is normally determined by correcting it for HR. This is done be the following formula: Actual QT interval (sec) / square root of the preceding R-R interval(sec). For example, if the actual QT interval is 0.36 sec and the preceding R-R interval is 0.64 sec, then the corrected QT interval (or QTc) is 0.36/ (square root of 0.64) = 0.36/0.8 = 0.45 sec (or 450 msec.) The reason that the correction is necessary is because the duration of ventricular repolarization shortens as the HR increases (or the R-R interval decreases.) Thus, one would expect shorter QT intervals in a patient when he/she has a faster HR. The QTc should be less than or equal to 450 msec.

With standard calibration, 10 mm = 1 millivolt. Occasionally, half-standard (5 mm = 1 mV) will be used when the voltage is very prominent. A measure of the calibration should be present on all ECGs. Be aware that often only the chest leads are placed at half-standard, while the arm leads remain at full standard. [Get into the habit of checking the standardization (and the pt's age) before even looking at the leads.]

Axis

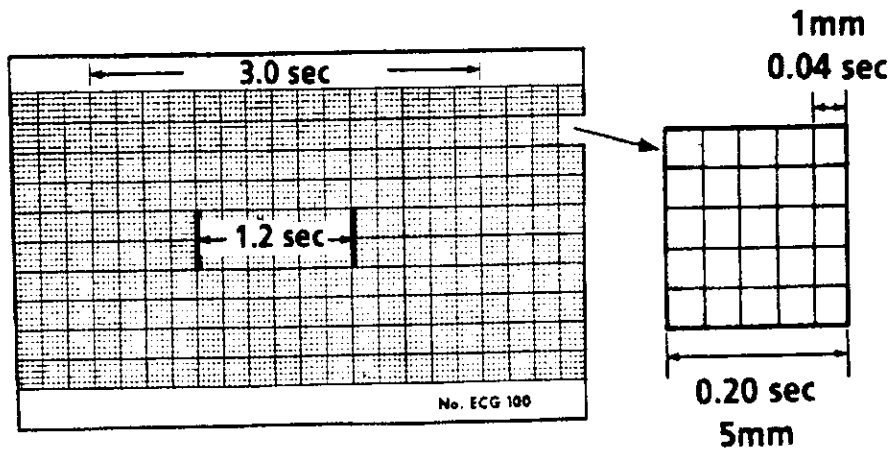
A number of different methods have been proposed for the quickest and easiest way of determining the QRS axis. One quick and easy way is to look at the lead which has the largest **net** positive force (R wave minus S wave.) The QRS axis is close to that direction. For example, if the largest positive forces are toward lead III, then the QRS axis is close to 120 degrees. Determination of the axis is important since it is sometimes helpful in the diagnosis of congenital heart disease. For example, left axis deviation is virtually always seen on the ECG of patients with tricuspid atresia or endocardial cushion defects, such as complete AV canal. Right axis deviation may be seen in patients with tetralogy of Fallot.



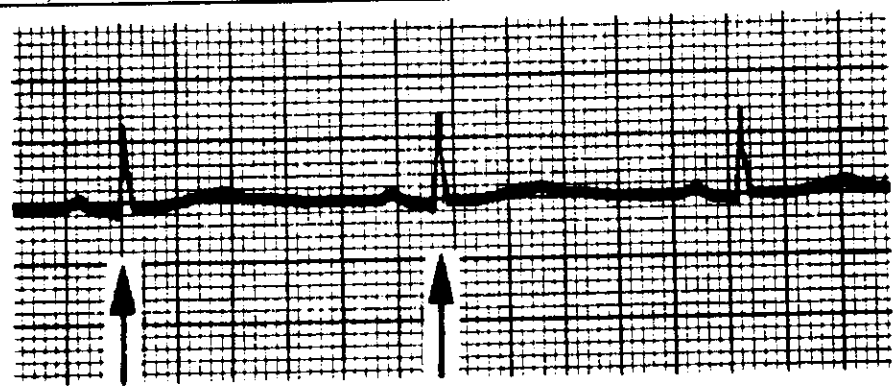
The P wave axis in sinus rhythm is typically between 0 and 90 degrees, assuming that the heart is in the left chest. Most frequently, the P wave is most positive in lead II. If the P wave axis varies significantly from these values, the it is possible that the rhythm is not sinus in origin. In that case, it is likely to be from either an ectopic atrial focus or possibly from the AV node (with retrograde depolarization of the atria.)

Rate

Remember that the normal recording speed of the ECG is 25 mm/sec. Recall also that one big box contains 5 little boxes. Each little box is equal to 1 mm, making one big box equal to 5 mm. That means that 5 big boxes (from left to right) is equal to one second in time and thus that one big box = 0.2 sec and one little box = 0.04 sec.



Above: ECG paper. Time is measured on the horizontal axis with each 1 mm = 40msec and each large division (5mm)=200 msec (0.2 sec). Every 7.5 cm (3.o sec or 1/20 minute) is marked on the top margin of the paper.
Below: The easiest way to determine rate is to take 300 and divide that by the number of big boxes (including fractions) between two consecutive QRS complexes. For example, if there are 5.8 big boxes between the QRS complexes, then 300/ 5.8 = 52.
Thus, the HR in this example is 52 BPM.



Remember when we discuss rate that we typically are referring to the number of QRS complexes per minute. Of course, the atrial rate may be faster or slower than this. Also, the HR as determined by the ECG may not be the same as the pulse rate. The pulse rate will not exceed the rate on the ECG, but it could be less then the ECG rate. Under what circumstances might that be true?

Rhythm

Rhythm abnormalities will be discussed in a separate section. NSR means "normal sinus rhythm". This is frequently inaccurately used as when one looks at lead II on an ECG monitor and 'declares' NSR. This is not possible. There are three elements required for 'NSR': 1) a P wave before every QRS and none alone; 2) normal PR interval [or otherwise the pt has AV block]; and 3) a normal P wave axis. Without at least two leads, one cannot determine the vector and therefore, one cannot say NSR based on the one lead available on the monitor.

Chamber hypertrophy/enlargement

There are a number of criteria listed for right and left ventricular hypertrophy in *Harriet Lane*. In general, if there is excessive voltage in the right precordial leads (V4R and V1), then there is likely to be RVH. The same holds true for the left precordial leads (V5 and V6) for LVH. In addition, if there are excessive negative voltages (S wave) in V4R and V1 then there is LVH, while large S waves in V5 and V6 suggest RVH.

Right ventricular hypertrophy:

- QR pattern in the right chest leads.
- T wave changes in the right chest leads. In general, this refers to an upright T wave in V4R and V1 after 3-7 days of age and before about 8 years of age.
- R wave amplitude in V4R and V1 above 98%ile.
- S wave amplitude in V5 or V6 above 98%ile.
- Abnormally high R/S ratio in the right chest leads or low R/S ratio in left chest leads.
- RSR' pattern in V1--this is frequently seen in patients with hemodynamically significant atrial septal defects.
- Right axis deviation.

Left ventricular hypertrophy:

- T wave inversion in V5 or V6.
- Tall R wave in V5 or V6 or deep S wave in V1(>98%ile.)
- Deep Q waves in V5, V6 or the inferior leads (II, III, or AVF).
- Absent Q waves in V5 and V6.

Biventricular hypertrophy:

- Abnormal voltage in both the right and left chest leads. (In the presence of isolated hypertrophy of one ventricle, the forces reflecting the other normal ventricle usually appear diminished on the ECG.)
- Abnormal voltage (R + S wave) in the midprecordial leads.

Right atrial enlargement:

- Increased amplitude of the P wave (generally >2.5 mm), particularly in leads II or V1.

Left atrial enlargement:

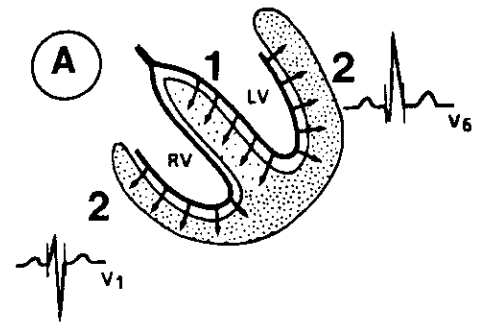
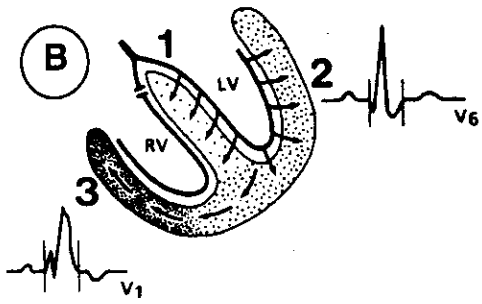
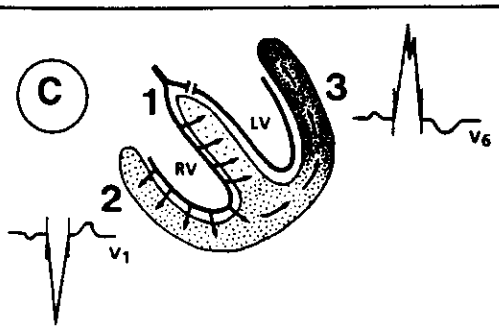
- Increased P wave duration, especially in lead II.
- Negative deflection of the P wave in V1 > 1mm.

Biatrial enlargement:

- Abnormal voltage and duration (usually seen best in lead II.)

Conduction Disturbances:

Chamber hypertrophy and ventricular conduction disturbances are the two most common form of ECG abnormalities in pediatric patients. Right bundle branch block (RBBB) is the most common form of ventricular conduction disturbance. In RBBB, the depolarization of the ventricular septum is normal, but the free-wall is activated through the myocardium rather than the Purkinje system and therefore at a slower rate. The result of this process is prolongation of the terminal portion of the QRS complex, which is called *terminal slurring*. Since the RV depolarizes last and it is located relatively rightward and anterior, then the terminal portion of the QRS complex in RBBB is directed to the right and anterior. Left bundle branch block (LBBB) is rare in children.

	**Panel A**: Sequence of normal vent depolarization. Because of the direction of septal depolarization (1), there will be an initial R in V_1 and a q wave in V_6. Simultaneous depolarization of both ventricles in the opposite directions (2) results in QRS complexes of relatively small amplitude and normal duration, with a dominant LV causing rS in V_1 and qR in V_6.
	**Panel B:** Sequence of vent depolarization in RBBB. the septal depolarization (1) is normal with resulting Q in V_6 and R in V_1. The terminal slurring that is directed anteriorly and rightward produces rsR` pattern in V_1 and qRS in V_6. The amplitude of QRS may be abnormally large.
	**Panel C:** Sequence of vent depolarization in LBBB. Note that septal depolarization proceeds in a direction opposite of normal, producing a Q wave in V_1 but not in V_6. The terminal slurring is directed leftward and posteriorly, thereby producing a wide S in V_1 and wide R in V_6. The amplitude of the QRS complexes may be abnormally large.

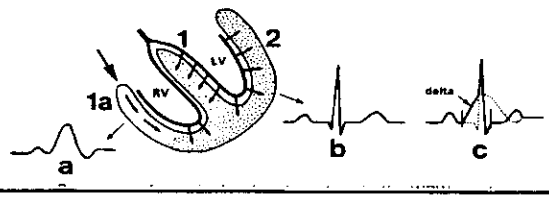
Wolff-Parkinson-White

At the earliest stage of embryogenesis, the heart is a single tube of muscle which conducts impulses from the sinus horns towards the aortic bulb producing a single continuous peristaltic wave. When the heart septates, the fibrous trigone is formed between the atria and ventricles. This not only serves as structural support but also electrically isolates the filling chambers from the pumps and forces all impulses to pass through the *penetrating* (penetrates the insulating sheet) bundle of His. Occasionally, some electrical connections persist, connecting atrium directly to ventricle; these are called accessory pathways and they bypass the AV node. Without the delay that normally occurs through the AV node, the ventricle which is connected to the anomalous bundle gets depolarized prematurely. This produces the initial slurring of the QRS complex (also called a delta wave) and a short PR interval. Typically, only a small portion of the ventricle becomes depolarized as a result of the accessory pathway, and the remainder of the ventricle is depolarized through the normal His-Purkinje system.

Criteria for making the diagnosis of WPW syndrome:

1) Short PR interval.
2) Delta wave (initial slurring of the QRS complex).
3) Wide QRS duration.

As long as there is conduction through one pathway only and *in only one direction*, the pt has no tachycardia. Rapid heart rates occur when there is antegrade conduction down one pathway and retrograde conduction [back to the atrium] through the other. In orthodromic reciprocating tachycardia, conduction occurs down the AV node and up the accessory pathway. In antidromic reciprocating tachycardia, conduction occurs down the accessory pathway and up the AV node.

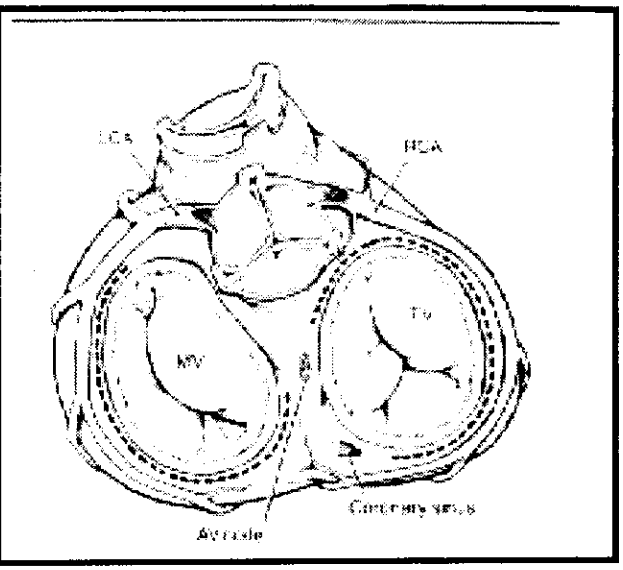


Left Panel: The area on the left side of the figure (1a) is pre-excited via the accessory pathway (AP), since conduction through this accessory connection is more rapid than that through the AV node. The delta wave on the ECG is the product of this early depolarization of the ventricle, but conduction through the ventricle myocardium is slow since depolarization moves from cell to cell. On the other hand, once conduction through the AV node is completed, the normal His-Purkinje system is utilized and thus occurs much more quickly. Thus, the remainder of the QRS complex is narrow.

ECG **a** illustrates what the QRS would look like if the entire ventricle was depolarized from the AP. ECG **b:** if conduction were entirely through the His-Purkinje system (what normally occurs). ECG **c:** when the two are combined, as occurs in W-P-W.

Locations of Bypass tracts in W-P-W Syndrome

The Figure to the right is *from above* with the atrial walls and great arteries removed. Mitral (MV) and tricuspid (TV) valves are shown as are the coronary arteries (RCA and LCA). The coronary sinus is seen connected by the bundle of His (not shown) with the A-V node. The dashed lines are where right- (near the TV) and left- (around the MV) sided bypass tracts are found. This is where surgical incisions were made to treat W-P-W before per-catheter techniques became available.



ST segment and T wave changes:

Although common in adults, pathologic ST and T wave changes are relatively infrequent in the pediatric population. Not all ST segment shifts are abnormal. Elevation or depression up to 1 mm in the limb leads and up to 2 mm in the precordial leads are within normal limits. Two important types of non-pathological ST segment shifts seen in pediatric patients are J-point depression and early repolarization.

J-point depression is a shift of the junction between the QRS and the ST segment without sustained ST segment depression. The T waves are not altered. In early repolarization, all leads with an upright T wave have elevated ST segments and those with negative T waves have depression of the ST segments. This is often associated with a tall T wave. The T wave axis remains normal and does not evolve over time as pericarditis does.

Pathologic ST and T wave changes are associated with the following conditions:

- LVH or RVH with 'strain'
- Digoxin effect
- Pericarditis, including that seen in the post-operative state
- Myocarditis
- Myocardial infarction
- Electrolyte disturbances:
  - **hypocalcemia:** prolongation of the QTc
  - **hypercalcemia:** shortening of the QTc
  - **hypokalemia:** flattened or diphasic T waves, ST depression, prominent U wave

hyperkalemia: (the following sequence is associated with a progressive increase in the serum K+ level)

-tall "tented" T wave
-QRS prolongation
-PR interval prolongation
-disappearance of the P wave
-wide, bizarre, diphasic QRS complex
-eventual asystole

Summary/Review for ECG Reading

The 'tic-tac-toe' diagram below summarizes the elements necessary for reading an ECG. It may help you to do readings by filling in the nine boxes of the design.

RATE	**RHYTHM**	**AXIS**
P-R Interval	**QRS duration**	**Q-T, corrected for HR**
P wave	**QRS complex**	**ST seg; T wave**

Skill in ECG interpretation requires effort and patience. It is important for the pediatrician and family practice physician to be able to determine rate, axis, and chamber hypertrophy as well as diagnose simple arrhythmias. This can only come from repeated practice.

2. Chest X-ray (CXR)

Introduction:

Though CXRs can be of significant value in screening for some heart problems and as an adjunct in following the progression of certain cardiac diseases, a "normal CXR" does not exclude the presence of all heart disease any more than the absence of a heart murmur.

Technical (non-patient specific) factors

These can affect the way in which a CXR appears and therefore is interpreted. Reading a CXR should begin with a critique of technique considering the following factors:

- *Orientation:* CXRs should be taken with the patient 'en face' with respect to the X Ray beam and photographic plate. If the patient is rotated or angulated, the size, shape and appearance of the cardiac contours are changed dramatically. Good rules of thumb are that there should be equal lengths of ribs or clavicles on either side of the spine and that only the very apical lung lucencies should extend above the clavicles.
- *PA rather than AP* views of the chest should be obtained as there is less magnification and greater image sharpness with the former. PA views, however, are not practical in infants and small children often causing normal-sized hearts to appear enlarged.
- *Inspiratory phase:* On expiration there is less air in the lungs causing the lungs to appear more "cloudy" and the heart to appear larger. For cardiac purposes, CXRs should be done at the end of inspiration. Rules of thumb for an adequate inspiratory effort are: 8 ribs anteriorly or 9 ribs posteriorly. Without magnification error and with an appropriate inspiratory effort, the maximum horizontal dimension of the heart should not exceed 50% of the chest width in its maximum dimension.
- *Penetration:* The way the pulmonary circulation and lung fields appear is to some degree a function of how much energy is used in making the film. If too little energy is used, penetration is inadequate, the film may appear whiter and vascular markings are more prominent. Too much energy and the film is overpenetrated making everything appear black. In a film of good penetration, the bony structures are lighter than the heart and blood vessels, which are much lighter than the lung fields.

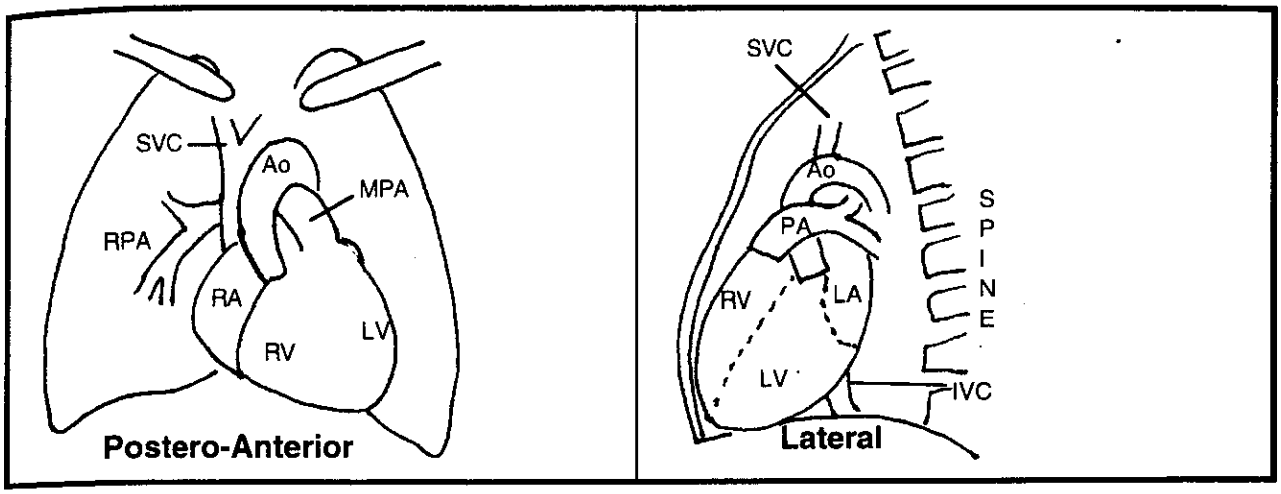
System for Evaluating a CXR:

Once a CXR has been critiqued for technical merit and **is deemed adequate for interpretation,** the viewing of the CXR should be done in a systematic

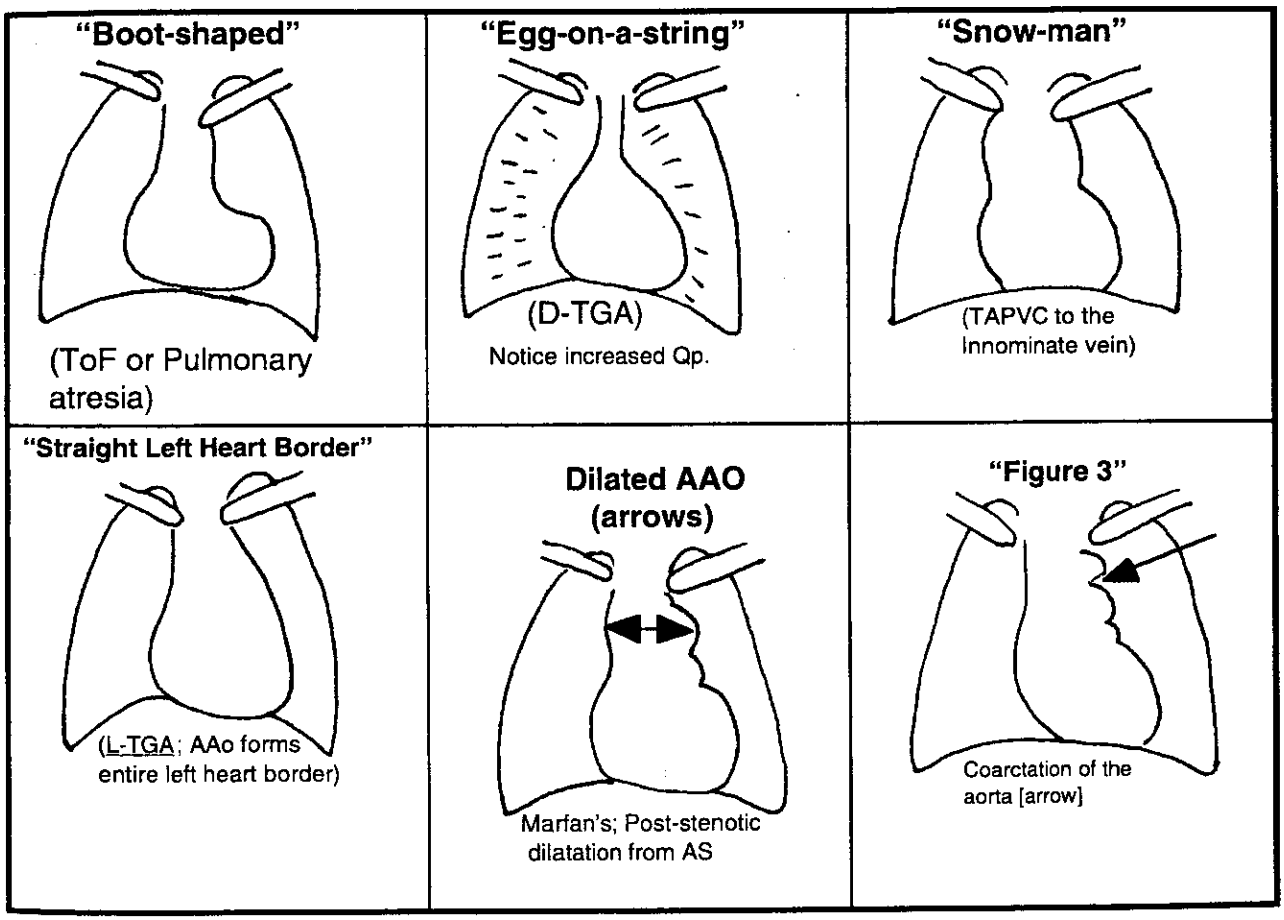
fashion to make the most of the study. (Beware of attempting to read a poor quality film as this usually results in an inaccurate interpretation.) The following sequence is one that many cardiologists use.

- *Bony structures:* Examine the spine, ribs and sternum for abnormalities. Hemivertibrae or abnormal numbers of ribs may suggest the "VACTERAL" association (see Syndromes section). Rib "notching" is found in long-standing Coa secondary to development of collateral vessels. Multiple ossification centers in the manubrium sternum suggests Down syndrome in which there is at least a 50% incidence of congenital heart disease.
- *Lung fields:* Should be examined for infiltrates, edema, fluid in fissures, pleural effusions.
- *Vascular markings:* it is normal to see pulmonary arterial markings up to 2/3 the way towards the lung periphery. If they extend farther and if many vessels are seen "on end", think L-R shunt. If there is an increased amount of more "vertical vascular markings" think elevated pulmonary venous pressure as occurs in obstructed pulmonary venous return, cor triatriatum, supravalvar mitral ring, mitral stenosis or regurgitation, or CHF (primary or secondary). Always check for symmetry of the markings as there may be different degrees of obstruction to flow in the lungs; also, systemic-to-pulmonary shunts may flow predominantly to one lung.
- *Laterality:* The normal visceral sidedness is: cardiac apex and stomach bubble on left, liver on right. Abnormalities in visceral sidedness (with the exception of situs inversus totalis--mirror image dextrocardia) are associated with a higher than usual risk of congenital heart disease. The laterality of the aorta can also be determined on a plane film as the trachea is deviated rightward by a left arch and leftward by a right arch etc. Sometimes there appears to be equal tissue on both sides of the trachea which might suggest a double aortic arch.
- *Contours:* The structures underlying the normal cardiac contours are shown in the Figures below. When a chamber or vessels is enlarged, its particular area of the cardiac contour becomes more prominent. When a chamber or vessel is atretic or hypoplastic, then its contour becomes smaller or is absent. Examples of abnormal contours suggestive of particular heart defects are also given diagrammatically below. Please see other chapters for more details regarding roentgenographic consequences of a particular heart lesion or classes of heart lesions e.g. cyanotic heart defects, left to right shunts etc.

NORMAL CARDIAC CONTOURS



ABNORMAL CARDIAC CONTOURS



3. Echocardiography

Introduction: Echocardiography uses sound waves in the ultra-high, non-audible, region of the spectrum to produce information concerning the structure and function of the heart. The sound waves are produced and detected by crystals which are Piezo-electrically active, meaning that they vibrate in response to application of an electrical current and generate an electrical current in response to a vibration (mechanical deformation). Accordingly, the crystals can be said to "transduce" electrical into mechanical or mechanical into electric activity. The electrical information generated by the crystals in response to reflected sound waves is then processed by a computer which generates images and other displays on a monitor screen.

Terminology:

Abbreviations:
LVEDD= LV end diastolic dimension
LVESD= LV end systolic dimension
F.S.= fractional shortening= LVEDD-LVESD/LVEDD
LVPW= LV posterior wall thickness in diastole
IVS= ventricular septal thickness in diastole
RVEDD= RV end diastolic dimension
RVAFW= RV free wall thickness in diastole
LAD= left atrial dimension at end systole

Transducer: This is the part of the echo apparatus that actually contains the crystals which generate and "listen" for sound waves. Air scatters sound waves. This means, the transducer must be held in contact with the patients body (sonic contact) to transmit and receive sound waves through and from body structures. Scatter of transmitted and received sound waves at the transducer/body surface interface is minimized by using a gel (improved sonic contact).

Frequency: Crystals and transducers are engineered to produce sounds waves of different frequency. Frequency simply defined, is the number of sound waves in a given time period (cycles per second). Frequencies useful to pediatric Echocardiography range from 2.0 to 7.0 M Hz. The higher the frequency the better the resolution of the image (ability to distinguish 2 close points as being separate), but the poorer the penetration. Conversely, the lower the frequency the better the penetration, but the poorer the resolution. This is why the higher frequency transducers are used in infants and smaller children, while lower frequency transducers must be used in larger individuals to provide adequate sound penetration (at the cost of resolution).

Transthoracic: refers to an echo done with the transducer in contact with the patients thorax.

Transesophageal: refers to an echo done with the transducer positioned, at the end of an endoscopic tube, in the patient's esophagus. This approach is particularly helpful in larger individuals or individuals with obstructive lung disease in whom the transthoracic image is poor due to scatter of sound waves. It is also often used intraoperatively to assess the results of a heart surgery, where a transthoracic approach is not practical.

Fetal Echocardiography: refers to an ultrasound evaluation of a fetal heart, usually done through the abdomen of the mother. The best medical and social reason for doing a fetal echocardiogram is that it may allow for in utero treatment of a rhythm disturbance or that it will allow for counseling of families regarding post-natal planning for babies found to have structural heart disease. Fetal echocardiograms are best performed between 18 and 24 weeks gestational age (structures too small before 18 weeks, "bony" interference after 24 weeks). Accepted indications for fetal echocardiography are: 1) biological parent or sibling has congenital heart disease; 2) maternal exposure to a known teratogen; 3) presence of maternal disease known to effect the fetal the cardiovascular system (e.g., IDM, SLE); 4) fetal hydrops; 5) presence of other fetal somatic defect associated with increased incidence of congenital heart disease (CHD) (e.g., esophageal or duodenal atresia, omphalocele, diaphragmatic hernia); 6) fetal syndrome associated with CHD identified (trisomy 21, 18 etc.); 7) possible fetal dysrhythmia; or 8) obstetrician or perinatologist tentatively identifies a heart problem.

M-mode echo: Also known as motion display echo or "one dimension" echo. Generates and detects a pin point or "ice pick" of sound waves. Displays the echo reflections at various depths vs. time. Was the first form of echocardiography developed, but its use now is generally limited to measurement of chamber sizes and wall thicknesses and assessment of LV systolic function (Fractional Shortening = LVEDD-LVESD/LVEDD). M-mode and two dimensional images do not necessarily give the same measurement of a structure.

Two dimensional echo: In this form of echo, a beam of ultrasound waves is either mechanically or electrically swept through an arc producing a two dimensional image of a sector encompassed by the arc. This is synonymous with "Sector scanning" and may also be called "real time echo" because the activity of the heart is displayed on screen as the events occur.

Three dimensional echo: In this form, a computer-generated three dimensional image is produced by "stacking" a sequential series of two

dimensional images. This form is investigational now, but probably will available for routine clinical use within the next 5 years.

Doppler ultrasound: When sound waves are generated or reflected by objects that are moving towards or away from a fixed object (i.e. transducer or crystal), the sound frequency observed at the fixed object will either be increased or decreased, respectively, compared to the original frequency. This is termed the Doppler principle after the physicist/ astronomer that discovered it. The change in frequency is termed the Doppler shift, or Doppler frequency (Fd) and is equal to the difference between the transmitted (Ft) and received (r) frequencies: (Fd= Ft minus Fr). This Doppler frequency can be measured and is a function of the transducers transmission frequency (Ft), the velocity of the moving object (V), the angle between the direction the object is moving and the direction of the incident sound waves (φ), and the speed the sound is traveling in the medium in which it is traveling (c), such that ($Fd=2Ft \times V \times \cos \varphi / c$). This means that the higher the transmission frequency (transducer frequency), the higher Fd. The importance of this is discussed below (pulsed Doppler). In practice, the Fd and Ft are input into the echo machine's computer which automatically calculates a velocity and displays on the screen.

Modified Bernoulli equation: When a fluid traverses an area of narrowing, the potential or pressure energy of the fluid is changed to kinetic energy (increased flow velocity). This results in a decrease in transmural fluid pressure. The modified Bernoulli equation relates the velocity change to the change in pressure across an obstruction, such that $^{\Delta}P=4(Vf^2 - Vi^2)$. In the case of a discreet obstruction, the Vi becomes insignificant compared to the Vf and can be dropped from the equation, such that $^{\Delta}P=4Vf^2$. This is the formula that the computer in the ultrasound machine uses to calculate a pressure gradient across a discreet obstruction (i.e. stenotic valve) from a flow velocity. However, if the obstruction is long-segment or tubular, Vi is not insignificant and failure to include it in the calculation will over-estimate the pressure gradient.

Pulsed wave Doppler: Also known as range-gated Doppler. In this form of Doppler study, a single crystal generates sound waves in short pulses and then listens for the reflected waves. In practice, the operator selects a depth of sample interest on the screen and the computer automatically alters how many pulses are sent out per unit time (pulse repetition frequency, or PRF). The greater the depth of interest, the lower the PRF has to be, because the longer the crystal has to listen in between pulses in order to "hear" the reflected waves. This form of Doppler allows the location of obstruction to be directly determined. However, high velocities can not be measured using

this technology because of the relationship between pulse repetition frequency and the Doppler shift frequency (Fd). To measure Fd accurately, the Doppler crystal must sample twice. This means that the maximum Fd that can be measured is equal to 1/2 of the PRF. This is called the Nyquist limit (Nyquist limit, or maximum Fd= 1/2 PRF). When the Fd, exceeds the Nyquist limit, a phenomenon called aliasing or "wrap around" occurs on the screen display. In general, the deeper the sampling, the lower the PRF has to be and the more likely aliasing will occur. Also, the higher the transducer frequency, the higher the Fd will be for a given velocity, the more likely the Nyquist limit will be exceeded at a given depth, and the more likely aliasing will occur.

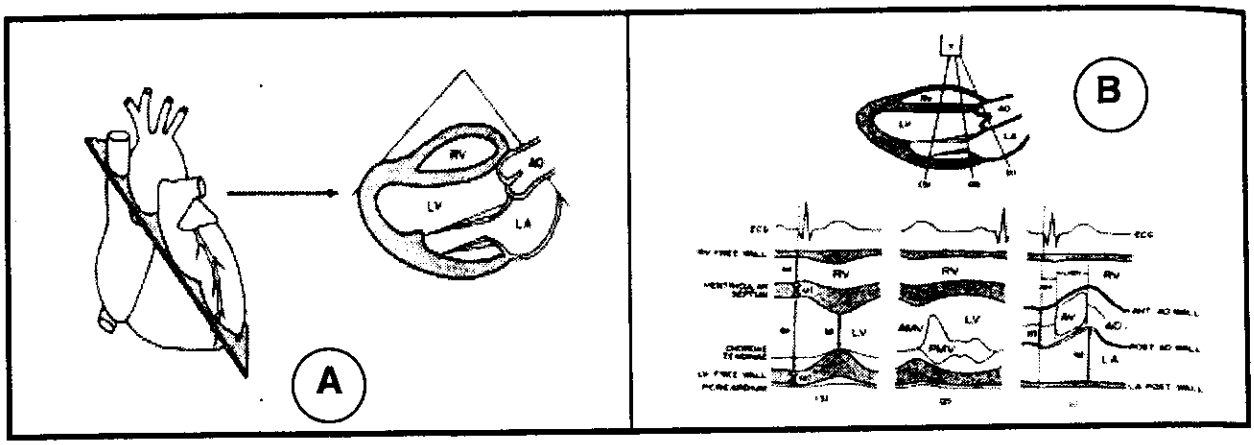
Continuous wave Doppler: In this form of Doppler, one crystal transmits sound, while another listens for reflections. This form of Doppler has the advantage of being able to measure high Fds and therefore high velocities, because it is always "listening" (pulse repetition frequency essentially infinity). However, it has the disadvantage of not being able to directly localize the depth from which the velocity is obtained. This must be deduced from prior two-dimensional imaging and pulse-wave Doppler sampling.

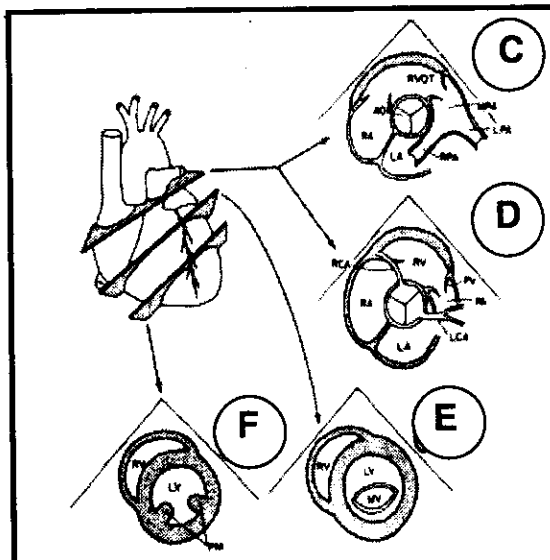
Color flow Doppler: Here, Doppler-detected direction and velocity of fluid flow are assigned a color by the computer. Flow towards the transducer is red, away from the transducer blue. Within these basic colors, shades are uses to connote velocity, so that the lighter the shade the higher the velocity. Like pulse-wave Doppler, aliasing also occurs in color flow at high velocities (when Nyquist limit is exceeded). This means, for example, that for a high velocity, exceeding the Nyquist limit, coming towards the transducer, wrap-around from red to blue will occur.

Two Dimensional Echocardiography

In experienced hands, most forms of congenital heart disease may be diagnosed using two dimensional echocardiography. This form of echocardiography produces a two dimensional slice of a three dimensional object, e.g., the heart. What is seen on the two dimensional slice is dependent on how the slice is taken which in turn is dependent on where the transducer is placed and pointed. No one slice can possibly image all heart structures, so multiple slices must be taken for all heart structures to be seen. Over the years, what slices are routinely taken have become standardized. They have been named according to where the transducer is placed and how the heart is "cut" in relationship to its long and short axes. Note illustrations on pages 94-95.

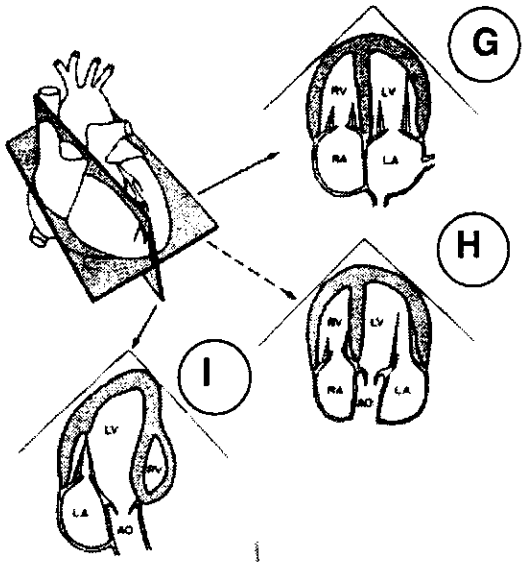
Parasternal long axis view: The transducer is placed along-side of the mid portion of the sternum and pointed so that sound sector "cuts" the left ventricle along its long axis. This produces an image that is schematically represented below (a). In practice, M-mode measurements of chamber size, wall thicknesses etc. are made under two-dimensional guidance from the parasternal long axis image. A typical M-mode "sweep" along the parasternal long axis is shown in (b) below.





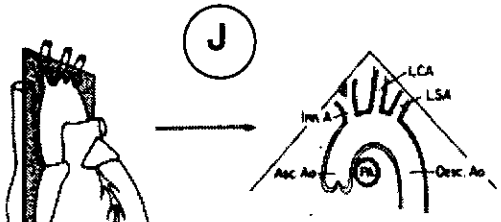
Parasternal short axis views:

From the same position on the chest as above, the transducer is rotated 90° so that the base of the heart is 'cut' in its short axis. The image that is produced is shown in C. With slight downward angulation of the transducer, the PAs go out of the beam and the proximal coronary arteries can be seen (D). With further downward angulation, the mitral valve and LV are seen in short axis (E). Still further downward angulation will bring the LV papillary muscles into view (F).

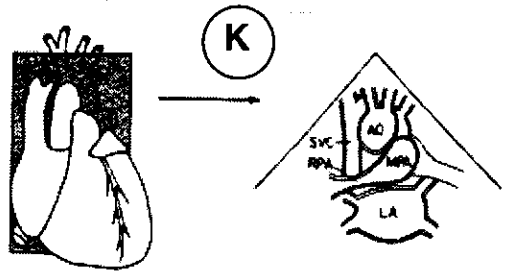


Apical views:

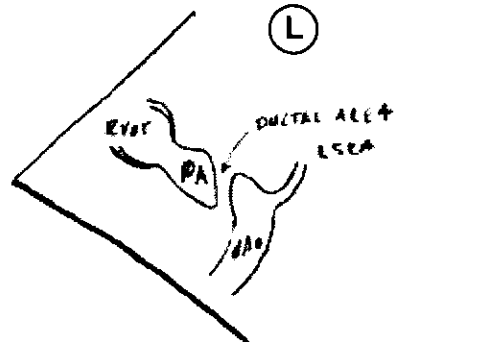
The transducer is placed directly over the apex of the heart and rotated so as to 'slice' through all four chambers (G). Slight upward angulation of the transducer brings the subaortic region and the aortic valve into view (H). 90° rotation of the transducer then produces an image similar to the parasternal long axis image (I).



Aortic arch view :
With the transducer placed high along the pt's sternum-in infants-or in the suprasternal notch in older children, an image of the aortic arch can be obtained)J). Note that the RPA is cut in cross-section in this view.



'Crab' or pulmonary vein view:
Once the aortic arch view has been obtained, the transducer can be rotated clockwise so as to image the RPA tangentially. With inferior angulation and with the aid of color mapping, all four PVs can then be imaged as they enter the LA (K).



Ductal view:
With the transducer placed in a position between those that produce the basilar parasternal short axis image and the arch view, an image is obtained of the juxtaductal area, including the ductus if present, the proximal descending aorta and the MPA-LPA junction.

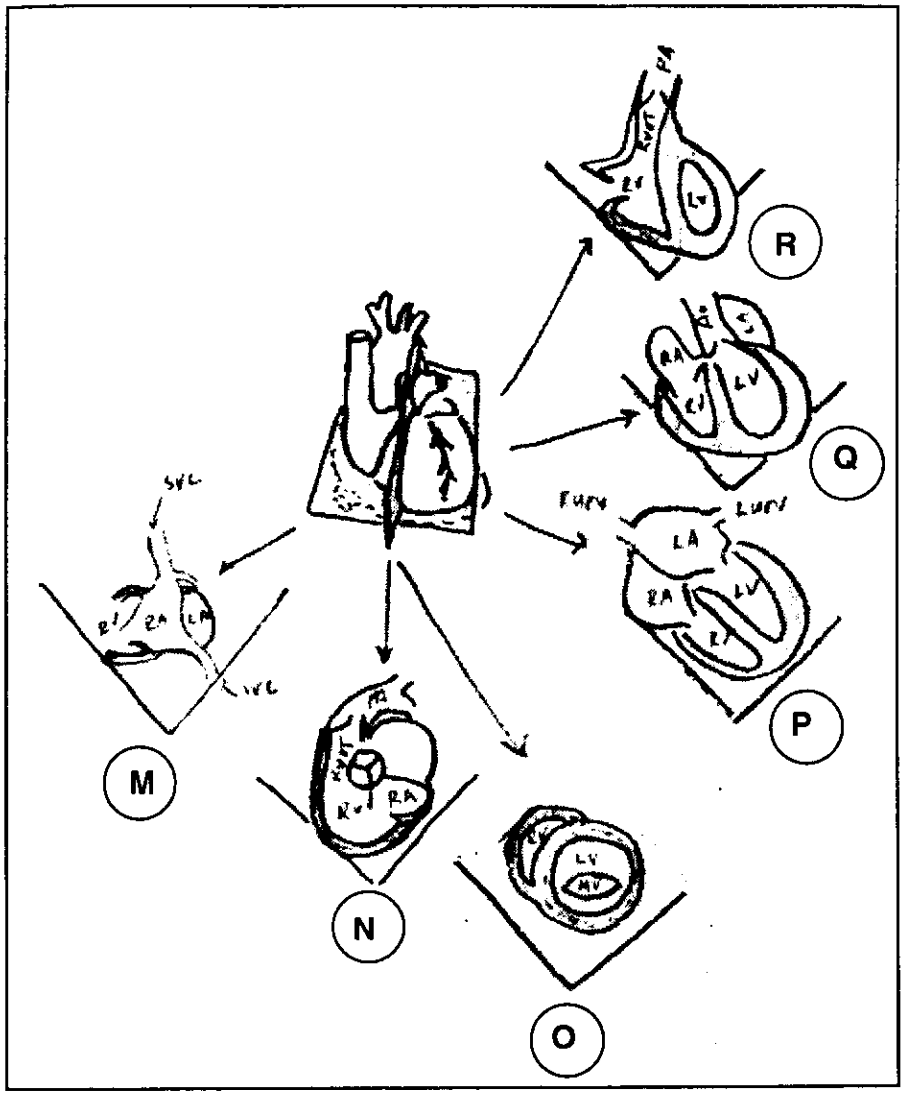
Subxiphoid views: The heart may also be imaged from below the costal margins and the xiphoid process. Images produced along the long or short axes of the heart are very helpful in examining the cardiac anatomy in infants and children, particularly when there is a complex defect, where a segmental analysis must be done to make an accurate diagnosis.

Subxiphoid short axis through atria, vena cavae, tricuspid valve, RV: (M) slices through the long-axis of the vena cavae. It is excellent for detecting sinus venosus ASDs.

Subxiphoid short axis through aortic valve, RV, PA: (N) produces an image equivalent to the basilar parasternal short axis image and is produced as the transducer is swept part way towards the cardiac apex in the short axis.

Subxiphoid short axis through LV: (O) is also similar to the parasternal short axis and is produced by further angulation towards the cardiac apex.

Subxiphoid long axis view. If the transducer is rotated ninety degrees from the short axis long axis images of the heart are produced. Inferior angulation will bring in all four cardiac chambers (p), more superior angulation brings in the aorta (q) and still more superior angulation brings in the pulmonary artery (r).



4. Diagnostic Cardiac Catheterization

Can be used for therapy (see #13-I) and/or diagnosis.

Diagnostic capabilities include:

a) basal hemodynamics by measuring O_2 saturation, pressures, and cardiac output;

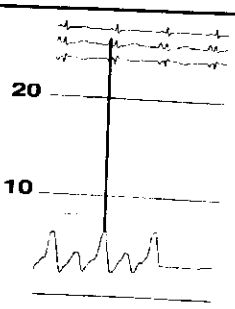
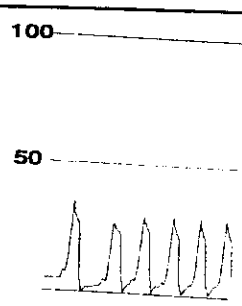
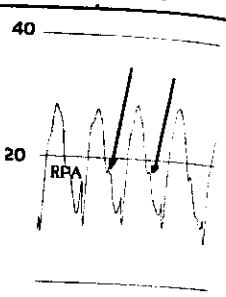
b) selective angiography by injecting contrast agents into specific chambers or vessels;

c) imaging via intravascular echocardiography;

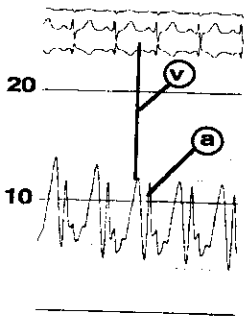
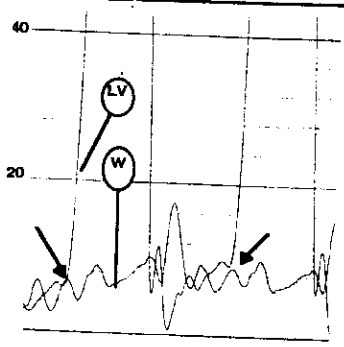
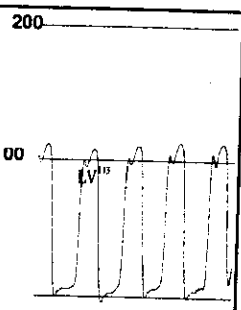
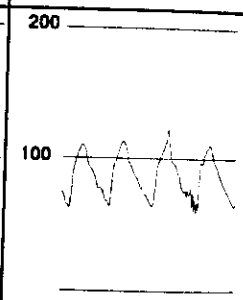
d) provocative testing to evaluate risk, e.g. for transplantation or to assess pulmonary vascular responsiveness;

e) predictive testing to see which therapies might work in a specific patient, e.g. what drugs lower pulmonary resistance in a patient with primary pulmonary hypertension.

Normal Pressure Tracings from Right Heart catheterization:

Site:	RA	RV	RPA
Pressure Tracings			
Normal Pressure	a=8, v=6, m=5	30 / 7	30 / 17, m=23
Note	The a wave coincides with the ECG P wave and the v wave follows the surface ECG T wave.	Compare to the LV pressure below. RVedp is generally somewhat lower than LV edp.	Different scale from RV; Note the dicrotic notch (arrows)

Normal Pressure Tracings from Left Heart catheterization:

Site:	LA	LV_{EDP} & PA wedge	LV	AAo
PRESSURE TRACINGS				
Normal Pressure	a=10, v=10, m=8	LVedp = 10 + a=10, v=11	90 / 9	90 / 45, m = 64
NOTE	LA pressure (LAp) depends on age, atrial compliance, and volume; it should = PA wedge pressure unless there is pulmonary vein stenosis. In contrast to RAp (see above), the LAp wave form is "M"- shaped. When there is a large ASD, LAp = RAp.	The a wave in the PA wedge pressure tracing (W) should equal end-diastolic pressure (LV) in the LV, unless there is obstruction in the pulmonary vein, left atrium or at the mitral valve.	Systemic systolic pressure is highly dependent on age (older → higher) and afterload. Note the LVedp which is ≈10.	Systolic pressures in the AAo and LV should be identical. Also remember: *renal* perfusion pressure = aortic mean pressure minus RA mean pressure.

Notes on prior graphs: Respiratory efforts--either spontaneous or from a mechanical ventilator--can have a significant impact on the pressure tracings, especially the atrial wave forms. On an ICU monitor, always check the wave form to be sure that the numbers on the screen reflect reliable pressures. The "normal" numbers given above are approximations and often do not reflect the pressure tracings shown in the graphs. Example: the LV pressure tracing shown demonstrates 113 mm Hg systolic pressure which is normal for a 13 year but quite elevated for a 3 day old; the 90/9 is a median 'normal' value for children.

Calculations and Rationale

- Calculations of flow and resistance are based on the *Fick principle* which states that blood flow through an organ or an entire circulation is related to the oxygen difference comparing the affluent blood to the effluent blood of that organ or circulation. Paraphrased, that means: flow is inversely proportional to A-V (arterio-venous) O_2 difference; see formulae which follow.

Without shunts, that means:

SVC sat. = RV sat. = MPA sat. = venous saturation, and
LA sat. = LV sat. = AAo sat. = arterial saturation.

Subtracting the venous saturation from the arterial saturation, one gets "A-V O_2 difference".

BUT, with a L→R shunt through a VSD, SVC sat. ≠ PA sat. and in a cyanotic child, e.g., with tetralogy of Fallot, and a R→L VSD shunt, LA sat. ≠ AAo sat.

- To obtain calculation of absolute flow and resistance, one must measure oxygen consumption (VO_2). One can get a reasonably approximate estimate of VO_2 using an assumed based on the landmark work of La Farge and Miettinen. [Yes, that is our Grant La Farge of Santa Fe.]
- Since the amount of Hb can affect oxygen delivery, tissue utilization and blood rheology, it is important to include the amount of Hb in the calculations by *converting saturation to content*, as: Hb X 1.39 = fully saturated Hb and then, O_2 content = (O_2 saturation) X (fully saturated Hb).

FLOW:

Qp = Pulmonary blood flow

$$= \frac{VO_2}{(\text{Pulm venous } O_2 \text{ content}) \text{ minus } (\text{Pulm artery } O_2 \text{ content})}$$

Qs = Systemic blood flow

$$= \frac{VO_2}{(\text{Aortic } O_2 \text{ content}) \text{ minus } (\text{SVC } O_2 \text{ content})}$$

Qp / Qs = relative flows, pulmonary-to-systemic.

Observe that as the A-V O_2 difference widens, the denominator increases, making the product less. This means that as the A-V O_2 difference becomes greater, the flow does DOWN. A wide A-V O_2 difference means low cardiac output. The converse is also true: a narrow A-V O_2 difference shows a high flow state.

RESISTANCE

- Resistance is a measure of what pressure difference (driving force) across the circulation in question is necessary to achieve the flow calculated for that circulation.

Rp = Pulmonary vascular resistance

$$= \frac{(\text{PA mean pressure}) \text{ minus } (\text{PV mean pressure})}{Qp}$$

Rs = Systemic vascular resistance

$$= \frac{(\text{Ao mean pressure}) \text{ minus } (\text{RA mean pressure})}{Qs}$$

Note the following:

- If flow is very high, e.g., Qp/QS > 3:1, then PVR must be normal.
- One can have elevated PA pressure but low resistance by having high flow and/or high pulmonary venous pressure.
- There is an inherent assumption that flow and resistance are the same in both lungs; when this is not true, the calculations shown above do not apply and one must calculate for each lung as though it were a separate circulation.
- The same principle is true of the systemic circulation, i.e., the calculations assume the same resistance throughout the systemic circulation. But if the pt has coarctation, the resistance is higher proximally than distally. Again, the resistance calculations do not apply in the presence of coarctation.

Sample calculations:

NORMAL (data from diagram of normal values; Hb=13; VO_2=100)

1. Hb X 1.39 = max O_2 content = 13 X 1.39 = 18.07
2. VO_2=100 (given)
3. PA mean pressure (mm Hg) = 17 & Ao = 64 (see diagram)
4. PV sat. (95%) X 18.07 = PV O_2 content = 17.17
5. PA sat. (69%) X 18.07 = PA O_2 content = 12.47
6. Qp = 100 ÷ (17.17 - 12.47) = 100 ÷ 47* = 2.1
7. Ao sat. (94%) X 18.07 = Ao O_2 content = 17.01
8. RA sat. (72%) X 18.07 = venous O_2 content = 13.01
9. Qs = 100 ÷ (17.01 - 13.01) = 100 ÷ 40 = 2.5

Clearly this is erroneous as we KNOW this pt is normal yet taken at face value, Qs > Qp. This shows that biologic variability forces one to consider the physiology as a whole rather than simply accepting the calculations as 'true'.

* (This is multiplied by 10 as the O_2 content is in cc but the VO_2 is in liters.)

10. Rp = (17 - 7) ÷ 2.1 = 10 ÷ 2.1 = 4.8
11. Rs = (64 - 3) ÷ 2.5 = 61 ÷ 2.5 = 24.4

Six month old with moderate-sized VSD (Hb=13; VO_2=100)

Site	Pressure, mean (mm Hg)	O_2 sat (%)	O_2 content
MPA	30	84	15.17
PV	8	95	17.17
Ao	60	95	17.17
RA	5	68	12.29

Calculations:

1. Qp = 100 ÷ (17.17 - 15.17) = 100 ÷ 20 = 5.0
2. Qs = 100 ÷ (17.17 - 12.29) = 100 ÷ 48.8 = 2.1
3. Qp / Qs = 5.0 ÷ 2.1 = 2.4

   Indicates that the lungs are accepting over double the amount of flow that is going through the body.
4. Rp = (30-8) ÷ 5.0 = 22 ÷ 5 = 4.4
5. Rs = (60-5) ÷ 2.1 = 55 ÷ 2.1 = 26.2

Conclusions (for the above patient):

a) Pt has large L→R shunt [Qp/Qs > 2:1]
b) Though pt has PAH, the PVR is normal.
c) Systemic flow and resistance are normal.

Unknown patient; try the calculations. Answers on the next page.

Hb = 12. VO_2 = 110

Site	Pressure, mean (mm Hg)	O_2 sat (%)
MPA	15	88
PV	8	95
Ao	60	95
RA	8	68

5. Holter and event recorders

Continuous ECG tape recorders represent the traditional *Holter monitor.* Typically , two ECG channels are recorded over a twenty-four hour period. Special computers are then used to scan the tape for abnormalities, including ectopy (both ventricular and supraventricular), changes in QRS, ST and T wave contours, and fast and slow ventricular rates. Holter monitors are used most frequently to confirm the suspicion of an arrhythmia or to evaluate for the presence of an abnormal cardiac rhythm in the presence of symptoms. It is also very helpful when looking for clinically silent arrhythmias and quantifying rhythm abnormalities, such as the number of PVCs over a 24 hour period. One of the limitations of Holter monitors is that if a patient complains of symptoms which occur less often than every 24-48 hours, the chances of being able to observe the rhythm during symptoms is low. Thus, another type of monitoring device may be employed, specifically the *event recorder.* This device is "patient-activated," meaning that the patient activates the recorder at a time in which symptoms occur. Transmitters are available which can then send an electrocardiographic signal transtelephonically to a receiver unit and available for viewing in a physician's office or hospital setting. Patients are able to keep these monitors for as long as needed (although generally not for more that one month) in order to determine the rhythm in association with symptoms. We have found that this is often a very effective way to determine that rhythms are NOT the cause of symptoms in certain patients, particularly those with complaints of "fast heart rate," palpitations, and lightheadedness. On the other hand, occasionally these recordings may reveal significant arrhythmias, and thus treatment can be initiated. Thus, there is a role for both of these monitoring devices in the evaluation and management of patients with documented and suspected arrhythmias.

Answers to cath calculations for Unknown pt.
Hb = 12. VO_2 = 110

Site	Pressure, mean (mm Hg)	O_2 sat (%)	O_2 content
MPA	15	88	14.68
PV	8	95	15.85
Ao	60	95	15.85
RA	8	68	11.34

Calculations:

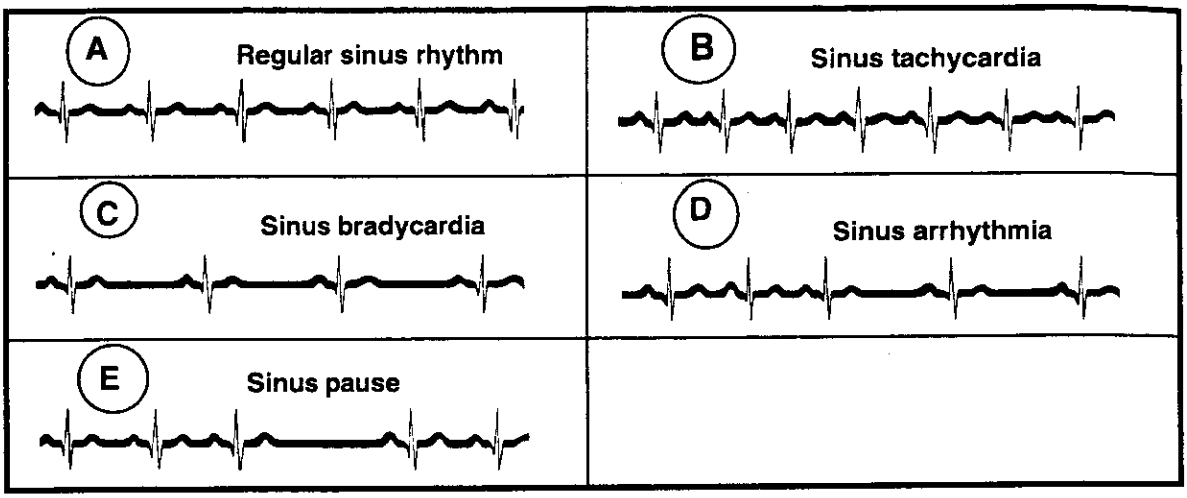
1. Qp = 110 ÷ (15.85 - 14.68) = 110 ÷ 11.7 = 9.4
2. Qs = 110 ÷ (15.85 - 11.34) = 110 ÷ 45.1 = 2.4
3. Qp / Qs = 9.4 ÷ 2.4 = 3.9
4. Rp = (15-8) ÷ 9.4 = 7 ÷ 9.4 = 0.7
5. Rs = (60-8) ÷ 2.4 = 52 ÷ 2.4 = 26.67

Conclusions:

a) Pt has very large L→R shunt [Qp/Qs ≈ 4:1 !]
b) Pt has normal PAP and very low PVR [as he must, given the huge L→R shunt.]
c) Systemic flow and resistance are normal.
d) These findings might be found in a child with a large ASD.

Basic Rhythm Interpretation

I. Rhythms originating in the sinus node



Panel A: Normal (Regular) sinus rhythm: The sinus node is normally the most rapid pacemaker in the heart and is located high in the right atrium. This produces P waves which are generally most positive in lead II, but the P wave axis can range normally between 0 and 90 degrees. In "NSR", the rate is normal for the age of the patient, there is one-to-one A-V conduction, the PR interval is normal and the P wave vector is also normal. There is usually a variation in heart rate of < 80 msec between RR intervals.

Panel B: Sinus tachycardia: A P wave precedes each QRS complex with an identical axis as that seen in NSR. The rate exceeds the normal range for a child of that age. Sinus tachycardia rates have been noted up to 260 BPM, but rarely are above 220 BPM, even in infants. Causes include any condition which requires increased cardiac output (thyrotoxicosis, exercise, fever, infection, anemia, anxiety, hypovolemia), congestive heart failure, myocarditis, hypocalcemia, and drugs such as sympathomimetic amines, decongestants, and vasodilators. Treatment is addressed to the causative factor for the sinus tachycardia.

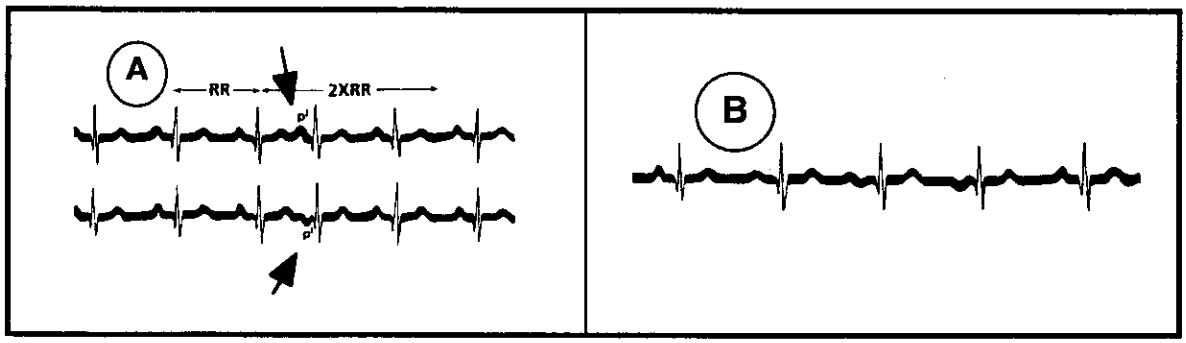
Panel C: Sinus bradycardia: The rate falls beneath that of the normal range for a child of that age. In general, the criteria for that would be a HR of < 60 BPM for an infant, 50 BPM for a child, and 40 BPM for an adolescent counted over a 6 second period. This can indicate sinus node disease and possibly loss of backup pacemakers (e.g., AV node.) It is rare in healthy children but

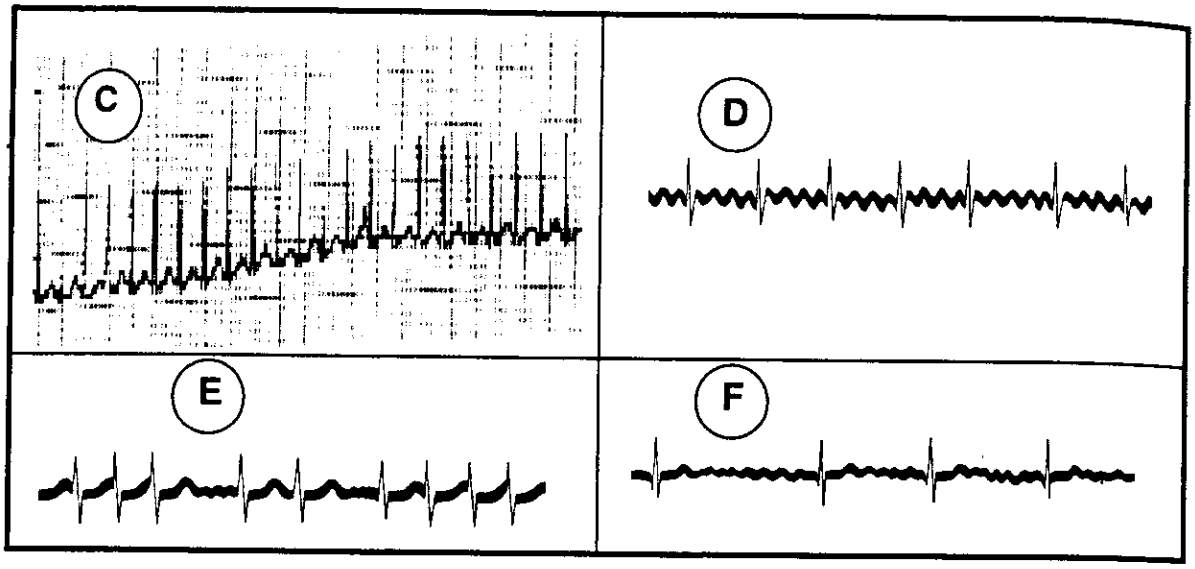
is seen in trained athletes. Causes include increased ICP, hypothyroidism, hypothermia, profound hypoxia, sick sinus syndrome, hyperkalemia, and drugs such as digoxin and beta-blockers. Treatment is addressed again to the causative factor(s), with immediate treatment only for the patient who is symptomatic. Atropine is effective short-term in this setting; other drugs which have been used include ephedrine, caffeine, and theophylline. A pacemaker would be placed for the patient with persistent symptomatic sinus bradycardia without an appropriate escape rhythm.

Panel D: Sinus arrhythmia: Similar to NSR, but there is a greater than 0.08 sec variation in the .PP interval. Generally, it varies with respiration, increasing during inspiration (decreased LV filling) and decreases with expiration (increased LV filling.) This rhythm is often pronounced in adolescents and indicates that the cardiovascular system is under vagal control but not under sympathetic control; therefore, it is regarded as a sign of good cardiac reserve. No treatment is necessary.

Panel E: Sinus pause: The result of a momentary failure of the SA node to initiate an impulse, which is generally of fairly short duration. A very long pause would be *sinus arrest* and usually results in an escape beat by a backup pacemaker. Sinus pause/arrest can be caused by an increase in vagal tone, hypoxia, or drugs such as digoxin. Treatment is similar to that outlined for sinus bradycardia.

II. Rhythms originating in the atrium





Panel A: Premature atrial complexes: Premature complexes are one of the most common causes of an irregular pulse. A premature beat is defined as a depolarization of the atrium, the AV node, or the ventricles which occurs earlier than expected. In the case of premature atrial complexes (PACs), there is a P wave on the ECG which occurs earlier than expected. The P wave morphology is often different from that seen in NSR since it comes from a different site within the atrium (See arrows). Since the sinus node is depolarized by the atrial activation, the sinus node is reset so that the RR interval following the premature QRS complex is normal. Occasionally the P wave will be buried in the T wave of the preceding beat, so *it is important to evaluate the T waves for changes when attempting to determine the origin of a premature beat.* PACs are common in healthy children and usually have no significance, but can be caused by central venous lines which go into the RA, hypokalemia, hypercalcemia, hypoxia, and hypoglycemia as well as drugs such as digoxin and sympathomimetic amines. They can also be seen in children with structural heart disease. Treatment is almost never required.

Panel B: Wandering atrial pacemaker: This represents a gradual shift of the site of impulse formation from the SA node to an ectopic atrial focus or the AV node. Thus, a variety of P wave morphologies are seen as the shift from one pacemaker to the other occurs. The P wave can disappear if the AV node takes over the pacemaker function of the heart. This is a benign finding and requires no treatment.

Panel C: Atrial tachycardia (including SVT): In these tachycardias, the rate is very regular and is fast, virtually always over 200 BPM and usually faster

than 250 BPM. There are actually several causes for supraventricular tachycardia (SVT):

1. Ectopic atrial tachycardia: an ectopic atrial focus takes over the pacemaker function of the heart at a rate which exceeds normal limits for a child of that age. These are often very difficult to control and do not generally respond to the usual treatment methods for SVT, such as vagal maneuvers, adenosine or electrical cardioversion. Rarely, there may be more than one atrial focus responsible; this is called **multifocal atrial tachycardia**. In this instance, a variety of P waves are seen on ECG with a wide variation in the P-P intervals. Both of these are examples of an automatic tachycardia, as opposed to a reentry tachycardia, the latter of which is far more common.

2. AV nodal reentry tachycardia: this refers to a reentry circuit within the AV node. This is more commonly seen in adults and since the reentry circuit does involve the AV node, it does respond to vagal maneuvers and adenosine. P waves are usually not seen on the ECG in this arrhythmia since atrial activation occurs simultaneously with ventricular activation (the P wave is buried in the QRS complex.)

3. AV reentry tachycardia: this refers to a site outside of the AV node as the point of reentry. This is the most common cause of SVT in children. The P wave is either buried in the QRS complex, as it is in AV nodal reentry tachycardia, or is seen following the QRS; this depends at least partly on how far the accessory pathway is from the AV node. Thus, the electrical impulse typically travels down the AV node, through the ventricles and back up to the atria via an accessory tract. When someone conducts down this bypass tract during NSR, then they are considered to have Wolff-Parkinson-White syndrome (WPW). Again, since the AV node is involved in the reentry circuit, then the acute treatment is vagal maneuvers or adenosine. If that does not work or the patient is *in extremis*, then electrical cardioversion would be appropriate.

Remember that in most children with SVT, the QRS morphology will be narrow; rarely, it will be wide because of aberrancy within one or both of the bundle branches.

Panel D: Atrial flutter: This arrhythmia is seen most often in patients with structural heart disease associated with dilated atria, myocarditis, cardiomyopathy and the post-op patient who has had atrial surgery. Occasionally, it is seen in the infant with a normal heart. Typically, it is characterized by a rapid, regular form of atrial depolarization which has a

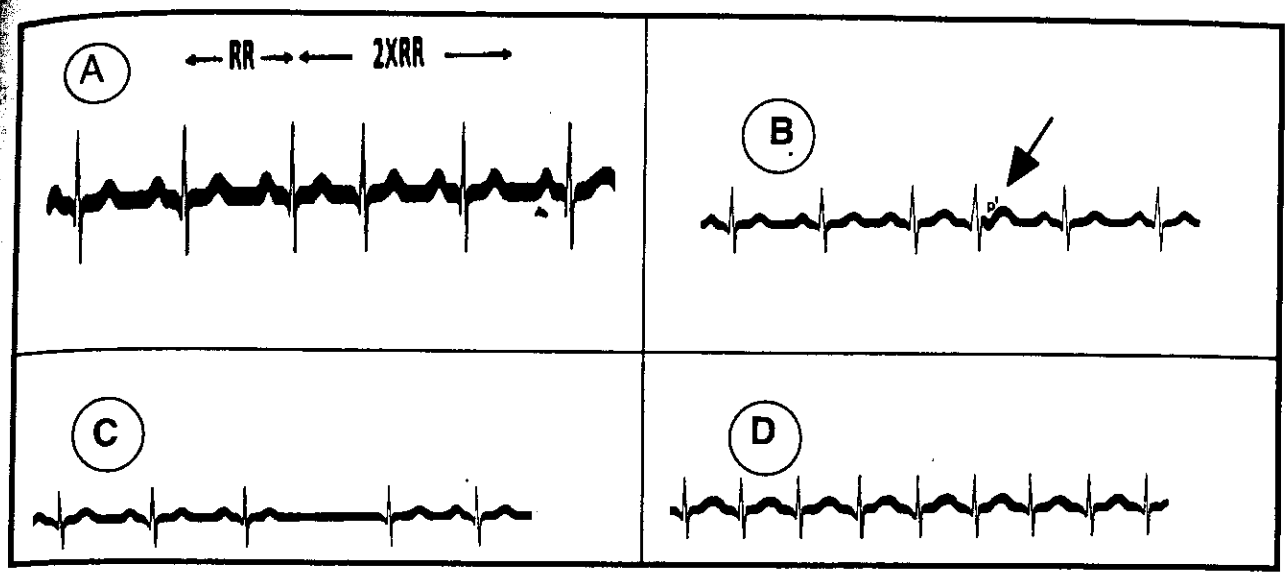
sawtooth or picket fence appearance, and are called flutter waves. This results from merging of the P waves without an isoelectric interval; it is most prominent in leads II, III, AVF, and V1. Occasionally, it is not so readily apparent. The atrial flutter rate is most commonly around 300 BPM, but can range from 280 - 450 BPM. The ventricular rate depends on how often the atrial impulses are able to conduct through the AV node to the ventricles. 2:1 AV conduction is common, giving an atrial rate of 300 BPM and a ventricular rate of 150 BPM, but 3:1, 4:1, and Wenckebach patterns (3:2, 4:3, etc.) are also seen. Patients with this kind of rhythm are often very stable, since they can tolerate the ventricular rate of 150 BPM easily. The ones that do poorly are those with 1:1 conduction (giving a HR of 300 BPM and more) or poor ventricular function. Treatment consists of controlling the ventricular rate with digoxin and/or a beta-blocker; this is especially important in those patients with 1:1 AV conduction. Conversion to NSR may require transesophageal overdrive pacing or electrical cardioversion.

Panels E + F: Atrial fibrillation: This is rarely seen in children and is nearly always associated with underlying heart disease, especially in post-operative patients. In this arrhythmia, the atria have an irregular, chaotic electrical pattern. On the ECG, the atrial waves are totally irregular and vary in size and shape from beat-to-beat. Often, the atrial rate cannot be accurately determined. The ventricular rate is also irregular and can be either fast (Panel E) or slow (Panel F). Acute treatment is aimed at controlling the ventricular rate, as it is in atrial flutter. This is usually done with digoxin and/or a beta-blocker. Electrical cardioversion is required to bring the patient back into NSR, but should only be done by a cardiologist since long-standing atrial fibrillation is associated with atrial thrombi; these patients require sustained anticoagulation prior to attempting electrical cardioversion.

III. Rhythms originating in the AV node (junction)

Rhythms originating in the AV nodal (or junctional) area are characterized by the following:

1. The P waves may be absent, or if present they occur after the QRS complex and are inverted.
2. The QRS complex is usually normal in duration and configuration.



Panels A & B: Premature junctional complexes (PJC) Basically, this looks much like a PAC except that there is no P wave identified which causes the premature beat. Sometimes, a retrograde P wave can be seen e.g., arrow in Panel B, following the QRS (from retrograde conduction.) The causes and treatment for PJCs are similar to PACs.

Panel C: Junctional escape beats This looks identical to the PJC except that it occurs later than one would expect rather than too early. It is not unusual to see a P wave immediately preceding the QRS complex at a PR interval which is shorter than the normal one. In this case, the P wave is not conducted to the ventricles and the origin of that particular ventricular complex is from the AV node. This requires no specific treatment.

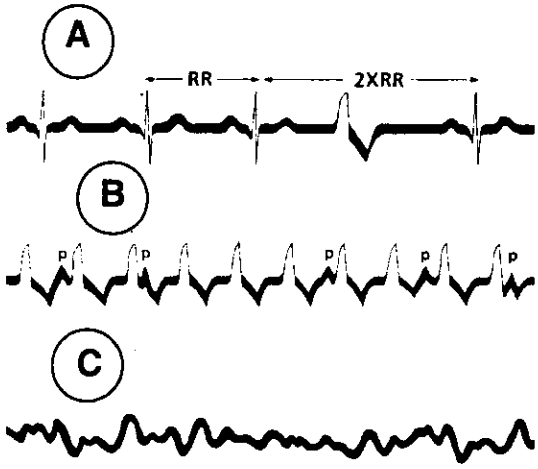
Panel D: Junctional tachycardia The rate ranges from 120 - 200 BPM. This is seen almost exclusively in the immediate post-operative cardiac patient and in digoxin toxicity. If the patient is not having significant hemodynamic problems from this, no treatment is indicated for the post-op patient. For the patient on digoxin, withdrawal of therapy (at least temporarily) would be appropriate. In the post-op patient who is compromised, these patients may require sedation, paralyzing agents and cooling of the body temperature in order to reduce the ventricular rate. Rarely, this rhythm is seen in the otherwise normal infant and can be extremely difficult to control. Flecainide is the drug of choice in these patients, although catheter ablation with placement of a pacemaker may need to be done in order to control this often fatal arrhythmia.

Children can also have an *accelerated junctional rhythm.* In contrast to the rate of 120-200 for junctional tachycardia, an accelerated junctional rate in a 6 YO would be from 60-120 BPM. In this rhythm, the AV node has enhanced automaticity and discharges at a faster rate than normal. It may actually take over the pacemaker function of the heart if it discharges at a rate which is faster than that of the sinus node. This rhythm is usually seen in patients with structural heart disease, especially in the post-operative patient, or those taking digoxin.

IV. Rhythms originating in the ventricle

Ventricular arrhythmias are characterized by the following:

1. QRS complexes are bizarre in configuration and long in duration.
2. QRS complexes and T waves often point in the opposite direction.
3. QRS complexes are randomly related to P waves.



Panel A: Premature ventricular complexes A PVC is manifest on the surface ECG as a premature abnormal QRS, which is not similar to the sinus QRS complex, that is not preceded by a premature P wave. In general, it fits the description noted above. In most cases, PVCs that originate from the right ventricle will have a LBBB morphology and those from the left ventricle will have a RBBB morphology. Retrograde impulses may or may not be blocked at the level of the AV node, and this may affect the timing of the subsequent QRS complex. In most cases, PVCs will come from a single focus and typically have a fixed "coupling interval," which refers to the time from the preceding QRS complex to the PVC. When a normal sinus beat alternates with a PVC, the rhythm is referred to as ***ventricular bigeminy***, while every third beat as a PVC is ***trigeminy***, every fourth beat is ***quadrigeminy***, etc.

Two consecutive PVCs are referred to as a ***couplet***; three consecutive PVCs or more is called a ***run***. Causes of PVCs include hypoxia, hypoglycemia, hypokalemia, acidosis, myocarditis, myocardial damage, intracardiac catheters, digoxin, quinidine, procainamide, sympathomimetics, TCAs, caffeine, and phenothiazines.

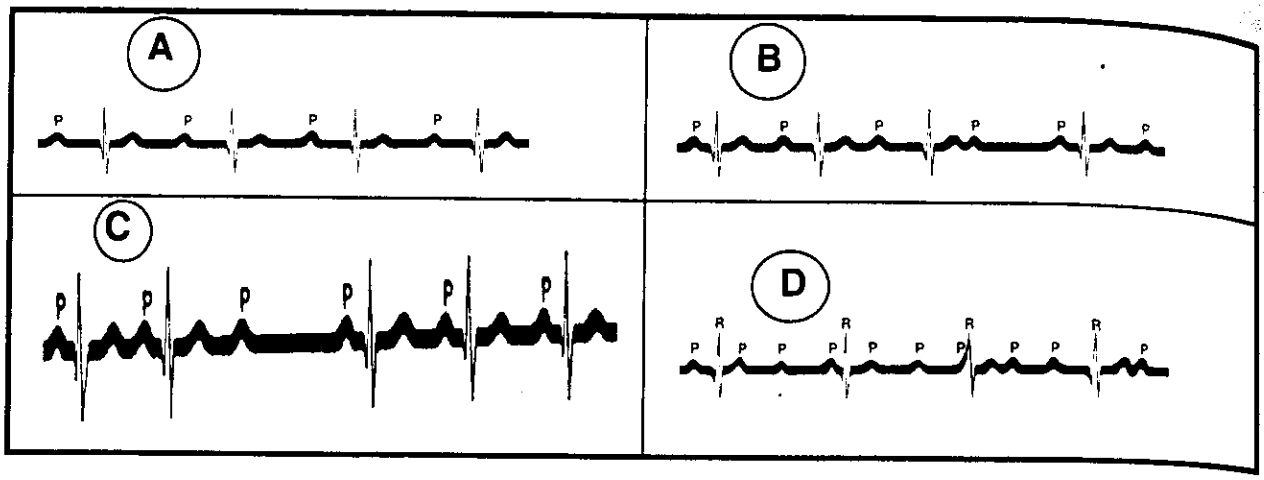
Occasional PVCs are a benign finding and require no treatment, particularly in patients with normal hearts. They nearly always disappear with exercise. Multifocal and frequent PVCs, especially if there are couplets or runs, those precipitated by activity, or if there is a significant underlying cardiac condition, are of more concern. Drugs commonly used to treat PVCs include Dilantin, propranolol, and less often quinidine and procainamide.

Accelerated ventricular rhythm: In this arrhythmia, the ventricular rate exceeds the sinus rate, It usually occurs because the sinus or AV nodal rate has slowed for some reason and the ventricular pacemaker has taken over the pacemaker function of the heart for that period of time. Typically, it comes on gradually and resolves in a similar manner. This usually occurs in patients with heart disease or who have digoxin toxicity. This rhythm is extremely rare in the pediatric population and generally has a good prognosis.

Panels B & C: Ventricular tachycardia: By definition, this is a run of three or more consecutive PVCs and is nearly always characterized by wide QRS complexes. Another feature that is seen in VT is AV dissociation. Unfortunately for the ECG interpreter, not all wide QRS complex tachycardias are ventricular tachycardia. Supraventricular tachycardia can also have a wide QRS if the bundle branches are refractory, resulting in slowed conduction through the ventricles. In the pediatric population, the mean rate of VT is 195 BPM and is less that 300 BPM in 93% of patients. Causes of VT are similar to that of PVCs. It occurs most frequently in patients with significant heart disease and particularly in the post-operative patient. Acute treatment is electrical DC cardioversion in the unstable patient, especially as VT can degrade to ventricular fibrillation (Panel C) Long-term therapy for VT depends on ventricular function; drugs used include propranolol, propafenone, verapamil, flecainide and amiodarone.

V. Disturbances of AV conduction

Atrioventricular (AV) block is a disturbance in conduction between the normal sinus impulse and the eventual ventricular response. There are three basic classifications:



Panel A: First degree AV block There is a disturbance in conduction between the sinus node and the ventricles produced by an abnormal delay through the AV node. On the ECG, this is reflected as an abnormally long PR interval. There are no dropped beats with a normal QRS configuration. This is sometimes seen in healthy children, but can be associated with a wide variety of cardiac conditions such as rheumatic fever and myocarditis. First degree AV block does not produce symptoms and does not require treatment.

Panels B & C: Second degree AV block is characterized by some (but not all) dropped beats in which some P waves are not followed by QRS complexes. There are two major categories:

- *Mobitz Type I (Wenckebach):* There is a progressive lengthening of the PR interval with a dropped ventricular beat (Panel B). The block almost always is in the AV node. On the ECG, one will often see groups of beats with pauses between the groups. It can be a sign of digoxin toxicity and can occur in any condition that causes first degree AV block. It has been reported to occur in 11% of normal children while asleep. Treatment is not indicated.
- *Mobitz Type II* block is characterized by sudden failure of AV conduction without prolongation of the PR interval before the blocked P wave (Panel C). If every other P wave is conducted, it is referred to as 2:1 block. It is not possible to determine if 2:1 block is Mobitz Type I or II. A 24-hour ECG (Holter) may be helpful in differentiating these. 3:1 or greater ratios can also be seen. This is a significantly worse problem than Mobitz Type I since the block is usually in the bundle of His and may progress to complete heart block. Prophylactic pacemaker is sometimes indicated.

Panel D: Third degree heart block is one in which the atrial depolarizations are not conducted to the ventricles; thus the atria and ventricles beat entirely independently of each other. The atrial rate is regular and at the appropriate rate for the patient's age; the ventricular rate is much slower. The QRS complex is usually narrow (the lower portion of the AV node or bundle of His takes over the pacemaker function for the ventricles at an escape rate.) Occasionally, the QRS complexes are wide with the pacemaker in one of the ventricles. This can be an acquired problem (due to infection or surgery) or congenital. Approximately 1:20,000 infants are born with CCHB, often related to connective tissue diseases, such as lupus, in the mother. In general, patients with CCHB do not require pacemakers until they become symptomatic; however, they do require very close follow-up.

Common office problems

1. Asymptomatic patient with murmur

Evaluation

History

Respiratory rate and effort, exercise tolerance, cyanosis, feeding patterns, growth, when murmur first noted, medications, other illnesses and family history.

Physical examination

Inspection: General appearance, physical abnormalities, color, clubbing, observation of chest, diaphoresis, arterial and venous pulsations. Observe the breathing pattern before disturbing the child.

Palpation: Peripheral pulses (rate, regularity, quality, symmetry);Chest (apical impulse, PMI, hyperactivity, precordial thrill, symmetry, AP diameter); Abdomen (liver, spleen, masses), edema, BP determination

Auscultation: Patient relaxed, quiet room, chest fully exposed, appropriate stethoscope with bell, diaphragm, short tubing (<18 inches). Pay special attention to S_2 as it is a window on physiology: fixed split means volume equalization across atrial septum; wide but variable split means delayed RV emptying; ↑ P2 suggests PAH.

Grading of murmur intensity on scale of 6 (__/VI):

- I/VI: very soft, can barely be heard with the stethoscope
- II: heard fairly easily
- III: moderately loud
- IV: loud, with thrill
- V: very loud, only part of stethoscope on chest
- VI: very loud, heard with stethoscope off chest

Also note: *phase* (systole, diastole, continuous), *shape* (crescendo, decrescendo, diamond-shaped, plateau), *timing* (early, mid, late), *length* (short, medium, long, pan), *quality* (vibratory, harsh, blowing, rumbling), *location of maximum intensity*, and *radiation*.

'Insignificant' Murmurs and Sounds

Still's murmur

"It's characteristic feature is a twanging sound, very much like that made by a twanging piece of tense string. This bruit is found mostly in children between two and six years of age. Whatever may be its origin, I think it is not due to any organic disease of the heart wither congenital or acquired." (George Still, 1909)

- Rare before 3 yo, with diminished incidence toward adolescence
- Vibrating, musical or buzzing with medium to low frequency
- Brief, begins shortly after S_1; intensity usually grade II
- Intensifies with exercise, anemia, fever, decreases with Valsalva maneuver, standing up

Pulmonary 'Flow' Murmur:

- Heard best at LUSB, blowing, non-musical, medium-pitched, crescendo-decrescendo
- Begins after S_1, ends well before S_2, intensity: Gr I to III; higher-pitched than Still's murmur, lower-pitched than most organic heart murmurs; may radiate to axillae and back
- More prominent with exercise, anemia, fever, pregnancy
- Best heard in supine position during expiration

Peripheral Pulmonary Murmur

- Heard in newborns, esp. premature infants; usually disappears by 2 mo.
- Short, generally mid-systolic, high-pitched, Gr I-II in intensity
- Heard best at LUSB or RUSB, radiates to back and BOTH axillae
- Accentuated with fever, anemia, after feeding, crying
- Caused by acute angle of bifurcation of the pulmonary arteries, or by ductal tissue in the LPA

Venous Hum

- Heard primarily in children, also in young adults
- Best heard in supraclavicular fossa just lateral to SCM muscle
- Upright position, usually more prominent on right
- Absent in supine position, digital compression, Valsalva
- Blowing, soft, high-pitched
- Deep inspiration sometimes augments murmur

Split First Heart Sound

- Source of confusion in CV exam in children
- Normal [split] S_1 is best heard at LLSB and apex
- Soft, low-pitched with first component at apex, second at LLSB
- Noted in late childhood or adolescence
- S_1 becomes louder in pts with thin chest wall, short PR interval, high output states
- Wide splitting of S_1 can be seen in RBBB, PVCs, ASD, Ebstein's

Third Heart Sound

- S_3 occurs when active ventricular relaxation ends and passive filling begins
- Can originate from LV (apex) or RV (LLSB)
- May be the result of decreased ventricular compliance or increased ventricular volume
- Characteristics: low frequency, low intensity, heard just after S_2, heard best with bell, accentuated in LLD position, diminishes with sitting, "Kentucky"
- Audible in 6-10% of children and adolescents, esp. those with thin chest wall &/or slow HR
- Origin: abrupt deceleration of blood and/or tensing of myocardium and AV valve support apparatus during rapid filling
- Intensified by rapid early diastolic filling, elevated atrial pressure, or abnormal diastolic compliance
- Must evaluate for other evidence of CV disease but is commonly a benign finding in children.

Fourth Heart Sound

- Origin: vibrations of the ventricular wall from rapid influx of blood during atrial contraction
- Characteristics: Low frequency, low intensity, late diastolic, heard best in LLD position, "Tennessee"
- Diminished by decreased blood return to LA (e.g., inspiration)
- Accentuated by increased blood return to LA (e.g., expiration)
- Seen in patients with LVH, increased LVEDP, restriction to diastolic filling
- From RV in pts with pulmonary hypertension, PS
- Rarely a benign finding; deserves CXR, ECG, cardiology referral

NOTE WELL: The incidence of congenital heart disease is only 0.8%. The prevalence of cardiac murmurs in the pediatric population is very high, approaching up to 60-90% in the school age population. Thus, the pediatrician or family practice physician must often be called upon to determine whether or not a murmur is pathologic. The primary care physician must balance between over-referral and possibly missing heart disease.

2. Syncope

A. Introduction

- Common problem: 3% of all ER visits; 1% of hosp admissions and 15% of all adolescents will have syncope between 6-20 years old.
- Syncope, near-syncope, pre-syncope are all degrees of same problem(s) and addressed as such here.

B. Pathophysiologic Mechanisms: [Low BP or 'Bad blood'.]

BP ≈ CO X SVR; this equation can be changed in many ways to cause acute decrease in BP, e.g.,

i) Bradycardia causes ↓ stroke volume which causes ↓ CO
ii) Tachycardia causes ↓ diastolic filling which causes ↓ CO
iii) Loss of autonomic tone causes ↓ SVR which causes ↓ BP
iv) Obstruction within heart causes ↓ CO or directly reduces BP.

Sudden hypotension → ↓ cerebral blood flow, ↓ cerebrovascular resistance, and ↓ cerebral O_2 consumption which causes ↓ function of brainstem reticular activating system which subserves consciousness.

Abnormalities of composition of blood can also cause syncope even with normal BP.

C. Causes of Syncope

1. *Vascular/reflex:* volume loss, vasovagal (also called neurocardiogenic), hyperventilation, carotid sinus hypersensitivity.
2. *Cardiac:* outflow tract obstruction (especially left), rhythm disturbances including long QT syndrome, myocardial dysfunction (cardiomyopathy).
3. *Neurologic:* seizures--can be primary or secondary. Central autonomic insufficiency. Riley-Day. migraines.
4. *Psychogenic:* one of the most important causes of syncope. Examples: hysteria, depression, panic disorder, conversion reaction. Syncope also is seen in children who are physically or sexually abused.
5. *Metabolic* (reduced levels of): glucose, CA^{++}, MG^{++}, pO_2.
6. *Drugs:*
   i) Prolong QT interval: TCAs, phenothiazines, some anti-arrhythmics.
   ii) Change vasomotor tone: diuretics, barbiturates, nitrates; [see Afterload Reducing Agents in CHF section.]

D. Diagnosis

HISTORY is the most important 'diagnostic study'. Focus on the event, preceding and post-fact status, position, activity, prodrome; dietary and drug history (both prescription and illicit). Discuss family/home

situation and psychiatric history.

Physical:

Exclude cardiac causes (AS, IHSS, mitral valve prolapse, PAH)

Check for bruising: a) from abuse; b) from the fall itself as true syncope does not allow the pt to protect him/herself.

Check hearing (re: Lange-Jervell, etc. syndromes)

Check for signs of a syndrome (cardiac, neurologic, metabolic)

Tests

i) ECG: only test proven to be beneficial

ii) Exercise stress testing: only when syncope is exercise-related

iii) Holter/event recorder: may be useful depending on history

iv) EEG, head CT, MRI: rarely helpful unless seizure disorder suspected.

v) Lab tests: of limited value unless to r/o specific metabolic or toxic drug condition.

vi) Tilt-table testing (TTT):

Seeks to provoke syncope while pt is monitored

Pt is brought abruptly upright from supine position.

Pts with neurocardiogenic syncope are much more likely to have symptoms with TTT than normals but separation is imperfect.

Done only when pt is >7 years old.

E. Treatment options in neurocardiogenic syndrome

i) Volume (re)expansion

Pts with neurocardiogenic syncope have ↓ intravascular volume .

Volume expansion usually prevents recurrence.

Easiest method: liberalize salt and water intake.

Fluorocortisone (Florinef)=pure mineralocorticoid which promotes salt (and H_2O) retention; it also sensitizes α-adrenergic receptors. Starting dose =0.1mg Q day; can increase up to 1.0 mg Q day in adult-sized pt.

ii) β-adrenergic blockers:

Work because circulating catecholamines play major role in neurocardiogenic syndrome. Good preventative is atenolol (tenormin): 25 mg QHS in smaller children and 50 mg in older/larger pts.

iii) Disopyramide (Norpace)

Anti-cholinergic with negative inotropic effects. ↑ SVR and therefore ↑ BP; beware in some children, e.g., with renal

disease). Relatively few other side-effects: pro-arrhythmic and ↑ QT interval. 150-300 mg PO TID in teenagers.

iv) α–Adrenergic agents

α–adrenergic stimulation causes vasoconstriction (which ↑ SVR and therefore ↑ BP); also induces release of Nor-epi. Generally use sudafed (pseudoephredrine) 60 my PO QAM and at midday. This schedule because neurocardiogenic syncope is more common in AM and early afternoon, also to minimize restlessness/sleeplessness. For younger, start with 30 my BID.

F. General Approach to Neurocardiogenic Syncope

i) Older pts: start with sudafed; ≈80% of pts respond to sudafed and volume expansion.

ii) Younger pts: start with Florinef (to avoid sudafed side-effects)

iii) If sudafed ineffective, ADD Florinef; if combo ineffective, discontinue and start β–blockade; if necessary, add Florinef.

iv) If β–blockade + Florinef not effective, switch to Norpace.

v) Many pts will feel must better (more energetic) when syncope stops; often they then go off Rx's and symptoms recur.

vi) Those who should be referred early to a pediatric cardiologist:

1) those < 7 years old;
2) Non-responders;
3) Those with organic murmur or abnormal ECG;
4) Pts with family history of deafness.

3. Chest pain

Common symptom in children; rarely related to the heart.

Differential Diagnosis:

Innocent

Chest wall/musculoskeletal
psychogenic

Cardiac

Inflammatory (myo-,or peri-carditis)
Aortic or pulmonic stenosis
Obstructive hypertrophic cardiomyopathy
Coronary artery disease (both congenital and acquired)
Dysrhythmia

- Pulmonary
  - Intra-pulmonary Infection (pneumonia)
  - Pleural inflammation/infection (pleuritis)
  - Asthma
  - Pulmonary embolus
- Gastro-intestinal
  - Esophagitis or esophageal spasm
  - Duodenal ulcer
  - Prolonged or forceful vomiting
  - Inflammatory bowel disease
  - Hepatobiliary disease

Evaluation

- History: past history esp trauma; detailed description of pain: type, location, temporal relation to other events (eating, sleeping, breathing, exercise), relation to body position.
- Physical exam:
  - General: vitals, rash/xanthomas/etc., relation to breathing.
  - Chest: evidence of trauma; localization; breasts developing (?).
  - Cardiac: palpation + auscultation; change in murmur with change in body position ?
  - Lung: rubs, rales/rhonchi/egophony, wheezing, absent breath sounds (e.g., pneumothorax)
  - Abdomen: ? localized tenderness (e.g., RUQ≈cholecystitis), masses; check tympani and bowel sound

Management (by diagnosis):

- Innocent: reassurance; minimal/no tests; rest, local RX and non-steroidal anti-inflammatories for chest wall syndromes
- Organic-Cardiac: immediate evaluation by cardiologist [some of the cardiac etiologies CAN be life-threatening]
- Organic-pulmonary or G-I: evaluation by appropriate consultants.

Syndromes with Cardiac Involvement

I. Genetic Disorders

A. Trisomies

Trisomy 21 (T21), Down syndrome:

- First described by Langdon Down in 1866.
- ≈ 95% of all cases are due to nondysjunction, which is associated with maternal age. This is the most important risk factor. If mother < 20 yo, chance of T21=1:1700; at 40 yo, chance=1:100. Parents of T21 infants may have a substantially increased risk of recurrence. Genetic counseling is advised in all cases.

Clinical Findings:

- **General:** hypotonia, protruding tongue, hyperflexibility, small stature with awkward gait.
- **CNS:** mental deficiency.
- **Craniofacial:** Flat faces, small nose, low nasal bridge, inner epicanthal folds, small ears, hypoplastic dentition, excessive skin on back of neck, slanted palpebral fissures.
- **Hands:** short metacarpals and phalanges, Simian crease.
- **Feet:** wide gap between first and second toe with plantar crease.
- **Skin:** Cutis marmorata, dry, hyperkeratotic skin in time.
- **Hair:** Fine, soft, often sparse.
- **Genitalia:** Male: relatively small penis and are infertile.
- **Others:** strabismus, eleven ribs, leukemia, TEF, duodenal atresia, cleft lip and palate, malrotation, Hirschsprung's disease, upper airway obstruction

Cardiac abnormalities (40-50%):

- Endocardial cushion defects
  (primum ASD, inlet VSD, or complete AV canal)
- Tetralogy of Fallot; ToF + A-V canal occurs *only* in T21 pts.
- Debate on-going whether T21 pts have tendency to early PVOD.
- Must be aware of other significant problems which can coexist, especially *upper airway obstruction* from hypertrophied tonsils &/or adenoids.

Trisomy 18:

- 0.3 per 1000 newborn babies. 3:1 female to male ratio. 30% die in first month; 50% by two months; 90% in first year. All have severe mental retardation and IUGR.
- Other common abnormalities: low-set malformed ears, short palpebral fissures, micrognathia, hypoplasia of nails (esp of fifth finger and toe), short hallux (big toe) which is frequently dorsiflexed, cryptorchidism. Polyhydramnios with a small placenta and single umbilical artery are also frequently noted.
- 90% have congenital heart defects, especially VSD, ASD and PDA. More severe cardiac defects can also be seen.

Trisomy 13:

- 1:5000 births. Abnormalities include holoprosencephaly type defect with varying degrees of incomplete development of forebrain and olfactory and optic nerves, apneic spells, severe mental deficiency, deafness, moderate microcephaly, microphthalmia, retyianl dysplasia, cleft lip and palate, Simian crease, polydactyly, cyptorchidism (male) or bicornuate uterus (female), single umbilical artery, inguinal of umbilical hernia.
- Have an extremely poor prognosis. 69% die by six months.
- About 80% will have cardiac defects, most commonly consisting of VSD, PDA, ASD, and transposition of the great arteries.

B. Autosomal Dominant

Marfan's syndrome:

- A heritable disorder of connective tissue in which the most prominent abnormalities occur in the skeletal, ocular, and cardiovascular systems.
- Occurs in about 1:10,000 individual with marked variation in clinical expression. Diagnosis can me made at any age from the newborn to adulthood. Seen in all racial and ethnic groups, male and female about equal. 55% of cases are sporadic.
- Abnormalities include tall stature, long, slender limbs, little subcut fat, muscle hypotonia, arachnodactyly, joint laxity with scoliosis and kyphosis, pectus excavatum and carinatum, narrow facies, lens subluxation, myopia, bluish sclera, and inguinal and/or femoral hernias.
- **Cardiac abnormalities** involve primarily the aorta, and the aortic and mitral valves. These findings may not be evident on physical exam and require the use of echocardiography. The ascending aorta may be dilated, sometimes severely such that replacement must be performed in order to avoid rupture. Other problems include aortic regurgitation, mitral valve

prolapse with or without regurgitation, aortic dissection and occasionally arrhythmias. Numerous reports of sudden death have occurred in individuals with undiagnosed Marfan's who suffered aortic rupture.

- Prophylactic repair has been suggested when the aorta reaches a diameter of > 6 cm.
- Patients with aortic dilation are treated with beta-blockers to reduce stress on the aorta. These individuals should avoid contact sports and marked physical exertion, especially weight-lifting. Should also have SBE prophylaxis. Pregnancy should be avoided, with a 50% recurrence risk as well as a higher risk of aortic dissection/rupture, especially in those patients with pre-existing aortic regurgitation or dilation.
- Associated with mutation in a single gene on chromosome 15 which controls formation of fibrillin (important support element in aortic wall).

Noonan Syndrome:

- 1:1000-2500 births. Described by Noonan and Ehmke in 1963. Has been called "male Turner's syndrome," but clearly is different than Turner's, with females and males being equally affected.
- Prominent features include short stature, mental retardation, epicanthal folds, ptosis, hypertelorism, strabismus, webbed neck, shield chest, pectus excavatum, cubitus valgus, small penis and cryptorchidism.
- Congenital cardiac defects include valvar pulmonary stenosis (50%) with an abnormally thickened, nodular valve. Other defects include ASD, asymmetric septal hypertrophy, VSD and PDA.
- Most cases are sporadic; percentage of inherited cases is thought to be about 30%.

Myotonic Dystrophy:

- Characterized by myotonia (the delayed relaxation of a contracted muscle), muscular weakness and atrophy, testicular atrophy in males and amennorrhea and ovarian cysts in females, ptosis and cataracts.
- When diagnosed in infancy, may have feeding difficulties and FTT. Presents with hypotonia, respiratory distress and difficulty swallowing in the first few days of life.
- Cardiac involvement is frequent with 90% showing ECG abnormalities: atrial and ventricular arrhythmias, AV block, and infiltration of the His-Purkinje system (80% of patients) with prolongation of the QRS complex as well as RBBB can be seen.

Tuberous sclerosis:

- Classic triad: mental retardation, seizures and adenoma sebaceum, although these features are not seen in all patients.
- Tuberous sclerosis refers to hamartomatous lesions in the brain as well as intracranial calcifications in the area of the basal ganglia, present in 90% of patients.
- Common (30-40%) cardiac finding=rhabdomyomata (multiple rhabdomyoas). Often seen in the neonates. Can lead to ventricular dysfunction and/or atrial and ventricular arrhythmias. Spontaneous regression occurs in most cases and resection of the tumor is performed only when there is life-threatening obstruction or arrhythmia.
- WPW and SVT have also been reported.
- 80% of cases are suspected to be the result of new mutations with unaffected parents.

Holt-Oram:

- First described in 1960
- Upper limb defects range from thumb hypoplasia to phocomelia. Left side is more commonly affected than the right (2:1)
- Cardiac defects (seen in 90%) include ASD most commonly, but also VSD, MVP and arrhythmias

Velocardiofacial:

(also called Shprintzen syndrome, CATCH-22, Di George):

- Multiple anomalies. The following problems are noted in over 40% of patients:
  learning disability, cleft palate, cardiac abnormalities, ear anomalies, slender hands and digits, retrognathia and pharyngeal hypotonia, microcephaly and mental retardation.
- Major cardiac defects include VSD (60-70%), tetralogy of Fallot (15-20%), right aortic arch (40-50%) and aberrant left subclavian artery (15-20%).
- Obstructive sleep apnea is a frequent problem in neonates.
- Have a characteristic "long face" with prominent nose, narrow palpebral fissures, long philtrum and upper lip and abundant scalp hair.

Alagille's (Arteriohepatic Dysplasia):

- Characterized by absence or reduction of the intrahepatic bile ducts. Incidence is 1:100,000 live births. Other features include a prominent forehead, hypertelorism, small, pointed chin. Butterfly vertebrae may be seen on X-ray.

- 20% of infants are premature or SGA.
- Cardiac abnormalities in 95% of cases, with isolated peripheral pulmonary stenosis (which can be quite severe) being the most common. Others include valvar pulmonary stenosis and tetralogy of Fallot.

C. Autosomal Recessive:

Ivemark's Syndrome (Asplenia syndrome):

- Represents a group of defects that interfere with the normal establishment of laterality.
- A wide range of cardiac defects are seen, but virtually all have: anomalous pulmonary venous connections, a-v canal defect, pulmonary stenosis and VSD; most ALSO have abnormal systemic venous return (especially bilateral SVC), bilateral right-sidedness, cardiac malposition, single ventricle, and abnormal abdominal organ positions.
- Absence of spleen is best documented by abdominal ultrasound. Howell-Jolly bodies in the peripheral smear is only suggestive.
- Depressed immune function because of absence of spleen. All should be on continuous antibiotic prophylaxis; administration of pneumococcal vaccine is important.
- Cardiac management is complex and virtually all require a staged approach. Prognosis is dependent on the severity of cardiac defects; most will require a modified Fontan operation.

Homocysteinuria

- Metabolic disorder with deficiency of cystathionine beta-synthetase elevating blood methionine and urine homocysteine + methionine.
- Marfanoid habitus, pectus excavatum, kyphoscoliosis, usually retardation, etc.
- Cardiovascular problem is venous and arterial thromboses, also medial degeneration in arteries and intimal hyperplasia/fibrosis.

Mucopolysaccharidoses:

Lysosomes are cytoplasmic organelles which contain hydrolytic enzymes responsible for the degradation of a variety of compounds, including mucopolysaccharides (also called glycosaminoglycans), sphingolipids and glycoproteins. Mucopolysaccharides are normally degraded by a series of acid hydrolases. A deficiency of a specific hydrolase results in partial degradation of the molecules and lysosomal storage of the residual fragments. Diagnosis is made by metabolic analysis of urine and blood.

- **Type I:** caused by a deficiency of alpha-L-iduronidase. There are three distinct types:
- **Type I-H**, (**Hurler syndrome**) inherited as autosomal recessive. Relentlessly progressive disease with death occurring before 10 YO. Dwarfism, coarse facies, CNS deterioration, corneal clouding, and numerous skeletal changes.
  Cardiac involvement is common: mitral &/or aortic regurgitation, CHF, systemic hypertension, involvement of the coronary arteries resulting in angina and myocardial infarction. 50% die from chronic CHF or sudden cardiac decompensation.
  Pathologic findings: thickened endocardium and valve tissues; short, thickened chordae tendinae; multifocal narrowing of the coronary arteries and myocardial fibrosis of the LV.
- **Type I-S, Scheie syndrome,** is manifested by aortic regurgitation and rarely, aortic stenosis. These patients can survive into the fifth or sixth decade.
- **Type II, (Hunter syndrome)** is an X-linked recessive disorder which commonly has cardiac involvement, similar to that of Type I-H. Cardiac dysfunction is the leading cause of death.
- **Type III**, or **Sanfilippo syndrome** generally has mild cardiac involvement.
- **Type IV**, or **Morquio syndrome**, has two genotypes: Types A and B. Both are manifested by valvular dysfunction, especially aortic regurgitation.
- **Type V** had been renamed to **Type I-S**.
- **Type VI**, or **Maroteaux-Lamy syndrome**, may have little cardiac involvement or, in more severe cases, the development of a dilated cardiomyopathy with endocardial fibroelastosis. Valvular dysfunction may occur as well, particularly of the aortic and mitral valves.
- **Type VII**, or **Sly syndrome**, generally has minimal cardiac involvement.

Smith-Lemli-Opitz syndrome

- First described in 1964. SGA, usually have marked FTT, hypotonia commonly born breech. Early mortality is high and, for survivors, the degree of mental retardation is moderate-to-severe.
- Facial features include ptosis, anteverted nares, microcephaly, rotated or low-set ears and micrognathia.
- Other features include a Simian crease and syndactyly of the second and third toes.
- Cardiac abnormalities include endocardial cushion defects, coarctation of the aorta, tetralogy of Fallot, VSD, and pulmonary valve atresia/stenosis.

Ellis-Van Creveld Syndrome (Chondroectodermal Dysplasia)

- First described in 1940 and common in the Amish population. There is disproportionate short stature with shortening of the distal extremities. Polydactyly of the fingers is usually present, occasionally of the toes as well.
- Other features include small thorax, hypoplastic nails, short upper lip, and dentition abnormalities.
- About half have cardiac abnormalities, most commonly an ASD.

D. X-linked recessive

Duchenne muscular dystrophy

- Early onset of progressive, generalized muscular weakness and "pseudohypertrophy" of certain muscle groups. Incidence ranges from 140 to 326 per 1,000,000 *male* births. Female carriers are usually asymptomatic.
- Cardiac abnormalities are common. ECG changes are almost invariable: tall R waves in the right precordial leads and deep Q waves in the left precordial and limb leads.
- Abnormalities of cardiac rate and rhythm may also occur. A persistent sinus tachycardia is often present (pulse rate of 100 BPM in children after 5 yo.) Other abnormalities: PACs, ectopic atrial rhythms, PVCs; 50% have cardiac conduction abnormalities.
- Poor motion of the posterobasal ventricular wall is common with reduced LV systolic function.
- Heart failure occurs terminally in 10% of patients.

Becker Dystrophy

- Resembles Duchenne, but generally has a later onset and disease progression is much slower.
- *Clinical* cardiac disease is unusual.
- ECG changes include abnormal T waves in leads II, III, AVF, V5, and V6, increased R waves in the right precordial leads. Also seen is left axis deviation, RBBB, LBBB, complete AV block.
- Poor cardiac function may occur, but tends to occur late in the disease.

Emery-Dreifuss Syndrome

- Rare disorder characterized by weakness in a humeroperoneal distribution, early joint contractures, and cardiomyopathy.
- Onset is 2-10 YO; the disease is slowly progressive.

- A cardiomyopathy occurs consistently; varying degrees of AV block are common which can lead to episodes of syncope, TIAs and stroke. Atrial fibrillation has also been seen.
- Prophylactic implantation of a pacemaker should be considered.

II. Other Syndromes

Turner syndrome

- First described in 1938. Occurs in 1:2500 females. Have only one X chromosome (also called Monosomy X.)
- 95% of fetuses with XO are miscarried during the pregnancy; thus only 5% survive to term.
- Clinical features include small stature, ovarian dysgenesis, transient congenital lymphedema, especially over the dorsum of the fingers and toes, broad chest with widely spaced nipples, mild pectus excavatum, prominent ears, narrow maxilla and palate, low posterior hairline, webbed posterior neck, cubitus valgus, abnormal nails, renal anomalies, hearing impairment and cardiac defects.
- Cardiac abnormalities occur in 20% of cases. Approximately 70% of these are coarctation of the aorta.

Williams syndrome

- Probably first described in 1952 by Fanconi et al with the description of infants with an "elfin face" and hypercalcemia. in 1961, Williams et al described the association of supravalvar AS with similar facial features.
- Facial features include short palpebral fissures, depressed nasal bridge, epicanthal folds, blue eyes, anteverted nares, long philtrum and prominent lips with open mouth.
- Other abnormalities include abnormal dentition, mental retardation with an average IQ of 56, outgoing, friendly personality, hypoteloris, fifth finger clinodactyly, small penis and pectus excavatum.
- Cardiovascular abnormalities are present in 75% of patients. Supravalvar aortic stenosis is seen in over half; other cardiac defects include peripheral pulmonary stenosis, valvar pulmonary stenosis, occasionally VSD, ASD, systemic hypertension, renal artery stenosis, diffuse narrowing of the aorta and coarctation of the aorta.
- There have been numerous reports of sudden death in children with Williams syndrome, particularly after cardiac cath; this is thought to be possible due to coronary artery stenosis.

- A small percentage of patients will have evidence of hypercalcemia in the first year of life; this may be related to impaired calcitonin excretion.

Di George syndrome

- First described in 1965. Combination of thymic hypoplasia, parathyroid hypoplasia and cardiac defects. These defects all result from developmental abnormalities of the third and fourth branchial arches.
- 80% of affected infants present with CHD in the first 48 hours. Defects seen are truncus arteriosus, interrupted arch Type B and right aortic arch. In one series, interrupted arch type B occurred in one third of patients with Di George syndrome and Di George syndrome was noted in one-half of autopsy specimens with interrupted arch Type B.
- Hypocalcemia can be a significant problem and tends to occur most frequently in the neonatal period. It often improves over time.
- T-cell studies should be performed, although they are frequently normal shortly after birth. One must wait three months after a blood transfusion before these studies can be obtained.
- These babies often have characteristic facies--see Velocardiofacial syndrome. This syndrome has been associated with a microdeletion of chromosome 22.

Infant of a diabetic mother:

- The effects of maternal diabetes on the fetal cardiovascular system:
    1. Increased risk of CHD
    2. Diabetic cardiomyopathy
    3. Increased risk of RDS
    4. Increased risk of stillbirth
    5. Increased risk of placental pathology
    6. Increased maternal vascular disease, leading to decreased uterine blood flow
- The placentas of diabetic women are larger than normal because of increased glycogen.
- Cardiovascular defects include transposition of the great arteries, VSD, single ventricle and HLHS. The risk of CHD in these infants is five times greater that the general population (≈4%.)
- The fetus is exposed to increased fetal insulin (secondary to increased maternal glucose levels), which caused fetal enlargement, myocardial cell hyperplasia and hypertrophy from increased fat and protein synthesis and glycogen deposition. Cardiac hypertrophy (more commonly of the LV) results which may or may not be symptomatic. The interventricular

septum may be profoundly affected. Resolution of the diabetic HCM ranges from 2-20 months, but usually within 6 months.
- Diabetic HCM is not familial, spontaneously resolves and does not have the typical histologic findings of HCM.
- Less than 1:10 infants actually develop cardiac dysfunction.
- The degree of cardiac hypertrophy and clinical disease does not correlate with the severity of maternal disease, although there may be a correlation with maternal glucose control during the pregnancy.

Pectus excavatum:
- Condition in which the sternum is displaced posteriorly
- Commonly observed in Marfan, Ehlers-Danlos, or Hunter-Hurler syndromes, homocystinuria, and a small percentage of patients with mitral valve prolapse or bicuspid aortic valve
- When severe, can interfere in pulmonary function but does not cause cardiac compression. Also associated with palpitations, tachycardia and fatigue.
- Displacement of the heart into the left thorax and prominence of the MPA may be noted on CXR
- Parasternal midsystolic murmur may be heard
- ECG changes include left axis deviation, posterior P wave axis (negative P wave in V1), RSR' pattern in V1, abnormally deep QS waves and T wave inversion in anterior and midprecordial leads, S wave in V7.

Pectus carinatum:
- Seen in Marfan's syndrome
- Generally does not cause cardio-pulmonary problem; is sometimes fixed for cosmetic reasons

Goldenhar's syndrome
- Asymmetric facial and vertebral anomalies (microsomia, hypoplasia)
- ≈25% having congenital heart defects: ToF, VSD, PDA, Coa.

- **Cornelia de Lange**
- Intra-uterine growth retardation, hypotonia, microcephaly, synophrys (fused eyebrows) [good word for roundsmanship!], hirsutism, profound retardation, etc.
- Heart disease is found in ≈30%, often VSD.

VACTERL (formerly VATER) association:

- (V) = vertebral,
- (A) = anal atresia,
- (C) = cardiac (7-35%),
- (TE) = tracheo-esophageal fistula,
- (R) = renal,
- (L) = limb defects.

CHARGE association

- (C) = coloboma,
- (H) = heart, 65-75% incidence, commonly conotruncal anomalies;
- (A) = atresia of posterior choanae,
- (R) = retarded growth and development,
- (G) = genital hypoplasia,
- (E) = ear anomalies including deafness.

Drugs in congenital heart disease

1. **Digoxin** (see CHF section)
2. **Diuretics** (see CHF section)
3. **After-load reducing agents** (see CHF section)
4. **Pressors** (see CHF section)
5. **β-blockers, eg., inderal**

Beta-blockers are used for a wide variety of problems, including such cardiovascular disorders as hypertension, angina, arrhythmias, and syncope. Individual agents exhibit a number of pharmacological properties including cardioselectivity (preferential blockade of cardiac beta-1 receptors), intrinsic sympathomimetic activity, lipid vs. water solubility and membrane stabilization. All beta-blockers share in common the following two properties: blockade of cardiac beta-receptors and nearly equal antihypertensive efficacy. Thus, the primary basis for the selection of one beta-blocker over another is to reduce or avoid particular side effects. In pediatric cardiology, one of the primary uses of beta-blockers is to slow AV conduction, thus slowing the cycle length or terminating SVT. It is also used in patients with ventricular ectopy, hypertrophic cardiomyopathy (to reduce contractility and thus LV outflow tract obstruction), atrial fibrillation and flutter (again to slow the ventricular rate), hypercyanotic episodes (to reduce RV outflow tract obstruction, and such non-cardiac conditions as thyrotoxicosis, pheochromocytoma, and migraine headaches.

The three main beta-blockers that are used in pediatrics include the following: propranolol (Inderal), atenolol (Tenormin), and esmolol. These drugs work by attaching to beta-adrenergic receptors, thus competing with beta-agonist agents (e.g., catecholamines) for those sites. In general, beta-blockers decrease HR, myocardial contractility, exercise tolerance, cardiac output, and conduction velocity through the SA and AV nodes. Side effects include: rashes, bronchospasm (be careful in patients with a history of reactive airway disease), CNS, raise serum cholesterol and lower HDL, fatigue, paresthesias, and dry mouth.

- *Propranolol* is a nonselective beta-blocker which has prominent lipophilic properties and thus crosses the blood - brain barrier (CNS side effects are more prominent with increased lipophilicity.) Thus, such CNS side effects as lightheadedness, irritability, and depression are more pronounced with propranolol than other beta-blockers such as Tenormin. This is the beta-blocker that has been around the longest and is the most tested. Unfortunately, it must be given every 6 hours (certainly no less often than

q8 hours), making compliance a real problem. The starting dose is 1-2 mg/kg/day divided q6 hours.

- *Atenolol* is a beta-blocker that has less lipophilic properties, is more cardioselective, and has a longer duration of action than propranolol. Its side effects of sluggishness is minimized if the drug is given at night before bedtime. It can often be given just once per day. This medication is frequently used in older patients (50 mg po qHS); dosage for a school-aged child is 25 mg po qHS. It has not been used extensively in younger children, toddlers and infants. CNS side effects are generally minimal.
- *Esmolol* is a short-acting beta-blocker that is given generally as an IV drip. It is also cardioselective and does not have significant lipophilic properties. Its duration of action is only about 10 minutes. This is ideal in the ICU setting when it is important to be able to withdraw the drug quickly if an adverse effect occurs and to titrate the effect carefully, much as one would with an inotropic agent such as dopamine or dobutamine.

6. Adenosine

General: Adenosine is an endogenous agent (a purine nucleoside) which has a variety of actions on the cardiovascular system. It is a coronary vasodilator, anti-adrenergic, a negative chronotropic agent and blocks conduction through the AV node. The half-life is very short (approximately one second). Its electrophysiologic effects result in sinus bradycardia which generally lasts about ten seconds. The result of this is that any tachycardia which involves the AV node will be affected by adenosine. In the instance of SVT, conduction through the AV node will slow or block, thus reducing the rate of the tachycardia and frequently terminating it. It is also useful in patients with SVT and WPW, since the AV node is involved in the reentry circuit. In atrial flutter, the flutter waves will become more apparent, but since flutter does not involve the AV node, the tachycardia will not be terminated. Obviously this is not helpful from a therapeutic standpoint, but it is sometimes helpful from a diagnostic one, particularly when the flutter waves are not readily apparent.

Side effects: flushing, sinus bradycardia, dyspnea, chest pressure, cough, headache and varying degrees of AV block. The good news is that all of these side effects are very transient, since the half-life is so short. This is considered to be a very safe drug.

Dosage: Start with 0.1 mg/kg IV, can give up to 0.3 mg/kg. It must be given in a good IV and the closer to the heart, the better. In addition, the drug

should be given IV push, as it will be ineffective if it is given slowly since the half-life is short.

- It is essential that an ECG be obtained before, during and after adenosine is given in order to determine its effectiveness. It is not unusual for the patient's arrhythmia to resolve briefly before resuming tachycardia. If that is the case, it may be useful to repeat the adenosine. Cardioversion is not appropriate in the patient in whom adenosine has been found to be effective, even if it is only briefly. In those instances, it may be necessary to give a different drug which will affect the conduction system (e.g., IV procainamide) such that conversion to sinus rhythm will be possible and sustained.

7. Oxygen

In CHF, oxygen will help considerably as pulmonary edema interferes with membrane function. In cyanotics with diminished PBF (e.g. ToF), the blood that is getting to the lungs is being oxygenated quite well, so breathing high concentration O_2 will be of minimal benefit. In some pts with TGA or TAPVC, O_2 can actually be harmful by reducing PVR. In all cases, the patient's particular physiology must be considered before 'routinely' giving O_2 for a less than normal O_2 arterial saturation.

8. Volume

- Many children with congenital heart disease have CHF and therefore, it is a general tendency to reduce volume. Diuretics are commonly given to children with large L-R shunts and poor cardiac function (e.g., cardiomyopathy). However, volume excess simply makes these children worse.
- In other conditions, hypovolemia can be life-threatening, especially patients with tetralogy of Fallot and/or those with shunt-dependent pulmonary blood flow.
- Additionally, in babies with large L-R shunts +/- CHF, one must take in sufficient calories to grow or no progress is possible; one often treats such children with 'excess' volume (to get calories) and much diuretic Rx to urinate off the water.

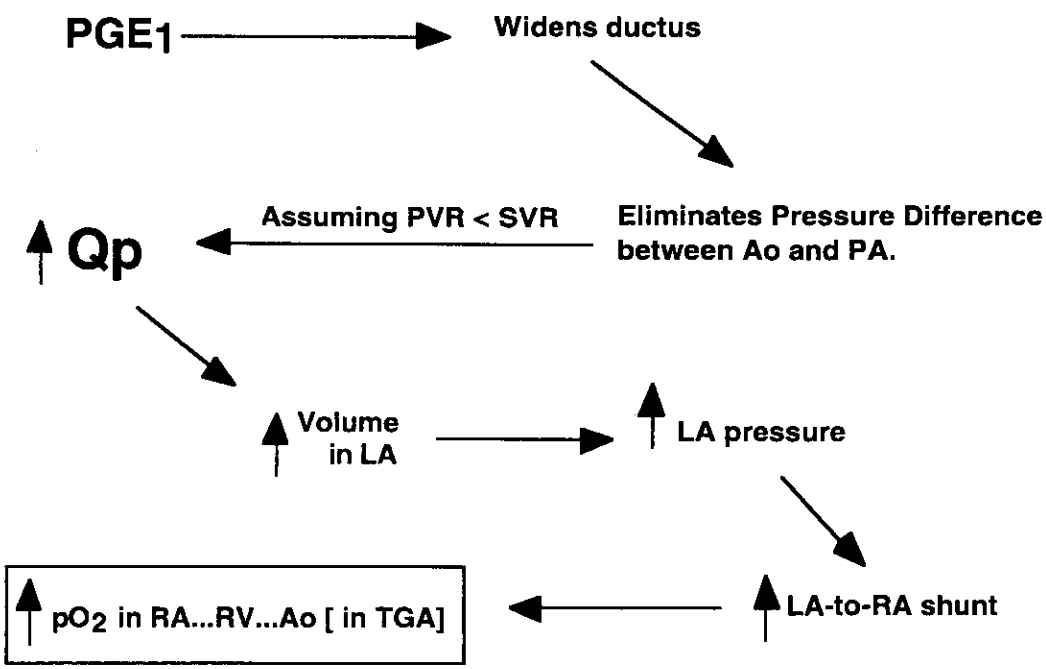
Volume is a critical component of resuscitation when a child is in low cardiac output and therefore, do not withhold volume even if the child *had been* in CHF.

9. PGE_1 (Also see Cyanotic heart disease)

Disconnection of the neonate from the placenta is the main impetus for closure of the ductus arteriosus. The two primary mechanisms involve 1) rise in arterial pO_2, and 2) loss of ductal dilators. 1) The placenta is a relatively inefficient oxygenator which maintains fetal pO_2 at ≈21-25. When the baby's lung take over oxygenation immediately after birth, the arterial pO_2 rises sharply to ≈60-80 which is 3-4 times the level to which the fetus and its ductus are accustomed. This level of systemic oxygen directly promotes ductal closure. 2) There are numerous substances secreted by the placenta, especially PGE_1 and PGE_2, which promote dilation of the ductus. By removing the baby from the placenta, the ductal dilators are withdrawn, promoting ductal closure in association with the rise in pO_2. By supplying PGE_1 to the neonate, one can maintain or restore ductal patency which may be life-saving in those with ductal-dependent physiology such as pulmonary atresia or coarctation--hypoplastic left heart syndrome. *It is important to note that high arterial pO_2 in the presence of PGE_1 does NOT promote ductal closure and therefore, oxygen can be safely given to the baby after PGE_1 is started.*

One aspect of PGE effect poorly understood is how it increases the arterial pO2 in transposition. This effect is indirect, by increasing LA-to-RA shunting as outlined in Figure below. Note that Qp, already excessive in TGA, must be further augmented in order to raise the arterial saturation.

Effect of PGE1 on Arterial pO_2 in TGA



Operations in Congenital heart disease

1. Coarctation (Coa) repair

a) Balloon dilation (BD) is not used in neonates and is controversial even in older *unoperated* children. When coarctation recurs, BD is the preferred option.

b) Surgery -

a. indicated for all in CHF and even without CHF, to reduce the level of cerebrovascular hypertension;

b. timing: seek to improve the child's overall status medically before proceeding to the OR;

c. Choice of operation based on the child's anatomy AND the surgeon's experience;

d. Operative choices are:

1) RETE = resection and end-to-end anastomosis (the original operative technique and now returning to favor);

2) SFA=subclavian flap aortoplasty; the second most frequently used repair procedure for coa.

3) PA = patch aortoplasty

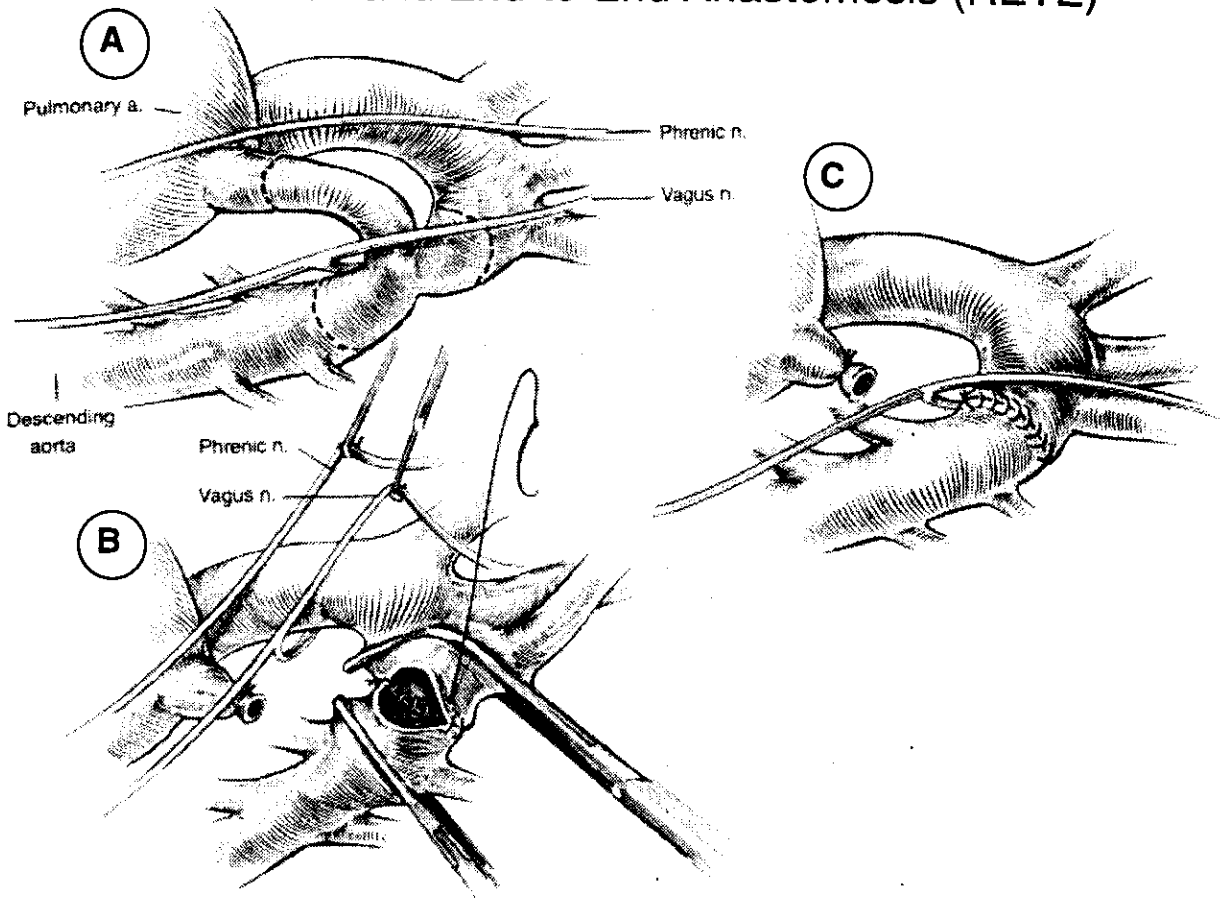
4) Tube graft from AAo to DAo

5) Combinations of the above.

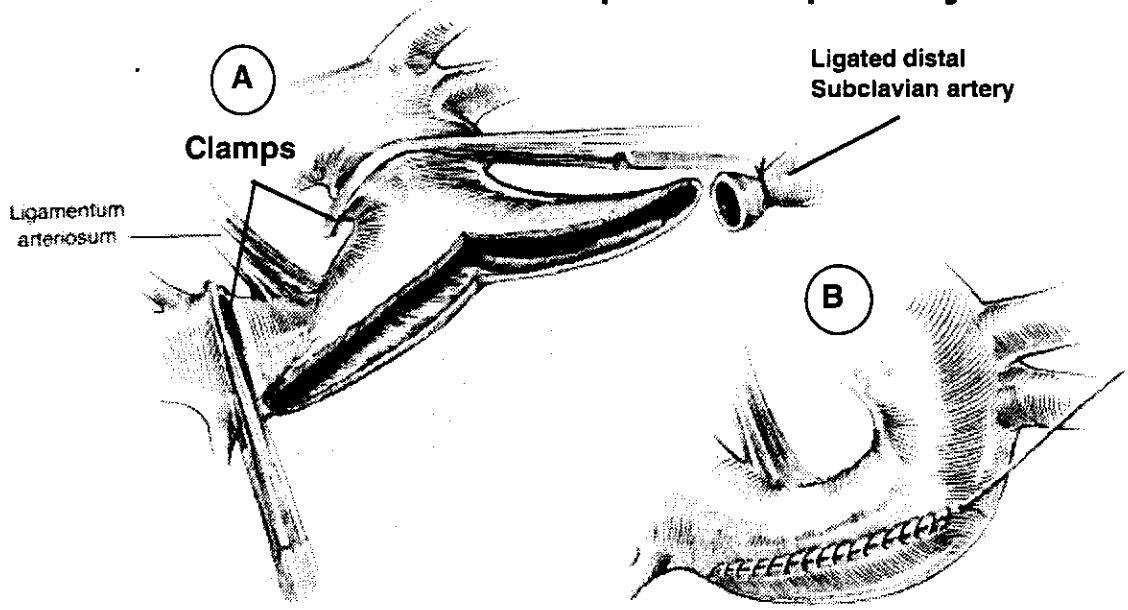
The RETE and SFA operations shown below are viewed from the surgeon's perspective through a left lateral thoracotomy. In the RETE, Panel A, the phrenic and vagus nerves are shown as is the ductus connecting the pulmonary artery with the aorta at the coarctation site. With the clamps applied (Panel B), the area within the dashed lines in Panel A has been resected and the open ends of the aorta are being sewn together, with completion shown in Panel C; note the recurrent larygneal nerve in immediate proximity to the operative site.

In the subclavian flap aortoplasty (SFA), with clamps applied and the distal subclavian artery ligated (Panel A), an incision is made along the side of the subclavian artery and extended down across the coarctation segment (identified by the insertion of the ligamentum arteriosum). This incision is then sewn ONTO itself (Panel B) which creates a living flap (as it is still connected to the arterial wall and therefore in contact with the aortic vasa vasorum).

Resection and End-to-End Anastomosis (RETE)



Subclavian Flap Aortoplasty



2. PDA closure

a) In neonates

i) Decision to intervene made by neonatologist and cardiologist in collaboration.

ii) *Never* intervene medically or surgically without echo to prove DA is patent, confirm that it shunts L→R and that there is no congenital heart disease.

iii) Indocin often works in the pre-term; first check platelet and renal status; effect can be transitory (ductus can re-open).

iv) Surgery is safe at any age and size, and usually can be done in the NICU.

v) Per catheter procedure is not presently available for neonates as the devices are too large and stiff; [children should be >10 kg for per catheter PDA closure.]

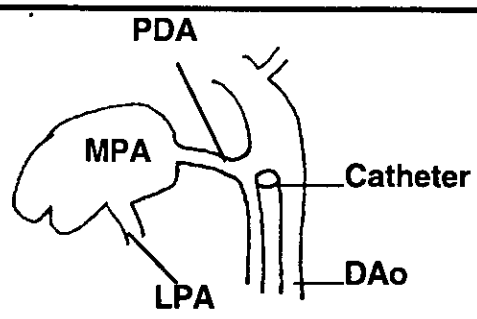
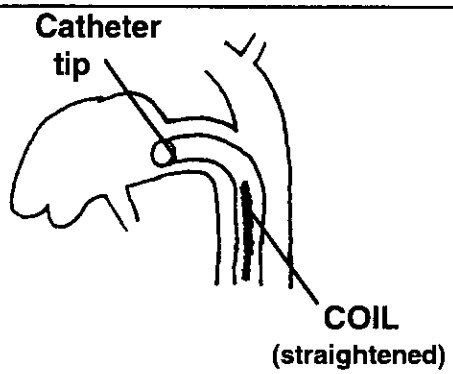
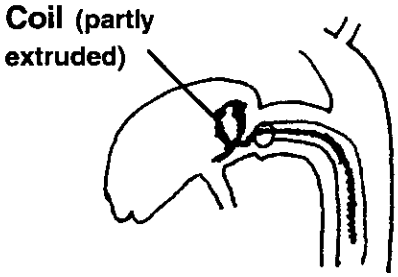
b) In older children

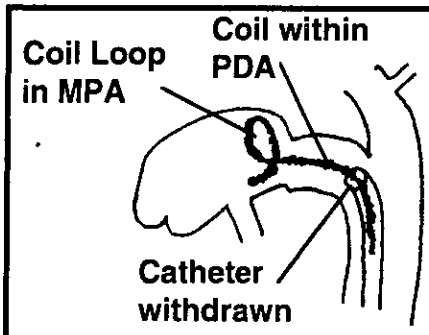
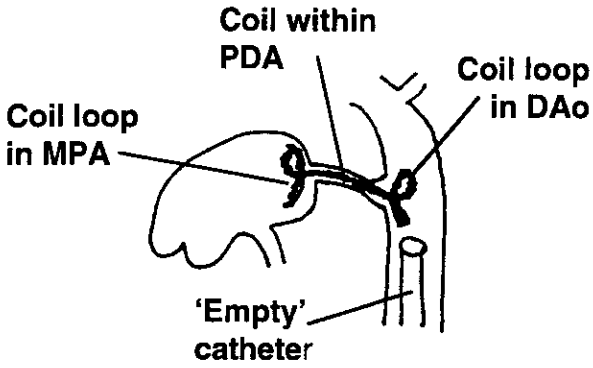
i) Closure indicated for CHF, PAH and even when ductus is small, closure is indicated to eliminate lifetime risks of bacterial endocarditis as well as aneurysm of the ductus.

ii) Echo is diagnostic; cath unnecessary for diagnosis.

iii) Options: Surgery (thoracotomy; bypass unnecessary)
Per catheter closure (only in selected Centers, including UNM).

Per-Catheter Closure of a Small Patent Ductus Arteriosus

	1: A small PDA is seen in lateral view. The retrograde catheter diameter is actually larger than the ductus; this is not uncommon.
	2: The retrograde catheter has been manipulated across the ductus into the MPA. This often stretches the ductus but, with care, risk of a tear is extremely low. (We have never seen or even heard of this.) The 'fuzzy' line within the end-hole catheter is the coil which has been straightened for delivery but retains its tendency to reform a spring-like shape.
	3: Part of the coil has been advanced so that one loop is within the MPA at the orifice of the ductus. This will anchor the coil for remainder of the procedure. Both the internal caliber and the length of the coil must have been calculated before delivery was started.

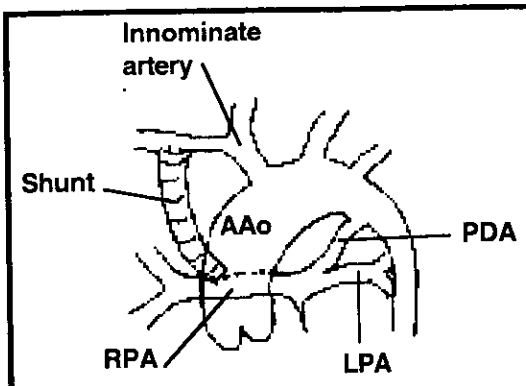
	4: The catheter is now withdrawn while maintaining the coil in position so that its first loop is in the MPA and its mid-part is within the ductus. This is the most delicate part of the technique.
	5: The coil has been delivered properly and is seated well. There is at least one loop of the coil at the pulmonary and aortic ends of the ductus with the mid-coil part inside the ductus. The dacron fronds embedded in the coil will cause in situ thrombosis so that 6 weeks after the procedure >95% of pts will have a completely closed ductus. Over 50% have a closed ductus when they leave the cath lab.

3. Systemic-to-pulmonary shunts

Done for palliation of cyanotic congenital heart disease with decreased PBF, e.g., ToF, tricuspid atresia with pulmonary stenosis.

If primary repair can be offered with low risk, shunt is NOT done as it increases cardiac work and is relatively inefficient.

Currently preferred procedure is called 'modified' Blalock-Taussig shunt: insertion of 4 or 5 mm goretex tube graft, side-to-side, from subclavian artery to the ipsilateral branch pulmonary artery.

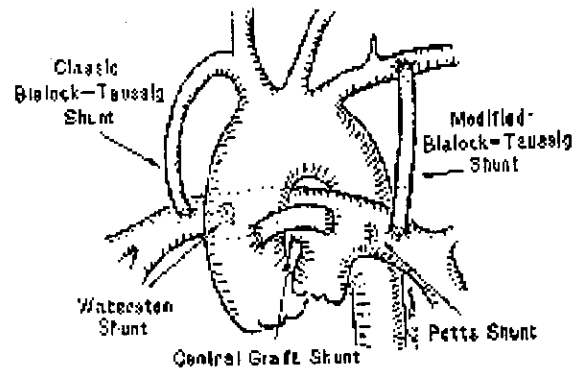


'Modified' Great Ormand Street Blalock-Taussig shunt (GOB-T)

Note that the shunt must be placed proximal to the upper lobe branch PA which is technically difficult on the left without obstructing the ductus (which provides PBF while doing the shunt). The shunt is usually done on the right, from a lateral thoracotomy. From the front, the aorta is [somewhat] in the way and from this approach, a central shunt is usually done (see Figure below). In the Figure below, the GOB-T shunt is shown on the left, but the artist did not include the ductus.

To the right are shown a number of st used in the past:

1) The classic Blalock-Taussig (subclavian art.-to-PA, end-to-side).
2) Waterston (AAo-to-RPA, side-to-side); → severe PA distortion.
3) Central shunt: tube graft from AAo-to-MPA; still used at times.
4) Pott's shunt: DAo-to-LPA, side-to-side; not used for >15 years.



Shunt is taken down (divided) when total repair is done.

Early after shunt, murmur of shunt is relatively poor way to follow pt.; Best is clinical course, CXR, and O_2 saturation optimally ≈ 80-84%.

Do the calculations as requested below to appreciate the implications of having a saturation over 90% when PBF is derived from the aorta (e.g., PBF from PDA, shunt or collaterals). [Cover up the answers provided below.]

The SVC saturation is 60%. Pulmonary venous saturation is 96%. Hb = 13 gms. VO_2 = 120 cc/min/m2.

If aortic saturation =	Then Qp / Qs =	
70%		
75%		
80%		
85%		
90%		
95%		

Answers:

If aortic sat. =		then Qp/Qs =
70	(10/26)	0.4 : 1
75	(15/21)	0.7 : 1
80	(20/16)	1.25 : 1
85	(25/11)	2.27 : 1
90	(30/6)	5 : 1
95	(35/1)	35 : 1

NOTE: when we seek to 'maintain' a baby's saturation near normal (≈95%) after a shunt for pulmonary atresia, we are asking the lungs to accept and the heart to pump a shunt of 35:1 ! [From the Table, one can see why we seek a saturation of 80-84%; this is the best balance of saturation with cardio-pulmonary work.]

4. Closure of ASD

[For anatomy, pathophysiology, clinical course and natural history, see section on L→R shunts.]

Despite lack of apparent clinical effects of an ASD in childhood, rt heart volume overload damages the RV and the pulmonary vasculature. By early adult years (20s-30s), the process may be irreversible. Large ASDs do not close spontaneously. Small ones sometimes do, but generally within the first two years of life.

Current recommendations:

i) Close ASD between 2 and 5 years of age.

ii) Closure can be performed either by surgery or by insertion of an

umbrella-like device, placed per-catheter in the cardiac catheterization lab.

iii) Surgery requires cardiopulmonary bypass; is very safe with mortality risk <<<1%.

iv) Surgery is deferred until > 2 yrs old to: a) attain size allowing 'bloodless' bypass surgery and b) allow for the (unlikely) chance of spontaneous closure. Per-catheter approach is available at UNM when the child is over one year old.

v) Echo is diagnostic; pre-op *diagnostic* cath is usually unnecessary.

vi) Surgeon routinely checks for insertion of all pulmonary veins before closing the ASD.

5. Closure of VSD

Anatomy/pathophysiologic/Natural history/Clinical: see L→R shunts

Indications for closure:

1. CHF
2. Failure-to-thrive or recurrent pneumonias
3. Pulmonary artery hypertension
4. Cardiomegaly (indicating significant volume overload) beyond one year of age
5. VSD in immediate proximity to aortic valve, with consequent risk for aortic regurgitation over time.

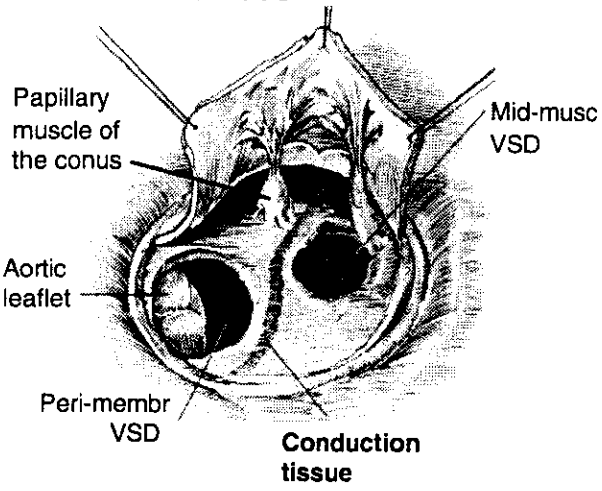
If CHF is controllable and child is growing satisfactorily, most will wait between 6 and 12 months to operate in order to give opportunity for spontaneous closure in those with membranous or muscular VSDs (the majority). As other VSDs do not close spontaneously, operation is generally scheduled after three months of age.

Many need pre-operative diagnostic cath and some do not; decided on case-by-case basis.

Surgery is only current option; per catheter closure is not under study for routine VSDs. Cardiopulmonary bypass is required.

'Direct' (suture) closure is generally not used as there is a high probability that cardiac motion will cause suture tearing and VSDs small enough to close with a simple suture are usually not recommended for surgery. VSDs are closed with patch material (dacron; goretex; autologous pericardium) which is sewn in place by FIRST placing the needles precisely in the septum so as to avoid creating heart block. The position of the His bundle and conduction system has been studied by serial sections of multiple lesions (ToF, DORV,

TGA, etc.) and is different depending on the type of congenital heart disease. The surgeon must know this and adjust suture needle placement accordingly.



The drawing to the left shows a pt with both peri-membranous and muscular VSDs (from the surgeon's view. The location of the conduction system is drawn in, but it is NOT visible in a real patient. The surgeon must know what type of VSD is present and then remember from conduction system studies where the conducting tissues are in relation to the edges of the defect.

Post-op: Most have no murmur. Occasionally, there is a 'residual VSD' present in/around the suture holes in the patch; these generally close over 1-3 months. Cardiomegaly on CXR may take 6-12 months to resolve. If no murmur present 6 months after surgery, there is no need for SBE prophylaxis. Most patients are unrestricted in athletics, including competitive/contact sports. [One year after surgery, the sternum is *at least* as strong as it was before surgery!]

6. ToF repair

Variability in anatomy and clinical effects gives wide spectrum of surgical responses, from shunt as neonate (in ToF with pulmonary atresia) with repair at 12-24 months, to elective primary repair at 7-10 months in an 'acyanotic' ToF patient.

Digoxin is usually contra-indicated in cyanotic ToF pts pre-operatively as it augments myocardial contraction, *including* the muscular subpulmonary area which increases obstruction and thereby ↓ PBF.

Repair consists of:

i) patch closure of VSD

ii) Relief of obstruction to RV outflow area (sub-, valvar, +/- supra-valvar stenoses)

iii) Correction of any additional defects, e.g., additional VSDs, PDA, collateral vessels, branch PA stenosis.

iv) Take-down of systemic-to-pulmonary shunt if present.

Note that relief of pulmonary obstruction often requires an incision in the muscle of the RV outflow tract. This is where important coronary artery branches may course and therefore, all ToF patients require diagnostic cardiac cath before repair (but not shunt) to delineate courses of the coronary arteries. This information is not necessary before a shunt.

Post-op:

i) May be quite ill because of long operation, small size of patient, hypoplasia of the pulmonary arteries, RV dysfunction, etc.
ii) Even 'uncomplicated' ToF repair carries mortality risk of ≈3-5%.
iii) Most will have pulmonary regurgitation murmur post-op.
iv) Many need digoxin +/- lasix because of pulmonary regurgitation and RV dysfunction.
v) ToF patients are followed indefinitely to check for arrhythmias and/or progressive RV dysfunction.

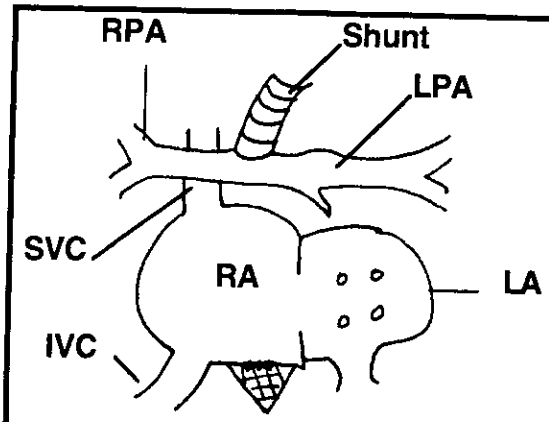
7. Fontan

Principle behind Fontan-type operations: one does not need a pump to get blood into lungs IF pulmonary resistance is low and the left heart works well. Therefore, it is critical to make pulmonary pressure low in any neonate who might be a candidate for Fontan approach.

Original technique (Fontan, 1973) is no longer used. Current modifications include: connect RA to the lungs (and close ASD), or connect SVC directly to RPA and 'tunnel' or baffle the IVC blood through the RA to get to the pulmonary arteries. This can be done in stages.

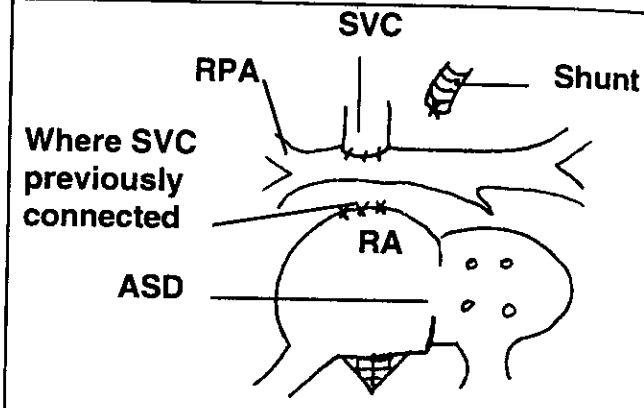
Most candidates need a palliative operation as a *neonate*, e.g.

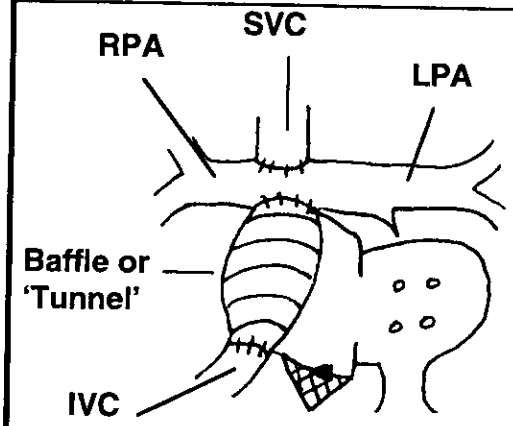
1. In a patient with single ventricle and no pulmonary stenosis, PAP will equal systemic BP. Left alone, this will elevate PVR and preclude a Fontan operation. Therefore, such patients need a pulmonary artery band to obstruct the flow into the PAs, thereby reducing PAP.
2. In a patient with single ventricle and pulmonary stenosis/atresia, the PBF is ductal-dependent and therefore, these children will need a shunt as a neonate.



Pt to right was shunted as neonate and is now ready for Fontan. Important success factors include: low PA pressure, well formed PA system, low/normal LVedp, and NSR.

Sometimes the Fontan is done in stages. To the right is a *cavo-pulmonary anastomosis.* (a 'partial' Fontan). The SVC is transected and sewn (end-to-side) to RPA, the hole in the RA is closed and the shunt is divided. The ASD is left large. This forces ≈40% of systemic venous return to the lungs with resulting O_2 saturation usually ≈ 84%.





To the left is a post-op *Fontan* pt. The SVC has been sewn to the top of the RPA (at the present procedure or at a prior one); a baffle has been constructed within the RA to connect the IVC with the bottom of the RPA. This forces all systemic venous blood into the PAs. Note that both SVC and IVC blood can flow to either lung.

Immediate post-op Fontan problems:

1. atrial or ventricular arrhythmias,
2. Low CO often secondary to ventricular dysfunction,
3. Effusions, both pleural and/or pericardial

Later post-op complications:

1. Pleural effusion or ascites
2. Protein-losing enteropathy

3. Elevated pulmonary vascular resistance with secondary low CO
4. Atrial arrhythmias.
5. Pulmonary arterio-venous fistulae

NB: Despite suboptimal long-term status of Fontan pts, it is the only physiologically near-corrective procedure available at present for pts with one ventricle.

8. Arterial switch

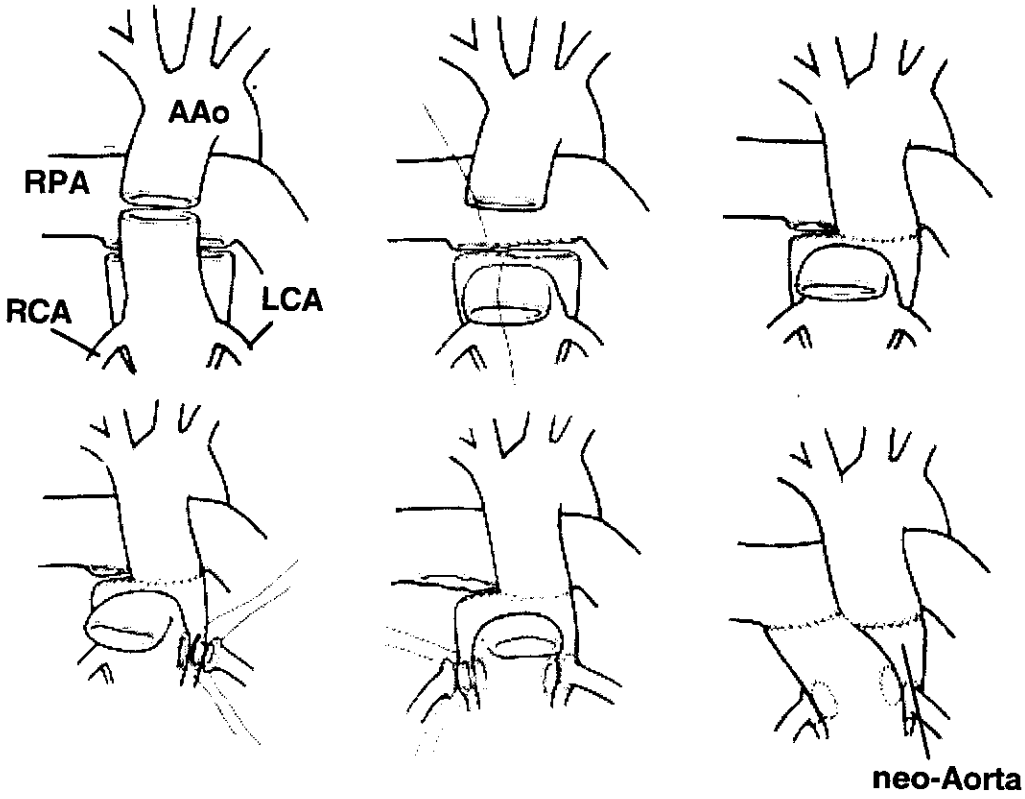
Done for transposition of the great arteries (TGA) both with and without VSD; occasionally done for other congenital heart defects.

Before surgery:

1. Maintain ductus with PGE_1;
2. Echo is diagnostic but may not fully delineate the coronary arteries;
3. Cardiac cath is usually unnecessary for diagnosis, and balloon atrial septostomy (Rashkind procedure) is only rarely needed.
4. Minimize the extra O_2 given to the patient as high O_2 reduces PVR which increases an already excessive PBF in TGA.
5. Watch the patient's pH rather than pO_2 or O_2 saturation.
6. Keep intravascular volume normal-to-high as low volume reduces the LA volume and therefore reduces the LA-to-RA shunt....which lowers the arterial saturation.

Operation: switch aorta and pulmonary artery (see Figure below), and relocate the coronary arteries to the posterior great artery (the one exiting the LV) which will (after surgery) be called the neo-aorta.

Arterial Switch Procedure for Transposition of the Great Arteries



Arterial switch must be done within 30 days of birth. In those without a VSD, the LV will lose its ability to pump high pressure. With a VSD, the child risks early pulmonary vascular disease. Therefore, repair is always done as a neonate.

Post-op: watch for coronary insufficiency; arrhythmias are uncommon. If pump run is long, low CO is often a problem. Other than supravalvar pulmonary stenosis, late po complications are quite uncommon.

9. Pediatric Cardiac Transplantation

In the past two decades, heart transplantation has been increasingly used as a life-preserving modality in infants and children. Despite the increasing experience, controversy persists regarding indications, best methods for following the transplant patient, optimal immunosuppressive regimen and long-term outcomes. Although originally both human (allograft) and non-human primate (xenograft) donor hearts were transplanted successfully, only allografts are currently in use. The primary indications for pediatric heart transplantation: 1) severe cardiomyopathy (dilated >>

hypertrophic) or fulminant myocarditis, : 2) Hypoplastic Left Heart Syndrome (HLHS), and 3) congenital heart disease unresponsive to other medical or surgical approaches.

Despite considerable advancement in many areas of heart disease in children, cardiomyopathy continues to be poorly understood; no mechanism or etiology is known in the majority of cases (see Chapter on Acquired Heart Disease). At present, treatment is symptomatic (diuretics, digoxin and afterload reduction). For those who do not respond or do not maintain adequate cardiac function after initial recovery, cardiac transplantation is a consideration. This is true also for those with myocarditis but transplantation is avoided during the acute phase for fear that the disease process will affect the new heart.

Heart transplantation for HLHS was pioneered by Dr. Bailey and associates at Loma Linda and has subsequently been performed in many centers across the country. Ten year survival for infants with HLHS who have received a cardiac allograft is quoted as 70% by Loma Linda. Unfortunately, a significant portion (20-30%) of HLHS infants die waiting for a suitable donor organ because of the paucity of neonatal/infant donor organs. Thus the choice between transplantation and Norwood procedure in HLHS remains controversial. In large pediatric transplant centers such as Denver, the most common reason for heart transplantation is rapidly becoming children with previously operated forms of congenital heart disease who's hearts have in essence "burned out". High on this list are children who have previously had a Fontan operation.

The surgical aspects of heart transplantation have been well established even for small children and therefore, purely technical peri-operative complications are uncommon. Most problems in children with transplanted hearts are medical including rejection, infection, graft coronary arteriopathy, and lymphoproliferative disorders The two primary ways that one checks for rejection are cardiac biopsy and echocardiography, the latter being the preferred approach in most centers. Medications used to suppress the immune system and prevent rejection are non-specific and include cyclosporin, immuran and glucocorticoids. However, other agents are also being used. As a consequence of non-specific immune

suppression , recipient children are placed at increased risk for infection (opportunistic, fungal or viral) and development of lymphoproliferative disorders. Graft coronary ateriopathy results from endothelial proliferation and can result in coronary obstruction and myocardial infarction. Its cause is currently the subject of investigation. Children may require re-transplantation because of rejection or graft coronary arteriopathy.

The complex and life-long follow-up of transplanted children is critical to their continued survival; without a stable and compliant family situation, the child will die of rejection or infection. Because of this, detailed psychosocial evaluation of child and family is a critical part of the pre-transplant evaluation.

While organ donation is fortunately an infrequent consideration in pediatric practice, when appropriate, it should be broached with the grieving family. Transplantation of hearts, lungs, livers and kidneys are performed in multiple centers around the USA with great success. The limiting factor is always availability of donor organs. The death of a child, while tragic and devastating, sometimes can give another child a chance to live. Painful and unpleasant as such a discussion is, it should be done when organ donation is possible.

10. Post-pericardiotomy syndrome:

The pericardium is opened in most operations for congenital heart disease, except systemic-to-pulmonary shunts and coarctation repair. Whenever an incision is made into the pericardium, a febrile illness can develop called post-pericardiotomy syndrome (PPS). Typically starting 4-8 days after operation, the clinical features include fever, irritability, increase in acute phase reactants, effusions in the pleural and/or pericardial spaces, and often the development of anti-heart antibodies. Such antibodies are not routinely evaluated but reports of their appearance support an auto-immune pathogenesis. The usual diagnostic concerns in such a patient include: infection (incisional; UTI; pneumonia; endocarditis is quite rare this early) versus atelectasis (most common) versus post-pericardiotomy syndrome, which is a diagnosis of exclusion. PPS is generally a self-limited, benign albeit uncomfortable condition, but the fluid accumulations, especially in the pericardium, can pose a real threat to the patient and should always be ruled out. Treatment is usually aspirin or non-steroidal anti-inflammatory agents; pericardiocentesis is occasionally necessary. PPS is of

significance to primary care physicians because of the trend toward early hospital discharge. It is not unusual for a child to be discharged 3-4 days after repair of ASD or VSD; such a child could easily develop a fever 5-6 days after surgery and PPS should be considered by the primary care physician, prompting a chest X-ray and possibly an echocardiogram after physical examination.

Therapeutic cardiac catheterization

The technology, indications and even the lesions approachable 'per catheter' change so rapidly that this section requires up-dating at least annually. (For a review article with illustrative photographs, see West J Med 1990; 153:288-295 or ask Dr. Waldman for a copy.)There are currently five therapeutic procedures done in the cath lab. These are done by pediatric cardiologists specially trained in interventional procedures. Endomyocardial biopsy (see Cardiomyopathy) is also done by interventional cardiologists.

a) Electrical therapy:

- Many types of tachycardia, both ventricular and atrial, are amenable to ablation by radio-frequencies delivered through catheters. This is done in the cath lab by electro-physiologic specialists.
- Temporary pacemaker catheters can be placed for bradycardia, either congenital or post-operative.

b) Balloon dilation: high pressure balloons can be used to open many types of obstruction including pulmonary, mitral and aortic valvar stenosis, pulmonary artery stenosis and coarctation of the aorta.

c) Embolotherapy: a term used to describe therapeutic insertion of a substance or device which closes an unwanted channel by in situ thrombosis. Currently, steel coils with dacron strands attached are used to close collateral vessels, residual shunts, PDA (see PDA closure section) etc. A more complex device is available to close ASDs.

d) Stent implantation: there are circular mesh 'sleeves' which are small (internal diameter = 8 mm) but can be expanded widely (to 30 mm) and once expanded, they do not retract to the former small diameter. This is used to enlarge vascular stenoses such as venous obstruction, branch pulmonary artery stenosis and is now being studied in coarctation of the aorta.

e) Pericardiocentesis: usually done in the cardiac cath lab under echocardiographic and fluoroscopic control. A catheter is inserted transcutaneously (not through the vascular system) into the pericardial space for drainage. This method is safer than using a needle, and the catheter can be left in place for hours to days.

f) Gene Therapy: while not in clinical usage at present, studies are commencing to assess the use of virally vectored gene therapy into the pulmonary circuit, changing the genetic code of pulmonary vascular smooth muscle cells or (in subsequent studies) other cells. The potential here is profound, e.g., to 'cure' PVOD or infiltrative disorders, even abnormal pulmonary membranes (capillary-alveolar block, etc.)