This is part 1 of a series of 4 lectures that are intended to give us a sense of the basics - how to think about heart disease. Congenital heart disease, our topic for today, is a very diverse group of conditions. Because Duke has a very good pediatric cardiology department, some of the things that you can see here don't even have names yet.
Keys to Congenital Hearts

• Normal Cardiac Anatomy
• Developmental Embryology
• Pathophysiology
  – Flow direction
  – Volume/Pressure effects

A Duke Student’s Worst Nightmare

Remember, we talk about these as being present in kids, but adults, too, can present with some of these abnormalities that they’ve had their entire lives. Often, this means that the adult is dealing with a whole set of problems caused by the untreated congenital abnormality.
Cardiac Development

- **Elongation and Folding of Tubular Heart**
  - BMP family – directs cardiac lineage
  - Outstrips growth of embryo as a whole
- **Partitioning into Four Chambers**
  - Endocardial cushions – atrioventricular division
    - BMP’s, TGF-β family
    - Ventricular Septum – from apex to base
      - Left and Right Ventricles are specific
        - HAND1, HAND2 – chamber restricted genes
  - Atrial Septum
    - Primary Septum: from roof to cushions
    - Secondary Septum: “closes” fenestration

Complicated by differing fetal & adult blood flow patterns

Genetics, not location, determines tissue characteristics

Unlike the ventricular septum, this is two muscular bands

Form tricuspid and mitral valves

Really quick embryology review: the heart forms from two tubes that fuse around day 19 of gestation; the area of fusion contains (from rostral to caudal): the bulbus cordis (future RV and parts of outflow tracts for aorta and pulmonary trunk), the primitive ventricle (future LV), the primitive atrium (anterior parts of LA and RA), and the right and left horns (not fused – still separate), which form the superior vena cava and part of RA. Then folding occurs - bulbus cordis moves anteriorly, inferiorly, and to the right, primitive ventricle moves left.

Foramen ovale

Animation: [http://ww.indiana.edu/~anat550/cvanim/htube/htube.html](http://ww.indiana.edu/~anat550/cvanim/htube/htube.html)
This heart is from a neonate. The heart didn't progress past the tubular stage. The left and right ventricles are in series rather than side by side.

The atria, however, did develop.
Atrial septum - this one grows down

Endocardial cushion

Secondary atrial septum - together, they will eventually close up the foramen ovale

Growing ventricular septum dividing the ventricles - this one grows up

A view of how things develop on the inside
Cardiac Development

• Great Vessels
  – Common Truncus Arteriosus
  – Spiral septum – forms to separate into aortic and pulmonary trunks

• Aortic Arches
  – Involute or evolve
    • 3rd arches – internal carotids
    • 4th arch – right subclavian; left aorta
    • 6th arch – pulmonary arteries

Remember, you start out with one great vessel that grows a spiral septum.
The formation of the spiral septum is a pretty complex event - multiple abnormalities can occur during this process.
This shows which arches involute and what each becomes - knowing this helps you figure out what caused an abnormality and scores you points on the boards.
Arch Abnormality?

I think this is the pulmonary vein, but that's not really the important point of this slide.

This heart is oriented the way it actually sat in the chest - the head is at the top of your screen.
Arch Abnormality

Pulmonary artery is going back up to the lungs.

This is the same heart from the previous slide flipped up to display a short common sac.

Truncus arteriosus - never split; all the normal aortic branches are coming off this short stump, all the way down to and including the celiac and the SMA.

To Dr. Dibernardo's knowledge, this has never been described before or since.
Completion – When?
Fetal Flow Pattern?
Changes at Birth?

Pressure change (lower pressure in lungs) closes “flap valve” of foramen ovale.

1st 8 weeks or so

Remember, the lungs are largely excluded from the flow pattern (high pressure compared to systemic flow).

Unlike diagrams you may have seen, the ductus is not a wimpy little branch. It’s as big as, if not bigger than the main pulmonary artery and aorta. A problem with the ductus may result in a small, hypoplastic aorta.
Congenital Heart Disease

• **Incidence:** 0.3 to 1.0% of live births

• **Etiology:**
  – Viral – rubella
  – Teratogens
  – Genetic: Down’s, Turner’s, VATER/VACTERL

- Vertebral anomalies
  - Anal atresia
  - Cardiac defects
  - Trachea problems (ex. tracheal esophageal fistula)
  - Esophageal atresia (blind stump)
  - Renal defects
  - Limb defects

Many named syndromes will encompass heart defects with other problems in the face or other solid organs.
Pathophysiology

- **Flow abnormalities**
  - Direction of flow/shunt
    - Determinants
      - Parts
      - Downstream compliance
      - Generally left to right
  - Obstruction
  - Effect on heart and organs (lungs)
    - Volume hypertrophy – enlarged chamber
    - Pressure hypertrophy – mass increase
    - Right to left shunts (cyanosis)
• Ventricular Septal Defects
  – 25-30%
  [Most common]
• Atrial Septal Defect
  – 10-15%
• Persistent PDA
  – 10-20%
• Truncus Arteriosus
  – 2%
• Anomalous Pulmonary Venous Return
  – Rare

Now onto different categories of defects:

Isolated Shunts

1 Patent Ductus Arteriosus
2 Atrial Septal Defect
3 Ventricular Septal Defect

"A hole in the heart" - an opening that shouldn't be there, but is

http://www.youtube.com/watch?v=I-h4A7bF8wQ - Tangentially appropriately-themed '90s nostalgia. If I were a pediatric cardiologist, this would be my theme song.
Atrial Septal Defect

1) Primum Type
2) Secundum Type
3) Patent Foramen Ovale

- Valve competency

L->R shunt: first RA hypertrophies, then RV. Because oxygenated blood is being pumped into R side, this is not usually caught immediately.

Defect in septum primum, close to center of heart

More prevalent; larger opening in secundum
Atrial Septal Defect

Endocardial Cushion Defect – AV Canal

"Super deluxe ASD" - a common opening in the center of the heart due to failure of endocardial cushions to separate chambers - size of opening can vary greatly; the closer to natural anatomy you are, the easier it is to repair.
Ventricular Septal Defect

- Membranous (high)
- Muscular
  - Anterior
  - “Swiss Cheese”
- Volume increase
- Pressure Increase
- Long Term?

Again, a L→R shunt with oxygenated blood getting into the RV

Dr. Dibernardo read the slide

Can be anywhere, tend to be anterior

Multiple holes, hard to close because it's hard to find all of them

In lung - causes lung damage over time

In RV, which gets the extra blood
VSD Endstage

Increased volume into pulmonary vessels

Thickening of vessels causes “obstruction” and pulmonary hypertension

Pressure in right ventricle increases

Right ventricle thickens (already volume hypertrophy)

Shunt direction reverses to bidirectional or right to left

Occurs when RV pressure ≥ LV pressure
Patency maintained by Prostaglandin E, Closure induced with Indomethacin

Why would you want a patent ductus arteriosus? If you have an issue with your aortic valve that prevents flow, you may need it to get flow out of the heart. To keep the ductus, give prostaglandin E. To close a PDA (in some cases), you can give indomethacin. Both sometimes require surgery, though.
Persistent Truncus Arteriosus

Spiral septum does not form; mixing occurs in the truncus between blood that would normally be in the pulmonary artery and blood that would normally be in the aorta. Remember, blood favors the lungs (more compliance) until you get secondary changes (pulmonary hypertension, etc.)
• Anomalous Pulmonary Venous Return
  - Total or Partial
  - Mixing lesion
    • Oxygenated and Deoxygenated blood
  - Associated shunt
    • Allows oxygenated blood to enter systemic circulation

Pulmonary veins meet in a separate chamber behind the heart instead of dumping into the LA. "Draining vein" takes this blood down through the diaphragm into the systemic venous system and back to right side.

Ductus, ASD, or VSD - if a kid doesn't have one of these, the first step may be creating one until a more complete repair can be done.
This is an example - viewed from behind

Heart is up here

Lungs

Horseshoe kidney

Liver

With higher power you see that the pulmonary veins have met and are draining down through the diaphragm to the hepatic vein.
Obstruction

- **Pulmonary Stenosis**
  - 5-7%

- **Aortic Coarctation**
  - 4-6%
  - Can even have an interrupted aortic arch - ascending and descending do not fuse during development

- **Aortic Stenosis**
  - 5-7%
  - Valvular
  - Sub/supra valvular

4 Coarctation of the Aorta
5 Pulmonary Stenosis
6 Aortic Stenosis

Can be muscle or fibrous bands or simply a failure of the structure to form

Remember, stenosis represents a range of defects - leaflets can be too large, valve can be too small, extra tissue can be present around the valve
Pulmonary stenosis results in early development of the same things you see happening with a VSD: RV has to pump extra hard and hypertrophies, RA pressure increases, and then with RA pressure > LA pressure, foramen ovale stays open - R -> L shunt.
Aortic Stenosis

- Obstructs LV outflow
- LV Hypertrophy
- Aortic Arch Hypoplasia

Won't grow without blood flowing into it

You get backup of flow on the left side, going up into the lungs
Aortic Coarctation

- Closely Pre- or Postductal
  - Proximal: Hypertensive
  - Distal: Hypotensive
  - Interrupted aortic arch
  - Collaterals: Intercostal arteries

Surgery: resect or put a flap on the coarctation to enlarge the aorta in this location.

Or, if right on it, juxta ductal.

Can lead to erosions of the rib from enlarged arteries.
Combination Defects – Cyanotic Heart Disease

- **Tetralogy of Fallot**
  - 6-15%
- **Double Outlet Right Ventricle**
  - Rare
- **Transposition of the Great Vessels**
  - 4-10%
- **Tricuspid Atresia**
  - 1%
- **Hypoplastic Left Heart**
  - rare

Most common:
- Ventricular septal defect
- Narrowing of the pulmonary outflow tract
- Overriding aorta that is shifted over the right ventricle and ventricular septal defect, instead of coming out only from the left ventricle
- Right ventricular hypertrophy

Remember, you'll see even the rare ones here...
Tetralogy of Fallot

- Pulmonary Stenosis
- Overriding Aorta
- VSD
- Right Ventricular Hypertrophy *

- Cyanosis from right sided pressure increase - shunting

Kids have "Tet spells" - become cyanotic when they need more blood flow (crying, etc.) Kids figure out quickly that squatting down increases systemic pressure and reverses the shunt.
Double Outlet Right Ventricle

Both aorta and pulmonary artery come off RV - there is usually an associated VSD to allow oxygenated blood to get out.
Transposition of the Great Vessels

Without any additional septal defect, you have two separate circuits - LV -> PA -> LA -> LV and RV -> Aorta -> Vena Cava -> RA -> RV. You MUST have a hole somewhere - ASD, patent foramen, or brachial arteries can provide collateral flow, or VSD.

RV hypertrophy
ASD
Transposition of the Great Vessels

It used to be that these kids were monitored and the defect was repaired when they got worse, but the changes that occur in the RV lead to right-sided heart failure, so those kids did worse. Now these defects are fixed as close to birth as possible.
Corrected Transposition

So your great arteries are transposed, and so are your ventricles. Note that the LV pumps to the lungs and the RV pumps to the body - two wrongs make a right... sort of... RV will hypertrophy, unlike this drawing.
Situs

Heart on right
Stomach on right
Liver on left

You can end up with too many organs on one side, though - spleen is usually mixed up: asplenia or polysplenia
This dude had 17 spleens. Does that count as splenomegaly, or is it just splenomultiply?
Tricuspid Atresia

- No tricuspid valve
- RV and PA hypoplasia
- ASD for venous return
- VSD for pulmonary flow
- Mixing and diminished pulmonary flow -- cyanosis

No way to get blood to the right side of the heart, pulmonary artery is hypoplastic because of low flow.

Another case where you might want the ductus to exist.

This one isn’t easily corrected because you are missing parts.
Hypoplastic Left Heart

- LV and aortic hypoplasia
- ASD - left to right flow
- Ductus Dependent for systemic flow
- May be secondary to Mitral Atresia

For these kids, whichever ventricle they have is made the systemic pump, and the lungs get blood through shunts
Implications

• Can it be Fixed?
  – Repair vs transplant

• When should it be fixed?
  – Palliate
  – Definitive
  – other

Problem is not enough hearts; kids waiting for transplant undergo secondary changes, never get a heart, and then are much sicker

The earlier the better
Palliation

• Shunts: Provide blood flow
  – Generally to lungs

• Septostomies: Allow mixing of blood

• Ductus preservation

Remember, palliation doesn't mean that it won't ever be fixed; it just means that it's a stopgap measure for right now.
Blalock-Taussig Shunt

No one wanted to do heart surgery; resident who did anesthesia ended up becoming chair for anesthesiology @ Duke

African American lab assistant figured out how to create the animal model for the tetralogy and how to fix it, but the doctors took all the credit.

Vivien Thomas
Blalock-Taussig Shunt

The left subclavian artery is divided and connected to the left pulmonary artery. This allows blood to flow to the lungs to pick up oxygen.

Designed for tetralogy of Fallot

This is the original procedure; these days you just add a tube of Gore-tex between an aortic branch and the pulmonary artery.
Shunts

Central Shunt

Glenn Shunt

Just examples of shunts that can be used - probably good pimping material for next year, but not likely to be on the test from the emphasis put on it (or lack thereof)
Repairs: Ross

1) Replace aortic valve with pulmonary valve
2) Donor pulmonary valve homograft

WHY?

Pt. does better with own valve in high-pressure system; prosthetic ok for low pressure
Repairs: Complex & Staged

Fontan: Tricuspid Atresia
Repairs: Complex & Staged

Transposition: Arterial Switch

Transposition of the Great Arteries
Corrective Arterial Switch Procedure

This is the catch - you have to re-implant the coronaries after you do the switch.

Note: If you don’t do this operation early, you can’t get the LV to be the systemic pump, but can inc. resistance in PA with a band around it for about a week ("Take the LV to the gym")
Fetal Surgery

The Center for Fetal Diagnosis and Treatment
1-800-IN-UTERO

The Fetal Treatment Center
UNIVERSITY OF CALIFORNIA SAN FRANCISCO

Prevent volume/pressure hypertrophy
No Scarring
Barriers remain

Future of surgery; not as well progressed on the heart as on other organs - heart-lung bypass is really tricky on these kids; premature delivery can be stimulated.

Advantages: no scarring = plastic surgeon's dream