Common Notes in Cardiac Surgery & Cardiology

Educational Coarse

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**ANATOMY AND PHYSIOLOGY**

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Chapter 1- Cardiac anatomy

1. Surface Anatomy
A. Right atrium anterior and to the right of left atrium
B. Left atrium a midline structure
C. Right ventricle anterior and to the right of left ventricle
D. Pulmonary artery anterior and to the left of aorta
E. Coronary arteries on surface follow A-V groove and interventricular septum

2. Cardiac Chambers
A. Right atrium

1) Wide based blunt appendage, crista terminalis separates trabeculated from non-trabeculated portion
B. **Left atrium**

![Left atrial appendage (narrow)](image)

1) Long, narrow appendage, smooth walls

C. Right ventricle

1) Coarsely trabeculated inlet/sinus, outlet portion

D. Left ventricle

1) Fine trabeculations inlet/sinus and outlet portions

3. **Right Atrium**

A. SVC - IVC

B. **Crista terminalis**
C. Coronary sinus  
D. Tricuspid valve

E. Fossa ovalis

F. Triangle of Koch  
G. Tendon of Todaro  
H. Inferior isthmus

4. Right Ventricle
A. Inlet portion supports tricuspid valve  
B. Trabecular sinus portion (main body of the RV)  
1) Moderator band  
2) Medial papillary muscle (of conus)  
C. Outlet portion
1) Infundibular (Conal) septum (separates semilunar valves)
2) Crista supra ventricularis - separates sinus (chamber) from outlet portion of the ventricle
3) Septal band (trabecula septomarginalis)

4) Parietal band (ventriculo-infundibular fold)
5) Pulmonary valve

5. Left Ventricle
A. Thick wall
B. Inlet portion supports mitral valve
C. Anterior and posterior papillary muscles
D. Outlet portion beneath aortic valve

6. Conduction System
A. Sinoatrial node - anterolateral RA
B. Interatrial conduction pathways - not well defined and somewhat controversial

C. Atrioventricular node - triangle of Koch
D. Bundle of His - AV node to membranous septum, usually located on the inferior/posterior wall of the membranous septum
E. Left bundle branch - left ventricular septal surface into multiple branches
F. Right bundle branch - below medial papillary muscle via septal and moderator bands to anterior papillary muscle
G. Inferior isthmus (right atrium)
H. Bachman’s bundle (left atrium)

7. Cardiac Valves
A. Aortic valve wedged between mitral and tricuspid, pulmonary valve separated
B. Mitral valve

1) Anterior leaflet wide, short, 1/3 of annular circumference

2) Posterior leaflet narrow, long, 2/3 of annular circumference

3) Papillary muscles and chordae tendineae

C. Tricuspid valve

1) Anterior, posterior, septal leaflets

D. Aortic and pulmonary valves

1) 3 cusp, semilunar

2) Sinuses of Valsalva

3) Nodulus Aranti and lunulae

8. Left Ventricular Outflow Tract

A. Semilunar aortic valve

B. Fibrous annulus is not a ring
C. Interleaflet triangles
D. Aortoventricular junction
E. Sinuses of Valsalva
F. Sinotubular junction (sinus rim) = junction of sinus of Valsalva and ascending aorta
G. Posterior commissure relates to mid point of anterior leaflet of mitral valve

9. Ventricular Band (Torrent-Guasp)
A. Biventricular myocardial band extending from pulmonary artery to aorta

B. Two loops: basal and apical
C. Double helix derived from spiral fold
D. Apex has **figure-8** configuration

10. **Coronary Arteries**
A. Right and left coronary arteries

B. **Dominant pattern** determined by origin of posterior descending

C. Dominance is usually right or balanced; 10-15% prevalence of left dominance

D. **Balanced pattern** occurs when there is no particular dominance

E. Septal blood supply 2/3 left anterior descending, 1/3 posterior descending

F. Sinus node artery from RCA - 55%

G. AV node artery from U bend at crux, just beyond the takeoff of the PDA if circulation is right dominant
11. Descriptive Variables
A. Situs of thoracic viscera and atria
1) This is best identified from the bronchial anatomy (3 bronchi on the right, 2 on the left)
2) Solitus, inversus, ambiguous
B. Situs of ventricles
1) Usual, concordant, D-loop, right-handedness
2) Inverted, discordant, L-loop, left-handedness
C. Dominance of ventricles
1) Balanced (usual), right (left small), left (right small)

12. Descriptive Variables
A. Cardiac connections
1) Atrioventricular and ventriculoarterial
2) Concordant or discordant (transposed)
B. Cardiac and arterial position
1) Cardiac apex; levo-, dextro-, mesocardia
2) Great arteries; transposition, malposition
3) The patient can have completely normal cardiac structures and still have dextrocardia - this only refers to the position of the cardiac apex
C. Conventional diagnosis; e.g., tetralogy of Fallot

Extended Outline

1. Cardiac Skeleton
A. Fibrous body
B. Right and left trigones

2. Coronary Arteries
A. Right and Left coronary arteries originate from proximal aorta via respective ostia
B. Common branches from main coronary arteries
1) Left main-- diagonal branches
2) Left anterior descending-- septal and diagonal arteries
3) Circumflex-- marginal arteries (and PDA in left dominant hearts)
4) Right coronary artery-- acute marginal, AV nodal, sinus node arteries (and PDA in right dominant hearts)
3. **Cardiovascular Silhouette**
   A. **Mediastinal Border**
   1) Right atrium
   2) Superior vena cava
   B. **Left Border**
   1) Aortic arch
   2) Pulmonary trunk
   3) Left atrial appendage
   4) Left ventricle

**Surgical Anatomy Of The Mitral Valve**

The mitral apparatus includes the leaflets, annulus, chordae tendineae, papillary muscles, and left ventricle.

A. **Leaflets**

- The mitral valve has two leaflets, the anterior (aortic) and posterior (mural) leaflets.
- The leaflets are attached directly to the mitral annulus and to the papillary muscles by primary and secondary chordae.

1. **Anterior mitral leaflet:**

- Is in direct continuity with the fibrous skeleton of the heart.
- This leaflet is contiguous with the left and noncoronary cusps of the aortic valve and the area beneath the intervening aortic commissure, termed the fibrous subaortic curtain.
- Although the anterior leaflet occupies only 35% to 45% of the annular circumference, its leaflet area is almost identical to that of the posterior leaflet.

2. **Posterior Leaflet:**

- Has two variable indentations or clefts that divide the posterior leaflet into three scallops: the largest or middle scallop, the posteromedial scallop, and the anterolateral scallop.
• Fan-shaped chordae insert into and define the clefts between the individual posterior scallops.
• Motion of the posterior leaflet is more restricted than that of the anterior leaflet; however, both mitral leaflets contribute importantly to effective valve closure.

The surface of the mitral leaflet is divided into three zones corresponding to areas of chordal insertion and leaflet coaptation.

1. **The rough zone:** is the leading edge of the anterior and posterior mitral leaflets. This zone is the contact surface of the mitral leaflets during systole.
2. **The clear zone:** is peripheral to the rough zone and represents most of the body of the leaflet; this portion of the mitral valve billows into the atrium during ventricular contraction.
3. **The basal zone:** between the clear zone and the annulus, receives the insertion of the basal chordae tendineae (tertiary chordae), which originate directly from the trabeculae of the left ventricle. The basal zone is found only on the posterior leaflet.

**B. Annulus**

• The mitral annulus is the site of leaflet attachment to muscular fibers of the atrium and ventricle.
• The annulus is flexible and decreases in diameter during each systolic contraction by approximately 26%.
• The orifice of the mitral valve also changes shape, from elliptical during ventricular systole to circular during late diastole. This flexibility increases leaflet coaptation during systole and maximizes orifice area during diastole.
• Anteriorly, the annulus is attached to the fibrous skeleton of the heart. This limits its flexibility and its capacity to dilate with mitral regurgitation (MR). The posterior annulus is more flexible and is not attached to rigid surrounding structures. This accounts for the clinical observation that dilation of the annulus occurs posteriorly with MR.
• **Important Anatomic Landmarks:**
1. The circumflex coronary artery courses laterally around the mitral annulus in the posterior atrioventricular groove.
2. The coronary sinus runs more medially in the same groove.
3. The artery to the atrioventricular node, usually a branch of the right coronary artery, runs a course parallel and close to the annulus of the anterior leaflet near the posteromedial commissure.
4. The aortic valve is situated between the anterior and posterior fibrous trigones. The bundle of His is located near the posterior trigone.

C. Chordae Tendineae

- The chordae tendineae are chords of fibrous connective tissue that attach the mitral leaflets to either the papillary muscles or the left ventricular free wall.
- They often subdivide and interconnect before they attach to the leaflets. The chordae are divided into:

1. **Primary chordae**: attach directly to the fibrous band running along the free edge of the leaflets. These chordae ensure that the contact surfaces (rough zone) of the leaflets coapt without leaflet prolapse or flail.
2. **Secondary chordae**: attach to the ventricular surface of the leaflets at the junction between the rough and clear zones. These chordae contribute to ventricular function. Secondary chordae enable the ventricle to contract in an efficient cone-shaped fashion; when secondary chordae are excised, the left ventricle assumes a globular shape.
3. **Tertiary chordae**: are unique to the posterior leaflet. They arise as strands directly from the left ventricular wall or from small trabeculae to insert into the ventricular surface of the leaflet near the annulus.

D. Papillary Muscles

- The anterolateral and posteromedial papillary muscles each supply chordae tendineae to both leaflets.
- The two groups of papillary muscles subtend the anterolateral and posteromedial commissures and arise from the junction of the apical and middle thirds of the ventricular wall.
• The anterolateral papillary muscle receives a dual blood supply from the anterior descending coronary artery and either a diagonal branch or a marginal branch of the left circumflex artery.
• The posteromedial papillary muscle receives its blood supply from either the left circumflex artery or a distal branch of the right coronary artery.
• Because of the single blood supply to the posteromedial papillary muscle, infarction of the posteromedial papillary muscle is much more common.

E. Left Ventricle

• The posterior left ventricular wall and papillary muscles play an important role in leaflet coaptation and valve competence.
• Papillary muscles are aligned parallel to the ventricular wall and attach via chordae to the free edges of the valve leaflets. These muscles project from the trabeculae and may be single, bifid, or a row of muscles arising from the ventricular wall.

During isovolumetric contraction the mitral leaflets are pulled downward and together by this interaction. Ventricular dilatation may affect the alignment and tension on the papillary muscles and valve competence.
Chapter 2 - Developmental Anatomy

1. Basic Principles
   A. Cardiovascular system is first functional system in embryo
   B. Blood circulation by 3 weeks (21 days)
   C. Heart develops 3-8 weeks

   D. Critical period for anomalies 3-6 weeks

2. Heart Development
   A. Endocardial tubes fuse to form heart tube (21 days)
   B. Heart begins to beat (22 days)
C. Heart folding - 21-22 days, folding - 23-28 days

1) D loop, L loop
2) **Bulboventricular loop** --- future ventricles

3) Cellular **differentiation**
4) **Bulbus cordis - conus cordis** --- RVOT

5) **Truncus arteriosus** --- great vessels

3. Atrial Septation
   A. **Septum primum** forms from roof of atrium

1) Ostium primum - closed by fusion of septum to endocardial cushion
2) **Ostium secundum** - coalescence of fenestrations

**B.** A-V canal divided by endocardial cushions

**C.** **Septum secundum** grows down from roof of atrium

1) Fuses with endocardial cushions

2) Overlaps ostium secundum

3) **Foramen ovale** remains open until after birth
4. Ventricular Septation and A-V Valves
A. **Muscular interventricular septum** forms
B. Fusion of ventricular septum with endocardial cushion must await partition of truncus arteriosus
C. Undermining of myocardium forms valve leaflets

D. Papillary muscles and chordae tendineae derived from ventricular myocardium
5. Clinical Correlates - Septal Defects
A. Atrial septal defect
1) Ostium secundum = excess resorption of septum primum or inadequate development of septum secundum (foramen ovale defect)
2) Ostium primum = septum primum fails to fuse with endocardial cushion (low defect with semilunar shape, right above the AV valves)
B. Ventricular septal defect
1) Failure of membranous portion to develop from extension of endocardial cushion to fuse with truncocoanal septum
2) Malalignment
3) Muscular defect = resorption of septum

6. Truncocoanal Septation
A. Bulbar-truncal ridges form truncocoanal or aorticopulmonary septum
B. Streaming of blood flow may account for spiral configuration of truncoconal septum
C. Bulbar-truncal ridges fuse to divide truncus arteriosus (aorta and pulmonary artery)
D. Fused bulbar-truncal ridges extend to fuse with endocardial cushion and muscular septum to partition ventricular septum. Semilunar valves derived from truncoconal swellings

7. Clinical Correlates - Truncoconal Septation
A. Truncus arteriosus = defective fusion of bulbotruncal ridges
B. Transposition of Great Arteries = failure of truncoconal spiral
C. Tetralogy of Fallot = unequal division of conus cordis
D. Semilunar valve stenosis = failure of development of truncoconal swellings or unequal partition

8. Aortic Arch Derivatives
A. Truncus arteriosus
1) Proximal ascending aorta
2) Main pulmonary artery  
B. Aortic sac  
1) Ascending aorta, 1/2 arch  
2) Brachiocephalic artery

9. Aortic Arch Derivatives Part II  
A. Aortic arches  
1) 1, 2, 5, R6 disappear  
2) 3 => carotid arteries  
3) 4 => mid arch, R proximal subclavian artery  
4) 6 => RPA and ductus arteriosus  
B. Dorsal aorta  
1) Left => descending aorta  
2) Right => R distal subclavian, distal disappears  
3) Internal carotid arteries

10. Clinical Correlates - Aortic Arch Derivatives  
A. Coarctation of the Aorta = probably related to ductus incorporation into the aortic wall  
B. Fetal blood flow and resorption of the dorsal aorta may also play a role  
C. Double aortic arch = failure of right dorsal arch to disappear  
D. Abnormal origin R subclavian artery = R4 arch and R dorsal aorta disappear, leaving 7 intersegmental artery originating as fourth branch of aorta behind esophagus

11. Fetal Circulation  
A. Three shunts permit most of the blood to bypass liver and lungs
1) Ductus venosus --- Ligamentum teres, venosum
2) Foramen ovale -- Fossa ovalis
3) Ductus arteriosus -- Ligamentum arteriosus
B. Shunts close after birth and become ligamentous
Chapter 3 - Echocardiography

Echocardiography

1. High frequency ultrasound = 2.0 - 7.5 MHz
   A. Adults = 2.0 - 2.5 MHz
   B. Pediatric = 3.0 - 5.0 MHz
   C. TEE = 3.5 - 7.5 MHz
   D. M-mode "ice pick view"
   E. 2D sector scanning
   F. Doppler effect
   G. Color flow imaging

2. Standard Transducer Positions
   A. Transthoracic long

B. Transthoracic 90o short axis
C. Parasternal long

D. Parasternal short
E. Apical

F. Subcostal 4 chamber
G. Subcostal ventricular septum

H. Suprasternal
I. Transesophageal
3. Doppler Effect
A. Sound frequency increases as sound source moves toward observer; frequency decreases as source moves away.
B. Ultrasound of known frequency is transmitted to heart or blood vessel.
C. Moving RBC’s reflect ultrasound waves at altered frequency depending on direction RBC’s are moving.
D. Frequency shift is used to estimate blood flow velocity.
4. **Color Flow Imaging**
   A. Doppler flow velocity sampled at multiple sites (gates)
   B. Frequency shift converted to color scheme
   1) Blood flow toward transducer = RED
   2) Blood flow away = BLUE
   3) Turbulence (multiple directions) = GREEN
   4) High frequency = WRAP AROUND OR ALIASING

5. **Hemodynamic Assessment by Doppler**
   A. Doppler shift measures blood flow velocity
   B. Flow velocity converted to pressure gradient by Bernoulli equation
      1) \( \Delta P = 4 \times (V^2) \)
   C. Sum of flow velocity during ejection period = time velocity integral (TVI)
      1) Used with cross sectional area to calculate flow
   D. Valve area
      1) Continuity equation
      2) Pressure half-time
   E. Flow velocity across a regurgitant valve is related to intracardiac pressure

6. **Typical 2D ECHO Patterns**
   A. Normal Anatomy
      1) **Four Chamber**
   B. Normal Valve Anatomy
      1) **Tricuspid**
      2) Mitral
      3) **Aortic**
   C. Pathologic variations
      1) **Valvular congenital aortic stenosis**
      2) **Subvalvular congenital aortic stenosis**
      3) **Ebstein’s Anomaly**
      4) Tricuspid atresia
      5) **Atrial septal defect**
      6) **Ventricular septal defect**
      7) **Cor triatriatum**
      8) **Total anomalous pulmonary venous connection**
      9) **Hypoplastic left heart syndrome**
      10) **Single ventricle**
      11) **Transposition of great arteries**
12) **Aortic endocarditis**
13) Mitral endocarditis
14) **Hypertrophic obstructive cardiomyopathy**
15) **Myxoma**
16) **Aortic dissection**
17) **Coarctation**
18) **Congenital mitral stenosis**
19) **Congenital rheumatic mitral disease**
20) **Ruptured mitral chordae**

7. **Intraoperative**
   A. **Ensure optimal result of reconstructive cardiac surgery**
      1) Cardiac valve
      2) Congenital defect repair
   B. **Minimize CV complications during operation**
      1) Air embolism
      2) Cardiac wall motion (value controversial)
   C. **Trouble-shooting the hemodynamically unstable patient**
Chapter 4 - Cardiovascular physiology/pharmacology

1. Heart Muscle Mechanics - 3 concepts
   A. TENSION (force) - Elements contributing:
      1) Contractile element => Active tension
      2) Elastic element (functional, not anatomic) => Resting tension
   B. LENGTH of muscle fibers influences Tension
      1) Starling's relationship (Tension (active & resting) vs Length)

2) Performance-wise this is PRELOAD effect

C. VELOCITY is influenced by Length and Tension
   1) Calcium activation
   2) Total calcium released
3) **Sarcomere** length alters calcium sensitivity

2. **Cardiac Performance**

Cardiac output = HR x Stroke volume

A. Stroke Volume affected by

1) Preload
2) Afterload
3) Contractility

B. Law of Laplace relates ventricular pressure and wall tension

1) \( T = Pr \)
2) \( 2h \)
3. The **cardiac cycle**

A. Isovolumetric ventricular contraction  
B. Rapid ejection phase  
   1) Reduced ejection phase  
C. Isovolumetric relaxation  
D. Rapid filling phase  
   1) Slow filling period  
   2) (Atrial contribution (20-30% in failing heart)  

4. Preload  
A. Normal heart - increased venous return results in increased cardiac output  
B. Failing heart - sarcomere length is already maximal; cardiac output increase requires increased contractility or heart rate  
C. After load  
D. Definition  
E. Increased after load - increase in LVEDV and radius (=preload)  
F. Anrep effect or homeometric autoregulation
**G. Contractility - inotropic state of muscle**

**5. Indicators of Cardiac performance**

A. Cardiac index = cardiac output/body surface area

B. LVEDP (or approximation)
   1) mean left atrial pressure
   2) mean pulmonary wedge pressure
   3) pulmonary artery diastolic pressure

C. CI and LVEDP together are better indicators of contractility than either alone

D. Ejection fraction = stroke volume/end-diastolic volume

E. Fractional shortening - calculated from the diameter perpendicular to the midpoint of LV long axis

**6. Coronary flow & myocardial O2 consumption**

A. Very efficient oxygen extraction (70% oxygen utilization coefficient)

B. Coronary hemodynamics - Q = P/R

C. Viscous resistance

D. Autoregulatory resistance

E. Compressive resistance

F. Transmural gradient in myocardium - DPTI x HR = driving pressure

G. Myocardial oxygen consumption

H. Pressure work, contractility, heart rate, basal cell metabolism, electrical activation

**CARDIOVASCULAR PHARMACOLOGY**

**7. Inotropes**

A. Digitalis
   1) Inhibit Na-K-ATPase - positive inotropic effect
   2) Parasympathomimetic and anti-adrenergic mechanisms
   3) Drug interaction - Quinidine, Verapamil, Amiodarone

4) Conditions that increase sensitivity

**8. Inotropes, Vasoconstricting**

A. Dopamine
   1) Low doses - D1 receptors in renal vasculature
   2) Increasing doses - b-1 receptors activated
   3) High doses - a-adrenergic receptor activation
B. Epinephrine
1) Potent b and a effects
C. Norepinephrine
1) Potent alpha effects

9. Inotropes, Vasodilating
A. Dobutamine
1) Beta > alpha effect
2) Reduces LV filling pressures
3) Decreases afterload
B. Milrinone, Amrinone
1) Phosphodiesterase inhibitors
C. Isoproterenol
1) Inotropic (beta), chronotropic effects

10. Vasodilators & Vasoconstrictors
A. Vasodilators
B. Nitroprusside
1) Generalized vasodilatation
2) "Steal phenomena"
3) Indications - hypertension, acute heart failure
4) (thiocyanate toxicity - rare; with renal failure)
C. Nitroglycerine
1) General vasodilatation
2) Low doses - venous; high doses - arterial
3) Preload reduction and coronary vasodilation
4) Useul in management of ischemia
5) Decrease LVEDP and pulmonary vascular congestion
D. NO and Isoproterenol - pulmonary effects
E. Vasoconstrictors
F. Neosynephrine (pure alpha)

11. Calcium Antagonists
A. Mechanisms
B. Interference of Ca2+ - mediated smooth muscle contraction - coronary and peripheral smooth muscle relaxation
C. Selective Ca2+ channel inhibition
1) Treatment of angina pectoris / supraventricular tachycardia / hypertension
D. Agents
1) Verapamil
2) Nifedipine
3) Diltiazem

12. ACE Inhibitors
A. Mechanisms
1) Prevent conversion of Angiotensin I to Angiotensin II - vasodilation
2) Decreased Aldosterone secretion
3) Indication - hypertension, heart failure, prophylactically after MI
B. Agents
1) Captopril
2) Low cardiac output states - improvement in renal blood flow
3) Angioedema/cough/neutropenia/nephrotic syndrome
4) Increase in creatinine - RAS
C. Enalapril
1) Enalaprilat (liver) - delay - long duration
2) Less side-effects

13. Beta Blockers
A. Mechanisms
1) b-1 and b-2; cardioselectivity
B. Indications
1) Hypertension, angina pectoris, arrhythmias, prophylactically after MI
C. Adverse effects
1) Bronchospasm, Inhibition of myocardial contractility
D. Drug interactions
1) Lidocaine/Verapamil/Cimetidine/Diltiazem
E. Agents
1) Propanolol, metropolol, atenolol
2) Esmolol - very short half-life
### 14. Anti-arrhythmic Drugs and Their Actions: Class Action Agents

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<td>Inhibit Na+ transport</td>
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<td>Reduced dV/dT of action potential</td>
<td>Procainamide</td>
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<td>IB</td>
<td>Slow dV/dT of phase 0</td>
<td>Disopyramadine</td>
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<td>Moderate prolongation of repolarization</td>
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<td></td>
<td>Prolongs PR, QRS, and QT intervals</td>
<td>Phenytoin</td>
</tr>
<tr>
<td></td>
<td>Limited effect on dV/dT of phase 0</td>
<td>Mexiletine</td>
</tr>
<tr>
<td></td>
<td>Shortens repolarization</td>
<td>Tocainide</td>
</tr>
<tr>
<td></td>
<td>Shortens QT in clinical doses</td>
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<tr>
<td></td>
<td>Elevates fibrillation threshold</td>
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### 15. Anti-arrhythmic Drugs and Their Actions

<table>
<thead>
<tr>
<th>Class</th>
<th>Action</th>
<th>Agents</th>
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<tbody>
<tr>
<td>IC</td>
<td>Markedly slows dV/dT</td>
<td>Flecainide</td>
</tr>
<tr>
<td></td>
<td>Little effect on repolarization</td>
<td>Ecainide</td>
</tr>
<tr>
<td></td>
<td>Markedly prolongs PR and QRS</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>Beta-adrenergic blockers</td>
<td>Metoprolol</td>
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<tr>
<td></td>
<td>Decrease nodal conduction</td>
<td>Atenolol</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Propanolol</td>
</tr>
<tr>
<td>III</td>
<td>Prolongs repolarization</td>
<td>Amiodarone</td>
</tr>
<tr>
<td></td>
<td>Alters membrane response</td>
<td>Bretylium</td>
</tr>
<tr>
<td>IV</td>
<td>Calcium channel blockers</td>
<td>Verapamil</td>
</tr>
<tr>
<td></td>
<td>Decrease nodal conduction</td>
<td>Nifedipine</td>
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<tr>
<td></td>
<td></td>
<td>Diltiazem</td>
</tr>
</tbody>
</table>
16. Thrombolytic Agents
A. Streptokinase - Indirectly activate plasminogen to plasmin => fibrin into FDP's (non-specific)
B. Urokinase - Indirectly - thrombolysis (non-specific)
C. tPA (Alteplase) - Clot specific thrombolytic - binds directly to clot via fibrin
D. APSAC - Like Streptokinase
Chapter 5 - Low Cardiac Output & Circulatory Support

CARDIOGENIC SHOCK

1. Definition
A. Definition
1) BP systolic < 80 mmHg (or 30 mmHg below basal, BP mean <60 mmHg)
2) CI < 2 L/min/M2 (with adequate filling)
3) LAP and/or RAP > 20 mmHg
B. Clinical Manifestations of Low C.O.
1) Decreased peripheral perfusion (pulses, cool, mottled)
2) Restlessness, confusion decreased mentation
3) UO < 20-30 ml/hr (adults)
C. Causes
1) MI, myocarditis, tamponade, arrhythmias, acute MR/AI
2) Massive pulmonary embolism, vena caval obstruction, tension pneumothorax
3) R/O hypovolemia, acidosis, anemia, sepsis

PRIMARY DETERMINANTS OF CARDIOVASCULAR PERFORMANCE
A. Heart Rate & Rhythm
1) Sinus Rhythm vs Atrial Fibrillation, AVB; bradycardia; tachycardia
B. Preload (Ventricular filling)
1) Frank-Starling effect
C. Ventricular Compliance (Distensibility)
1) Effect of ischemia, injury, pericardial space
2) (Tamponade - decreased CO, BP, Pulse Pressure, increased LAP=RAP)
D. Ventricular Contractility
E. Inotropes
1) Sympathomimetic amines, phosphodiesterase inhibitors
F. Afterload (Vascular resistance)
1) Vasoactive therapy

SECONDARY DETERMINANTS OF CARDIOVASCULAR PERFORMANCE
A. Oxygen delivery
1) O₂ carrying capacity (Hgb)
2) Oxygenation

B. Metabolic - acid/base status
1) Acidosis (effect on contractility)
2) Alkalosis (decreases release of O₂ from Hgb, Left shift oxygen-Hgb dissociation curve)

C. Metabolic stress/load
1) Fever, agitation, respiratory distress

APPROACH TO CARDIOGENIC SHOCK

A. Medical Management of Reversible Causes
B. Primary Determinants of CV Performance
   1) Rate & Rhythm, Preload, Compliance, Contractility, Afterload
C. Secondary Determinants of CV Performance
   1) Oxygen delivery, Acid/base status, Metabolic load
D. Assisted Circulation
   1) Intra-Aortic Balloon Pump (IABP)
   2) Cardiopulmonary Support (CPS)
   3) Ventricular Assist Device(s) (VAD’s)
   4) Total Artificial Heart (TAH’s)

INTRA-AORTIC BALLOON PUMP

1. Indications for Use
   A. Failure to wean from CPB (49%)
   B. Post-MI cardiogenic shock (22%)
   C. Refractory myocardial ischemia (15%)
   D. Post-op cardiogenic shock (7%)
   E. MR or VSD (temporizing)
   F. Ischemic arrhythmias
   G. (Bridge to transplant)

2. Contraindications for Use
   A. Aortic valve insufficiency
   B. Severe peripheral vascular disease (?)

3. Complications
   A. Limb ischemia (5-18%)
B. Insertion site hemorrhage (2-4%)
C. Infection (1-2%)
D. Aortic or iliac perforation (1-2%)
E. Aortic dissection (1%)
F. Renal artery embolism or thrombosis (1%)
G. Mesenteric infarction (1%)
H. Spinal cord injury (0.5-1%)
I. Gas embolization/rupture (0.5%)
J. CVA (0.5%)

4. Results
A. Post-cardiotomy Failure
1) 75-85% weaned
2) 55% survival
B. Post-MI Cardiogenic Shock
1) 75% will improve hemodynamically
2) In post MI use, mortality is 85%
3) Post-MI + intervention - mortality = 40-50%

ADVANCED MECHANICAL SUPPORT

1. Indications
A. Post-cardiotomy cardiogenic shock
B. Post-MI cardiogenic shock
C. Post-transplant graft failure
D. High-risk PTCA support
E. Cardiopulmonary Resuscitation (CPR)
F. Hypothermia rewarming
G. Bridge-to-transplant (or recovery)
H. Alternative to transplantation (future)

POST-CARDIOTOMY MECHANICAL CIRCULATORY SUPPORT

1. Intraoperative Management
A. Pharmacologic support
B. Intra-aortic balloon pump
C. Optimization (volume, metabolic, respiratory, drugs)
D. Decision for VAD
1) Patient selection
2) Early intervention

2. Patient Selection
   A. Inclusion Criteria
      1) Cardiogenic shock: CI < 2 l/min/M2, BP systolic < 80 mmHg
      2) LAP > 20 and/or RAP > 20 mmHg
      3) (after medical optimization - pre/afterload, respiratory, metabolic)
      4) (after pharmacologic support)
   B. Exclusion Considerations
      1) Technically imperfect operation
      2) Perioperative MI (vs. stunned myocardium)
      3) Age
      4) Preoperative "emergency" status
      5) Massive bleeding
      6) Long CPB
      7) End-organ failure (renal, hepatic, pulmonary .. )
      8) Infection (i.e. endocarditis)

3. Intraoperative Management - Implementation of support
   A. Select VAD, cannulae
   B. Cannulate, implement VAD support
   C. Re-assess cardiac performance
   D. Secure hemostasis
   E. Wound handling (close vs. open)

4. Equipment
   A. Ventricular Assist Devices
      1) (Considerations: cost, availability, familiarity, anticoagulation, blood trauma, monitoring)
      2) Pulsatile, pneumatic
      3) Centrifugal pumps
      4) [ Roller pumps ]
   B. Cannulae
      1) Uptake: R. side: 34-51 Fr; L.side: 28-36 Fr
      2) Return: Ao and PA: 22 Fr

5. Management of VAD Support
A. Observe for bi-ventricular failure
B. Institute second VAD as needed
C. Secure Hemostasis
   1) Reverse Heparin
   2) Fibrin Glue
D. Wound Handling
   1) Close sternum/skin
   2) Close skin only, support sternum
   3) Leave open (silastic or Esmark ...)

6. Postoperative - General
A. Maximize Myocardial Recovery
   1) Reduce Inotrope support
   2) Keep heart decompressed
B. Anticoagulation
   1) Intraop - heparin is reversed
   2) When CT output OK - ACT > 180
   3) When weaning VAD - ACT > 220
C. Maintain Pulsatile Perfusion (?)
   1) Leave IABP in place

7. Postoperative - Weaning
A. Time Course
   1) At least 24 hours
   2) But <10% survivorship after 7 days
B. Follow Recovery
   1) Reduce VAD flow (i.e. to 1L/min)
   2) Observe LAP,RAP,AoP,PAP,SVO2
   3) Observe cardiac function w/ TEE
C. Remove VAD
   1) With good hemodynamics at low VAD flow
D. Wean IABP & drips as able

8. Problems
A. Cardiovascular
   1) RV failure with LVAD
      a) decreased LAP, decreased VAD out, increased RAP
   2) LV failure with RVAD
a) decreased RAP, decreased VAD out, increased LAP
3) Hypovolemia (decreased LAP/RAP decreased VAD out)
4) Cyanosis - shunting through PFO
B. Device-Related
1) Thromboemboli
2) Cannula obstruction
   a) increased LAP/RAP, decreased VAD out
3) Device failure
4) Hemolysis
C. Systemic
1) Bleeding (30-45% return to OR)
2) End-organ failure (renal, respiratory, hepatic)
3) Infection

9. Results
A. Weaned - 50-60%
B. Survived - 25-50%
Chapter 6 - Assisted Circulation

1. Advanced Mechanical Support
   A. Indications
      1) Post-cardiotomy cardiogenic shock
      2) Post-MI cardiogenic shock
      3) Post-transplant graft failure
      4) High-risk PTCA support
      5) Cardiopulmonary resuscitation (CPR)
      6) Hypothermia rewarming
      7) Alternative to transplantation (clinical trials)

2. Circulatory Support
   A. Mechanical cardiac assist
      1) Intra-aortic balloon pump (IABP)
      2) Ventricular assist devices (VAD)
      3) Cardiopulmonary support (CPS, ECMO)
   B. Mechanical cardiac replacement
      1) Total artificial hearts (TAH)
   C. Others
      1) Biologic cardiac assist - cardiomyoplasty
      2) Ventricular remodeling
      3) Pacing

3. Mechanical Circulatory Support - Characterization
   A. Output hemodynamics
      1) Pulsatile
      2) Non-pulsatile
   B. Drive mechanism
      1) Pneumatic; electric (hydraulic, mechanical)
   C. Configuration
      1) TAH, BVAD, RVAD, LVAD
   D. Status/availability
      1) Approved for market, IDE trials, in development
4. Placement position
   A. Orthotopic; heterotopic; extracorporeal
   B. Paracorporal; transcutaneous
   C. Implantability
      1) Fully; partially; not at all
   D. Application/permanence
      1) Temporary; bridge-to-transplant, cardiogenic shock; bridge-to-recovery
         2) Permanent; alternative-to-transplantation

5. Device Selection for Bridge-to-Transplantation

<table>
<thead>
<tr>
<th>Criteria</th>
<th>LVAD</th>
<th>RVAD</th>
<th>BVAD</th>
<th>TAH</th>
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<td>LV failure</td>
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<td>--</td>
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<tr>
<td>RV failure</td>
<td>--</td>
<td>++</td>
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<td>+</td>
</tr>
<tr>
<td>LV &amp; BV failure</td>
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<td>+</td>
<td>+</td>
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<tr>
<td>Unresectable trombus</td>
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<td>+</td>
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<tr>
<td>S/P mechanical valve</td>
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<td>+</td>
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<td>AI (or PI)</td>
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<td>+</td>
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<td>Irreparable intracardiac shunts</td>
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<td>Uncorrectable arrhythmias</td>
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<td>?</td>
<td>+</td>
<td>+</td>
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<tr>
<td>Refractory ischemia, angina</td>
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<td>+</td>
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<tr>
<td>Transplant heart rejection</td>
<td>--</td>
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<td>+</td>
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<tr>
<td>Acute MI at cannula site</td>
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<td>?</td>
<td>?</td>
<td>+</td>
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<tr>
<td>Unresectable cardiac tumor</td>
<td>--</td>
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<td>--</td>
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</table>

6. Bridge-to-Transplant
   A. Problems
   B. Cardiovascular
      1) Failure on non-supported ventricle
      2) Arrhythmias
3) Cyanosis/shunting with PFO
4) Ischemia/angina

C. Systemic
1) Hemorrhage
2) End-organ failure
3) Infection
4) Infection
5) Immune sensitization
6) Compromised quality of life

D. Device related
1) Thromboemboli
2) Obstruction/compression
3) Improper orientation
4) Device infection
5) Device failure
6) Hemorrhage
7) Air entraniment/embolus
8) Hemolysis

E. Results
1) 65-75% successfully bridged (90+% possible)
2) 90+% of those transplanted are discharged

7. Mechanical Circulatory Support– Issues for the future
   A. Technological improvements
      1) Size, biocompatibility, control, reliability, power and durability
   B. Clinical effectiveness
      1) Longevity, quality of life, complications, recovery, expertise
   C. Cost-effectiveness
      1) Of technology and implementation
   D. Societal and ethical concerns
      1) Allocation of resources; patient populations
   E. Permanent Implantation– future NEED
      1) By the year 2010
         a) Number or patients: 35,000- 70,000 per year for long-term support
         b) Devices:10,000-20,000 TAH and 25,000-60,000 VAD
8. Total Artificial Heart

A. Results—Bridge-to-transplant

<table>
<thead>
<tr>
<th></th>
<th>TAH</th>
<th>Control</th>
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<tr>
<td>N (%</td>
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<tr>
<td>Patients</td>
<td>27</td>
<td>18</td>
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<tr>
<td>Transplanted</td>
<td>25</td>
<td>8</td>
</tr>
<tr>
<td>Discharged home</td>
<td>28</td>
<td>7</td>
</tr>
<tr>
<td>Neurologic-embolic</td>
<td>9</td>
<td>--</td>
</tr>
</tbody>
</table>

B. Copeland et al

9. Summary

A. May be life saving in selected patients with end-stage heart disease
B. Need for this intervention is increasing with decreasing donor availability
C. May ultimately become an alternative to transplantation
Chapter 7 - Hemorrhage and Thrombosis

COAGULATION BASICS

1. Overview
   A. Primary hemostasis
      1) Platelet (a) adhesion, (b) activation, (c) aggregation
   B. Secondary hemostasis
      1) Activation of plasma coagulation (form fibrin)
         a) Extrinsic pathway (via tissue factor)
         b) Intrinsic pathway (subendothelium or foreign contact)
         c) Common pathway
      2) Inhibition of systemic clotting
         a) Natural anticoagulants (AT III, Protein C & S)
         b) Fibrinolytic system, i.e. Plasmin (degrades fibrinogen)
   C. Other reactions
      1) Complement activation (increased permeability, cell lysis)
      2) Kinin generation (vascular dilation, increased permeability)

2. Platelet Function
   A. Contact
      1) With subendothelium after endothelial injury
      2) With proteins adsorbed onto synthetic surfaces
   B. Adhesion
      1) Via attachment mechanisms i.e. Glycoprotein Ib/IX
      2) (GP Ib/IX) receptor
   C. Activation
      1) Begins as platelets spread with a conformational change
      2) Release TxA2, ADP, serotonin, (PF4, BTG)
   D. Aggregation
      1) ADP induced change in GpIIb/IIIa receptor permits binding of adhesive proteins, like fibrinogen, between platelets
PHARMACOLOGY

3. Anticoagulants
   A. Heparin
      1) Glycosaminoglycan, MW 3K - 100K
      2) Acts by binding enzyme AT III
         a) (AT III inhib's IIa,Xa,IXa,XIa,XIIa)
      3) Half life is 60-90 minutes
      4) Monitored with aPTT or ACT
      5) Complications: bleeding; HIT => thrombosis, "white clot"
      6) (Ab versus Hep-PF4 complex); osteoporosis

4. Alternatives to heparin (future)
   A. Hirudin (Hirulog, synthetic analog)
      1) From leeches, direct inhibitor of thrombin
      2) Does not require ATIII
      3) Prolongs TT, aPTT, PT, and ACT
   B. Ancrod
      1) From venom of Malayan pit viper
   C. Others

5. Warfarin
   A. Acts as Vitamin K antagonist
      1) (Vitamin K required for Fx II, VI, IX, X; Prot C,S)
   B. Half-life is 36 to 42 hours
   C. Monitored w/ INR = Pt. PT / Control PT
   D. Reversed w/FFP (immediate); Vit K (8-24 hrs)
   E. Complications
      1) Bleeding, skin necrosis (Protein C & S deficiency), fetal abnormalities

6. Antiplatelet Agents
   A. Aspirin
      1) Inhibits cyclo oxygenase (rate-limiting enzyme for PG's)
         a) Reduces TxA2 from platelets (causes aggregation)
         b) (Low dose inhibits Plt cyclo oxygenase but not endothelium)
      2) Irreversible inhibition for Plt lifetime (7-10 days)
   B. Ticlopidine (ASA substitute)
      1) Blocks fibrin-GpIIb/IIIa interaction
2) Onset slow, 2-3 days  
C. Dipyridamole  
1) Inhibits Plt adhesion  
D. IV Dextran (40 - MW 40,000 daltons)  
1) Decreases Plt-vascular endothelial interaction  
2) Decreases von Willebrand factor  

7. Hemostatic Agents  
A. Protamine  
1) Basic protein, binds heparin  
2) 1 mg protamine = 100 U heparin  
3) Adverse reactions  
a) Transient systemic hypotension  
(1) Related to infusion rate, total dose  
b) Anaphylaxis - pulmonary hypertension, systemic hypotension, bradycardia  
(1) (Risk factors - prior exposure, DM's/NPH)  

8. Aprotinin  
A. Mechanism: proteolytic enzyme inhibitor  
1) Inhibits fibrinolysis, kinin activation, platelet activation  
B. Benefits  
1) Decreased blood loss, decreased systemic response to CPB  
C. Risks  
1) Prothrombotic effects, renal failure (?)  
2) Anaphylaxis with re-exposure (cutaneous testing, predose)  
D. Usage guidelines  
1) Patient risk should influence use - high risk patients (reoperations, long procedures, coagulopathy, need to avoid transfusions)  
2) ACT monitoring  
E. Other agents  
1) Amicar (Epsilon-amino caproic acid)  
2) Desmopressin (DDAVP)
ANTICOAGULATION FOR CPB

9. Heparin
   A. Standard initial dose = 300 U/kg
   B. Maintain ACT > 300-350 (>300?)
   C. Monitor with ACT
      1) (or direct Heparin concentrations)
   D. Redose to maintain therapeutic level
      1) 100 U/kg every 60 - 90 minutes (approx.)
      2) Use dose-response curve
   E. Protamine for heparin reversal
      1) Estimate heparin present (dose response curve)
      2) Give 1.1 - 1.5 mg protamine : 100 U heparin
      3) Confirm reversal to baseline

HEMOSTASIS WITH CPB

10. Basic Considerations with Cardiopulmonary Bypass (CPB)
    A. Cardiopulmonary bypass leads to:
       1) Activation of clotting cascades
       2) Activation of fibrinolytic system
       3) Platelet activation and removal
       4) Kinin system activation
       5) Complement activation
    B. Results in hemostatic derangement
    C. Results in systemic inflammatory responses

11. Blood Conservation Options
    A. Cell saver recycling
    B. Hemoconcentration of excess CPB blood
    C. Reinfusion of shed blood from chest tubes
       1) (Consider time, volume, infection hazard)
    D. Prevention/reversal of bleeding diathesis
       1) Optimization of heparin/protamine use
       2) Autologous plasma, fresh whole blood
       3) Aprotinin (Trasylol)
       4) Epsilon-amino caproic acid (Amicar)
    E. Heparinized CPB circuits
1) More biocompatible, more thrombo resistant
D. Autologous blood donations (with erythropoietin)

HEMORRHAGE

12. Post-CPB
A. Consider
  1) Surgical bleeding
  2) Heparin excess
     a) Incomplete neutralization; reinfusion of anticoagulated blood; heparin rebound
  3) Clotting cascade procoagulant deficiency
  5) Platelet dysfunction or thrombocytopenia
  4) DIC, depleted fibrinogen (preop thrombolitics)
B. Exploration (< 3 - 5%)
  1) >500/h x 1 hr; >400/hr x 2 hrs; >300/hr x 3 hrs;
  2) >1000 total in 4 hrs; >1200 total in 5 hrs

THROMBOSIS

13. CABG Graft Patency
A. Vein patency rate = 75-90% at 1 year
B. Technique is important
  1) Avoid endothelial injury
C. Antiplatelet therapy
  1) ASA, before or within POD 1 to > 1 year
  2) Ticlopidine if allergic to ASA, or with coronary endarterectomy
  3) Persantine, likely adds nothing

14. Prosthetic Valves
A. Mechanical valves
  1) T-E rate = 2 - 4% per patient-year
  2) Coumadin, INR=2.5-3.5, any position
     a) (ACCP/NHLBI consensus opinion)
     b) Bleeding complication rate = 2-3% per patient-year
  3) Adding anti-platelet drug => decreased T-E, increased bleeding
     a) Reserved for T-E despite therapeutic coumadin
  3) Bioprosthetic valves
     a) T-E: greatest 6-12 wks post-op then 2% per patient-year
b) Coumadin, INR=2-3 x 3 months (Opt for AVR)
c) With large, LA, LA clot, prior CVA - extend x 3-12 mos
4) Valve thrombosis
a) Thrombolytics emerging as front-line therapy

15. CAD
A. Acute MI
1) Heparin => decreased LV thrombus/embolism
   a) Especially large (anterior) MI's, LV dysfunction
2) Coumadin - possibly beneficial
B. Unstable angina
1) Heparin + ASA

THROMBOSIS - DVT

16. General
A. Risk factors (Virchow's triad)
1) Stasis - immobility, surgery, CHF/atrial fibrillation, obesity
2) Hypercoagulable states, BCP's, malignancy
3) Vein injury
B. 48% incidence after CABG
C. Prophylaxis
1) Mechanical, SQ Heparin
2) (ASA, Persantine - ineffective)

17. Therapy
A. Distal DVT - low risk for pulmonary embolism
B. Proximal DVT - Anticoagulate
1) Heparin => Warfarin (INR 2-3) x 3-6 mos
2) IVC filter if anticoagulation contraindicated or ineffective
18. Incidence
A. 630,000/year with 200,000 deaths/year
B. Origin
1) DVT (above calf), tumor, foreign body
C. Pathophysiology
1) Combination of mechanical and reflex effects
2) Cardiodynamic effects, cyanosis, pulmonary vasoconstriction
D. Pathologic sequelae
1) Most resolve spontaneously
2) May lead to pulmonary infarction

19. Diagnosis of Pulmonary Embolism
A. Clinical
1) SOB, tachycardia, increased P2
2) Classic hemoptysis, pleural rub, S3/4, cyanosis - 1/4 of patients
3) Signs & symptoms of DVT - 1/3 of patients
B. Examinations
1) CxR: normal +/- decreased vascularity (Westermark’s sign)
2) ECG: dysrhythmia, ST depression, T-inversion (III,AVF,V1,V4-5)
3) V:Q scanning
4) Pulmonary arteriography

20. Management
A. Anticoagulation
1) Heparin x 8-10 days (until DVT adherent)
2) Coumadin x 6 weeks-6 months
B. Thrombolytic therapy
C. Percutaneous extraction
D. Surgical management
1) IVC Interruption
a) Anticoag contraindicated, recurrent pulmonary emboli on anticoagulation, multiple small pulmonary emboli, pulmonary hypertension, after pulmonary embolectomy
E. Pulmonary embolectomy
1) Indications: persistent hypotension, hypoxia despite medical Rx
PULMONARY EMBOLECTOMY

21. Indication for operation
A. Hypotension, hypoxia, despite medical therapy (O2, anticoagulation, inotropes)
B. Operation
1) Median sternotomy, cardiopulmonary bypass, bicaval cannulation, pulmonary artery exploration, lung compression
C. Results
1) 25% mortality (major cause - cardiac complications)

EXTENDED OUTLINE

Hemorrhagic and Thrombotic Complications of Cardiac Surgery

1. History
A. 1953 - Gibbon - first use of CPB for open heart surgery in a human - screen oxygenator
B. Early screen, bubble, and disc oxygenators were traumatic to blood à frequent bleeding diatheses

2. Pre-op hemostatic disorders
A. Personal/family history and PE are most important tools for identifying a bleeding diathesis
B. Hereditary bleeding disorders
1) Hemophilia
   a) X-linked recessive
   b) A = Factor VIII deficiency - tx= factor VIII concentrates
   c) B = Factor IX deficiency - tx=prothrombin complex or FIX
   d) Factor XI - less common
   e) aPTT prolonged, PT, platelet (plt) fxn, bleeding time (BT) are normal
2) von Willebrand’s Disease
   a) Most common inherited bleeding disorder
   b) von Willebrand’s factor stabilizes FVII essential for plt fxn
   c) Mucocutaneous bleeding and bruising
   d) Prolonged bleeding time, impaired plt aggregation to ristocetin
   e) Frequently a prolonged aPTT
3) Treatment
   a) A (FVIII deficiency )-FVIII concentrates
b) B (FIX deficiency) - prothrombin complex or FIX
c) Emergency - FFP or cryoprecipitate (for FVIII or vWf deficiency)
4) “Acquired hemophilia” - autoantibodies to FVIII
C. Acquired bleeding disorders
1) Plt dysfunction 2° to abnormal heart valves or assist devices
   a) BT helpful
   b) Plt transfusions will only be transiently helpful
   c) Plt transfusion after discontinuation of CPB
2) Congenital cyanotic ht dz
   a) Impaired plt aggregation in 14% in acyanotic CHD, 38% cyanotic
   b) More profound with hypoxemia and hemoconcentration
   c) Hepatic synthesis of clotting factors may be impaired
   d) Phlebotomy and hemodilution to Hct 50-60% improves plt number and fxn
3) Drugs
   a) Most common cause of impaired hemostasis in cardiac surgery
   b) Anticoagulants
      (1) Coumadin - hold for 1-2d pre-op, give Vit K or FFP
      (2) Heparin - response may vary after pre-op heparin
   c) Drugs that affect plts
      (1) ASA
         (a) Increases post-op blood loss
         (b) D/C 5-7days pre-op
         (c) Prolonged BT - correct w/8-12U plts
      d) Fibrinolytics
         (1) tPA, urokinase, streptokinase
         (2) Can reduce fibrinogen levels below safe (100mg/dl)
         (3) FDP's interfere w/plt fxn
         (4) Heparin can compound the effect
4) Renal, hepatic failure and disseminated intravascular coagulopathy (DIC)
   a) Uremia
      (1) Defect in plt fxn due to plasma factors and anemia
      (2) vWf-plt interactions impaired
      (3) Plt transfusions ineffective due to uremic plasma
      (4) Tx= correct anemia, dialysis, cryo (for vWf), DDAVP
   b) Hepatic insufficiency
      (1) Impaired synthesis of clotting factors (esp. vit K dependent - II,VII,IX,X)
      (2) Tx= vit K if PT prolonged, plts if thrombocytopenic
3. Effects of cardiopulmonary bypass on hemostasis

A. Initial events of blood-surface interactions

1) Adsorption of fibrinogen and other plasma proteins to foreign surface is initial event
2) Contact activation of factor XII (intrinsic pathway)
3) Platelet adherence, release of cytoplasmic granules, thromboxane A-2
4) Contact activation initiates complement cascade and kallikrein/kinin system
5) Decreased velocity from hemodilution may β damage to formed elements in blood, β net blood loss, improve capillary perfusion
6) Frothing, high shear rates, and turbulence in pump damage formed elements àhemolysis, plt activation
7) Bubble oxygenator (blood-gas) contributes significantly to impaired hemostasis after 2-3 h. total bypass time
8) Intracardiac suction, “pump sucker”

B. Dynamics of plasma coagulation during CPB

1) Significant amounts of plasma proteins are not lost in extracorporeal circuit
2) Though diluted (£50%), clotting factor levels remain adequate
3) Prolonged clotting times post-op correlate poorly w/bleeding
4) Fibrinolysis
   a) ?? responsible for derangements of clotting tests early post-op
   b) Activated plasmin degrades fibrin and fibrinogen
   c) FDP’s act as anticoagulants
   d) Aprotinin (see below)

C. Platelet dynamics during CPB

1) Number
   a) ~ to 40-50% baseline in 1st 10-15 min, then stabilizes
      (1) “Passivation” of foreign surfaces after initial exposure
      (2) Reduced plt adhesiveness
   b) Rarely < 75,000/mL
   c) Plt ct returns to normal 3-5d post-op (?
      sequestration in liver)
   d) Microembolus formation contributes to platelet consumption

2) Function - substantially altered
   a) Plasma levels of Tx A2, plt-specific proteins rise at onset of CPB
   b) Plt stores of ADP & ATP depleted
   c) Fxn returns to normal 3-5d post-op
   d) Clot retraction impaired by heparin
      (1) High concentrations of heparin impair vWf-platelet binding
      (2) Reduction in clot retraction correlates w/post-op bleeding
e) Hypothermia, plasmin, other proteases  
f) Neutrophil activation by surface glycoprotein (GMP-140 or P-selectin)  
g) Attempts to inhibit plt activation during CPB (ASA, dextran) à excessive hemorrhage

4. Conduct of cardiopulmonary bypass  
A. Heparin  
1) Heterogenous family of glycosaminoglycans, not protein (6,000-20,000 dalton)  
2) Accelerates by 2,500-fold the neutralization of thrombin by antithrombin III (ATIII)  
3) Affects factors IX, X, XI, XII, activation of heparin Cofactor II, inhibition of smooth muscle proliferation, cytoprotective  
4) Source of heparin (porcine gut mucosa or bovine lung) has little effect on anticoagulation, but long-term bovine lung heparin more frequently associated w/HIT  
5) Platelet factor 4 is an anti-heparin compound  
6) Monitoring  
a) ACT or equivalent whole-blood clotting time at least q1h - maintain 300-350 sec  
7) Heparin rebound - coagulopathy and increased clotting times  
a) Pathogenesis not understood - ?protein-bound heparin unavailable to protamine  
b) Tx=protamine  
c) FFP will not reverse effects of residual heparin  
B. Protamine- the sole effective heparin antidote  
1) Small, highly positively charged protein, binds heparin  
2) Derived from fish sperm  
3) 1mg protamine /100U heparin (0.6-0.7 per Dr. Hurst)  
4) Toxicity  
a) Excess can have anticoagulant effect - overrated  
b) Myocardial depression  
c) Vasodilitation  
5) Heparin-protamine complexes - mediators of inflammation and anaphylaxis - granulocytopenia, pulm sequestration of leukocytes, vasodilitation  
6) Allergic reaction (rare) - pulm edema, hypoxia, hypotension more common in DM exposed to NPH

5. Perioperative adjuncts to hemostasis and blood conservation  
A. Intra-op (topical agents)  
1) Bovine thrombin - platelet activation and direct fibrinogen clotting-neutral pH
2) Oxidized cellulose (Surgicell) - contact activation of coagulation cascade - surface for fibrin polymerization
3) Microcrystalline bovine collagen (Avitene, Instat) - plt activation and adhesion
4) Hemostatic glues
   a) Cyanoacrylate
   b) Fibrin glue = cryo (for fibrinogen) + bovine thrombin

B. Autotransfusion
1) Pre-op phlebotomy and reinfusion post-bypass
2) Cellsaver - washes red cells (no plt or clotting factors)
3) Shed mediastinal blood - no study has shown reduction in use of banked, homologous blood

C. DDAVP
1) Vasopressin analog
2) Transiently increases vWF and FVIII
3) Probably only useful w/ impaired vWF-dependent hemostasis (low vWF, drugs, plt receptor)

D. Aprotinin
1) Protease inhibitor from bovine lung
2) Inhibits kallikrein activity, and in turn, contact activation of coag cascade
3) Inhibits conversion of plasminogen to plasmin
4) Secondar preservation of plt fxn
5) Most effective in preventing initial contact activation of blood and plt

6. Evaluation of post-op bleeding
A. <3% require early re-exploration
B. 1-3 u PRBC in uncomplicated cases
C. How much is acceptable? - author >100ml/hr for several hours; see chart from Kirklin

D. Transfusion: indications and risks
1) Hct 24%, Hb 8g/dl may be acceptable - individualize
2) Hepatitis in 7% (mostly hepatitis C)
3) HIV - 0.25% of donor pool is HTLV-III antibody +

E. Differential diagnosis of excessive bleeding
1) Plt ct, PT, PTT in all pts post-op
2) Heparin excess, integrity of coagulation cascade, plt

F. Excess anticoagulants
1) Heparin or FDP
2) Protamine trial - aPTT or ACT will normalize if heparin-related
3) Thrombin time +/- protamine - protamine will not correct FDP-related coagulopathy

G. Thrombocytopenia and plt dysfunction
1) Plt ct <75,000 + bleeding - tx w/8-12U plts
2) Normal plt count, normal coags + bleeding - DDAVP, plts
3) Bleeding time inaccurate post-op

H. Pathologic fibrinolysis
1) All clotting times abnormal, thrombocytopenia, hypofibrinogenemia - tx = transfusions + antifibrinolytics (amicar, aprotinin)
2) Cryoprecipitate (supra normal fibrinogen, vWF, FVIII concentrations) - for fibrinogen <100mg/dL

I. Massive transfusion
1) Plasma protein dilution (1-1.5 blood volume transfusion)
2) Thrombocytopenia most frequent derangement

7. Special hemostatic challenges

A. Jehovah's Witnesses
1) Tx pre-op w/vitamins, iron, erythropoietin
2) 7% mortality

B. Heparin-induced thrombocytopenia (5% receiving continuous heparin)
1) Autoantibody to heparin-plt factor 4 complexes
2) Thrombocytopenia (<100,000) resolves within days of heparin withdrawl
3) Dx by plt aggregate testing
4) Strategy: elective - in vitro testing and postpone surgery - ab’s go away
5) Heparin-like substances, LMW heparin have high cross-reactivity
6) Org 10172 - rarely induces aggregation
7) Post-op - D/C all heparin

8. Future trends

A. Specific indications for DDAVP, aprotinin
B. Novel heparins - chemically modified
1) Hirudin - family of direct thrombin inhibitors
C. Anti-plt drugs
1) Ab’s to glycoprotein Iib/IIIa
2) Synthetic peptides mimic fibrinogen
9. Thromboembolic complications of prosthetic valves

A. INR
1) DVT - 2.0-3.0
2) Prosthetic valves - 2.5-3.5

B. Mechanical valves
1) Thromboembolic rate
   a) 0.5-3%/PT-yr - overall
   b) MVR = 1-3
   c) AVR = 0.5-2
2) Addition of an antiplatelet agent further reduces risk (ASA 160mgQD or dipyridamole 400mgQD)
3) Bleeding complications 0.7-6.3%/pt-yr

C. Bioprosthetic valves
1) Thromboembolism - 2%/pt-yr
2) More common in first 6-12 wks after operation
3) Recommendation - INR 2.0-3.0 for 3 months
4) Benefit from long-term ASA

D. Complicating
1) Child-bearing
   a) Warfarin is teratogenic, crosses placenta - bad for fetus
   b) Self-administration of SC heparin to PTT 1.5-2 x control
   c) Antiplt tx alone?
2) Vascular and prosthetic grafts
   a) SVG - 75-90% 1-yr patency
   b) ASA + dipyridamole helps - ASA early post-op, dipyridamole pre-op
   c) ASA alone may be effective
Chapter 8 - Myocardial Protection and Cardiopulmonary Bypass

1. Myocardial Perfusion
A. Normally, subendocardial flow exceeds subepicardial flow
B. Myocardial perfusion, however, is altered by cardiopulmonary bypass
C. Narrow pulse pressure and variable mean pressure affects coronary perfusion pressure
D. Wall tension is increased in the empty, smaller heart
E. Ventricular fibrillation also increases wall tension
F. Regulatory and inflammatory factors are released which affect coronary resistance
G. Microemboli from the circuit and hemodilution impair oxygen delivery
H. Endothelial and myocardial edema further affect perfusion
I. Subendothelial vulnerability is increased by hypertrophy, coronary disease, fibrillation, cyanosis, shock, and chronic heart failure
J. The acutely ischemic heart may have poor reflow to the injured area

2. Myocardial Ischemic Injury
A. Acute ischemic dysfunction
   1) Global myocardial ischemia
   2) Reversible contractile failure, mostly from change in perfusion pressure
   3) Immediate recovery as oxygen supply is restored
B. Stunning
   1) Reversible systolic and diastolic dysfunction, no myocardial necrosis
   2) Begins in subendothelium and progresses outward
   3) May be accompanied by endothelial dysfunction
   4) Results from ischemia-reperfusion insult, mediated by increased intracellular calcium accumulation
   5) Recovery occurs within hours to weeks
C. Hibernation
   1) Reversible chronic contractile depression
   2) Related to poor myocardial blood flow
   3) Recovery occurs within weeks to months
D. Necrosis
1) Irreversible ischemic injury with myocardial necrosis
2) Hypercontracture occurs first in the subendothelium and is more rapid in the hypertrophied heart
3) Typically results in contraction band necrosis, rarely "stone heart"
4) Osmotic and ionic dysregulation produce membrane injury and myocyte lysis

3. Cardioplegia
A. Studies in animals have inconsistent correlation with clinical results due to species differences, extent of disease, and perioperative events that precipitate, extend, or enhance myocardial damage
B. The goals of cardioplegia are to protect against ischemic injury, provide a motionless and bloodless field, and allow for effective post-ischemic myocardial resuscitation
C. Cardioplegic techniques vary according to perfusate (blood vs. crystalloid), duration (continuous vs. intermittent), route (antegrade vs. retrograde), temperature (warm vs. cold), and additives
D. Special considererion is required for the acutely ischemic heart and the neonate

4. Mechanisms of Cardioplegic Protection
A. Mechanical arrest (potassium-induced) will reduce oxygen consumption by 80%
B. Hypothermia will reduce consumption by another 10-15%
C. Aerobic metabolism can be maintained with oxygenated cardioplegia
D. Hypothermic arrest is sustained with readministration every 15-30 minutes
E. Retrograde delivery protects the left ventricle more completely than the right ventricle
F. Prevent myocardial rewarming with systemic hypothermia, aortic and ventricular vents, and caval occlusion
G. In acute ischemia, use warm induction with substrate enhancement (glutamate, aspartate)
H. Reperfusion should be controlled, using warm, hypocalcemic alkaline cardioplegia
I. This approach combats intracellular acidosis and rapid calcium infusion injury
J. Retrograde or low-pressure antegrade perfusion is preferred for reperfusion
K. Ensure uniform warming

5. Neonates and Children
A. Children older than 2 months have similar myocardial physiology to adults
B. The neonatal myocardium, however, is different in several ways
C. Hypoxia is more easily tolerated
D. There are greater glycogen stores and more amino acid utilization
E. ATP breakdown is slower due to deficiency in 5' nucleotidase
F. Multidose cardioplegia is disadvantageous
G. Cyanosis may worsen resistance to ischemia
H. Amino acid substrate enhancement is beneficial

6. Cardioplegia Composition
A. Blood has the advantage of oxygen carrying capacity, histidine and hemoglobin buffers, free radical scavengers in RBCs, and metabolic substrates
B. Blood also has improved rheologic and oncotic properties, which may lessen myocardia edema
C. Buffers such as THAM, histidine, and NaHCO3 form a slightly alkaline solution for reperfusion that can counteract intracellular acidosis
D. Small amounts of calcium (0.1-0.5 mM/L) restores calcium that has been chelated by citrate
E. Potassium concentrations range from 10-25 mM/L, with the first dose being the highest
F. Other substrates are being evaluated, including allopurinal, SOD, deferoxamine, adenosine, nucleoside transport inhibitors, and potassium-channel openers

CARDIOPULMONARY BYPASS

1. The Circulatory Environment
A. Cardiopulmonary bypass is an abnormal circulatory state
B. Non-pulsatile flow, hemolysis, hemodilution, foreign surface exposure, general stress response, and the inflammatory response all contribute
C. Mechanical components
1) Roller pumps are slightly non-occlusive, resistance-independent, and may cause less blood trauma
2) Centrifugal pumps are dependent on inflow or outflow resistance; will cease flow at very low inflow resistance and very high outflow resistance
3) Venous drainage can be active or siphoned
4) Active drainage requires vacuum through the venous reservoir or negative pressure from the pump
B. Heat exchanger
1) The cooling or warming gradient is usually within 10-14 degrees of the patient’s temperature
2) This minimizes the tendency for gas to come out of solution and risk of air embolism
3) Mixed blood temperature should be less than or equal to 38.5°C
4) The water bath should stay between 15 and 42°C to prevent organ damage (too cold) and hemolysis (too warm)

C. Oxygenator
1) Largest foreign surface contact area
2) Membrane oxygenators can be microporous, hollow fiber, or silastic (true membrane)
3) Gas flow is titrated to maintain PaO2 between 85 and 250mmHg to avoid O2 toxicity
4) PCO2 is regulated by gas and blood flow through the membrane
5) pH is controlled by adjusting the PaCO2
6) alpha stat adjusts the pH to 37°C, with the goal of providing optimal enzymatic function during hypothermia
7) pH stat corrects the pH to the temperature of the patient’s blood, with the goal of relative hypercarbia to increase cerebral blood flow

2. Mechanisms of Injury

A. Mechanical
1) The foreign surfaces of the bypass circuit (boundary layer of oxygenator, heat exchanger, filters, tubing) interact with the blood
2) Shear stresses include the pump, cardiotomy suction, and cannulae
3) Microemboli can form as particles from the oxygenator, platelet aggregate, or fibrin aggregates, and are greatest within the first 15 minutes of bypass

B. Humoral
1) Factor XII (Hageman factor), the alternative complement cascade (C3a), kallikrein, and plasminogen are activated in various degrees
2) Other factors interrelate and amplify the inflammatory reaction, including the arachidonic acid cascade, interleukins, TNF, and PAF

C. Cellular
1) Neutrophils play a major role in humoral activation and are sequestered in the lung, releasing cytotoxin and free radicals which increase vasoreactivity and vascular permeability
2) Monocytes and mast cells also participate, although their role is unclear
3) Lymphocytes have a minor role, if any
4) Platelets are activated and elaborate GPIB, IIB, and IIIA
5) Absolute number of platelets is reduced by 40% by the end of bypass, and the number of receptors is also decreased
6) Endothelial cells are affected by abnormal flow, humoral factors, and local ischemia
7) A wide variety of substances are expressed by the endothelium, including prostaglandins, thromboxanes, leukotrienes, and interleukins

3. Miscellaneous
A. Circulatory arrest with profound hypothermia (18-20°C) is generally safe up to 45 minutes
B. Over 60 minutes is associated with increased incidence of neurologic deficit
C. The period between 45 and 60 minutes is unclear, as histologic injury seems to be greater than functional injury
D. Maintain a gradient of 4-6°C, as rapid cooling produces uneven cerebral cooling
E. Retrograde and low flow cerebral perfusion are currently being evaluated
F. Pulsatile flow has not been shown to be superior to non-pulsatile flow
G. Lower ACT of 300-350 seconds is not associated with greater complications compared to standard ACT of 450
H. Aprotinin will elevate the ACT (600-800), neutralizes the kallikrein cascade, and protects platelet receptors
I. Protamine reactions occur through the classical component pathway and cause direct myocardial depression
Chapter 9 - Cardiac Arrhythmia - Bradycardia

1. Heart Block Definition
   A. First Degree - PR interval > 0.2 seconds
   B. Second Degree - Intermittent AV conduction
   C. Third Degree - Atrial impulses do not conduct

2. Bradycardia
   Heart Rate < 60 beats/min:
   A. Asymptomatic
      1) Athletic conditioning
      2) Sinus bradycardia
   B. Symptomatic
      1) Inadequate cardiac blood flow
      2) Loss of atrial augmentation
      3) Dizziness, syncope (inadequate cerebral blood flow)

3. Heart Block - Complete
   A. Causes
      1) Congenital - often asymptomatic
      2) Valvular calcification - Aortic, Mitral
      3) Myocardial infarction - inferior, anterior septal
      4) Surgical - VSD repair, subvalvular stenosis resection, valve replacement (IHSS)

4. Sinus Node Dysfunction
   Amyloid deposition
   A. Surgical damage
      1) Fontan repair, atrial switch, Maze II, superior approach for Mitral valve repair
   B. Sick sinus syndrome
      1) Tachycardia, bradycardia
      2) Diagnosis by prolonged ambulatory ECG

5. Carotid Sinus Syndrome
   A. Cardio-inhibitory - Carotid sinus stimulation
      1) 3 second or greater pauses
      2) Pacemaker appropriate
   B. Vasodepressor - Carotid sinus depression with Atropine
1) BP drops without slowing
2) pacemaker may not help symptoms

6. Indications
A. Symptomatic bradycardia
1) Syncope, dizziness, exercise intolerance, CHF
B. Asymptomatic bradycardia
1) profound bradycardia, usually brief
2) congenital third degree heart block with wide QRS complex
3) BBB?? with intermittent second degree heart block post-MI
4) bifascicular block with intermittent second degree heart block
5) IHSS

<table>
<thead>
<tr>
<th>Chamber Paced</th>
<th>Chamber Sensed</th>
<th>Response to Sensing</th>
<th>Programmable Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>V- Ventricle</td>
<td>V- Ventricle</td>
<td>T- Trigger pacing</td>
<td>P- Simple programmable</td>
</tr>
<tr>
<td>A- Artium</td>
<td>A- Atrium</td>
<td>I- Inhibits pacing</td>
<td>M- Multi-programmable</td>
</tr>
<tr>
<td>D- Dual (A&amp;V)</td>
<td>D- Dual (A&amp;V)</td>
<td>D- Dual (T&amp;I)</td>
<td>C- Telemetry</td>
</tr>
<tr>
<td>O- None</td>
<td>O- None</td>
<td>O- None</td>
<td>R- Rate responsive</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>O- None</td>
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</table>
7. Lead placing
A. Atrial
1) Threshold
2) Pacing
3) Sensing ≥ 2 mVolt
B. Ventricular
1) Threshold
2) Pacing
3) Sensing ≥ 5 mVolts
4) Slow rate ≥ 0.8 mVolts/sec.
Chapter 10 - Cardiac Arrhythmia-Tachycardia

1. Supraventricular Tachycardia
   A. Atrioventricular (AV) nodal re-entrant tachycardia
      1) Most common cause of paroxysmal tachycardia
   B. Wolff-Parkinson-White Syndrome (WPW)
   C. Accessory atrioventricular (AV) conduction pathways (Kent bundles)
   D. Atrial flutter
   E. Atrial fibrillation
   F. Ectopic atrial tachycardia

2. WPW characteristics
   A. short PR interval wide QRS- delta wave accessory pathway
   B. Free wall Left Atrium- Type A
   C. Right Atrium: anterior superior- Type B Tricuspid
   D. annulus: anterior ventricular septum- Tricuspid or Mitral
   E. posterior ventricular septum
      Reciprocating tachycardia
   F. AV conduction- anterograde
   G. Accessory bypass- retrograde
      Atrial fibrillation
   H. Life-threatening
   I. Rapid conduction via accessory pathway

3. WPW Treatment
   A. Surgical ablation- historical significance
   B. Catheter ablation- successful in 80-99% of patients
      ‘C. Drug treatment- often dangerous

4. Atrioventricular nodal re-entrant
   A. Successfully treated with catheter ablation
      1) Ectopic atrial tachycardia
         a) Often multiple ectopic foci
         b) Treated with catheter ablation
5. Atrial flutter- fibrillation
A. Mechanism
1) Multiple macro re-entrant circuits
2) Atrial refractory period
3) Structural, fibrosis, SVC, IVC, ASD
B. Effects
1) Irregular heart beats
2) Loss of AV synchrony
3) Risk of thromboembolism
4) Normal Atrial Activation

5) Atrial Flutter
6) **LA Isolation Procedure**

6. **Treatment- Pharmagologic**

A. Rate Control
1) Digitalis, Beta-blockers, calcium channel blockers
2) Prevention
3) IA- Quinidine, procainamide, disopyramide,
4) IC- Flecanide, propafenone
5) III- Solatol, amiodarone
7. Antiarrhythmic Drugs

<table>
<thead>
<tr>
<th>Class</th>
<th>Action</th>
<th>ECG</th>
<th>Drugs</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Membrane Stabilizers</td>
<td>Sodium ion inhibition</td>
<td></td>
<td>Quinidine, Procainamide, Disopyramide</td>
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<tr>
<td>IA</td>
<td>reduction in upstroke velocity; prolongs repolarization</td>
<td>QRS lengthen, QT lengthen</td>
<td></td>
</tr>
<tr>
<td>IB</td>
<td>No change in upstroke velocity or repolarization</td>
<td>None</td>
<td>Lignocaine, Mexitilene</td>
</tr>
<tr>
<td>IC</td>
<td>Reduction in upstroke velocity; no change in upstroke velocity</td>
<td>QRS widen</td>
<td>Encainide, Flecainide, Propafenone</td>
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<tr>
<td>II Beta blockers</td>
<td>Block catacholamine action</td>
<td>Bradycardia, PR increase, QT decrease</td>
<td>Propranolol, Acebutolol, Atenolol</td>
</tr>
<tr>
<td>III Anti-arrhythmics</td>
<td>Block potassium efflux; prolong repolarization</td>
<td>QT increase</td>
<td>Amiodarone, Sotalol</td>
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<tr>
<td>IV Ca-Channel blockers</td>
<td>Blocks calcium channels</td>
<td>PR increase</td>
<td>Verapamil, Diltiazem</td>
</tr>
</tbody>
</table>

8. Treatment - Surgical
A. His bundle ablation
1) Pacemaker insertion (controls rate only)
B. "Corridor" procedure
1) Controls rate only
C. "Maze" procedure
1) Controls rate
2) Preserves AV synchrony
3) Reduces risk of thromboembolism

D. **Atrial Fibrillation**

E. **Catheter Ablation of HIS**
F. Corridor Procedure

G. Maze Procedure
9. Atrial Fibrillation Incidence

Incidence of Atrial Fibrillation

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>LVAD</th>
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<tr>
<td>25-35</td>
<td>2-3</td>
</tr>
<tr>
<td>55-64</td>
<td>30-40</td>
</tr>
</tbody>
</table>

Overall incidence = 0.4% of population

Approximately 1.5 million people in U.S

Ventricular Tachycardia

10. Etiology
A. Idiopathic
B. Non-ischemic Cardiomyopathy
C. RV Dysplasia
D. UHL’s Syndrome (Parchment Heart)
E. Long QT syndrome
F. Ischemic Ventricular Tachycardia

12. I. Idiopathic
A. Usually normal ventricles although occasionally dilated

13. II. Non-ischemic Cardiomyopathy
A. Diffuse dilatation or both ventricles
B. patchy fibrosis

14. III. Arrhythmogenic RV Dysplasia
A. Congenital cardiomyopathy
B. Surgical Rx- RV free wall isolation

15. IV. UHL’s Syndrome (Parchment heart)
A. No myocardial layer

16. V. Long QT syndrome
A. Criteria
1) Congenital deafness
2) Long QT
3) Syncopal episode- VF
4) Abnormal Repolarization
5) Torsades de pointes
6) Aggravated by Quinidine

17. Ischemic Ventricular Tachycardia
   A. Periphery of scar
   1) Endocardium and Subendocardium
   2) Re-entrant problem
   3) Non-uniform repolarization
   4) Surgical Treatment
   5) Mapping and endocardial resection
   6) Endocardial cryoablation
   7) Aneurysm repair
   8) AICD

Extended Outline
Surgery for Supraventricular Arrhythmias

1. Introduction
   A. Radiofrequency (RF) ablation has replaced surgery as treatment of choice for certain re-entrant arrhythmias.
   1) Accessory pathways-- Wolff-Parkinson-White Syndrome
   2) AV nodal pathways from perinodal pathways
   3) Ectopic atrial tachycardias
   4) Certain Type I atrial flutte
   B. Surgery for RF ablation failures
   C. Maze procedure for chronic paroxysmal or sustained atrial fibrillation/flutter

2. Accessory atrioventricular connections
   A. Anatomy
   1) Divide heart into four "spaces" (LV free wall, RV free wall, posterior, anterior septal).
   2) RF ablation of right sided pathways from septum above TV, left sided from beneath MV annulus
   3) No accessory pathways exist between the left and right fibrous trigone- the only area in A-V groove where atrial muscle is not in contact with ventricular muscle
4) Majority of L-sided pathways are juxta-annular
5) Right sided pathways are more variable
6) Anterior and posterior septal pathways are variable-unsuccessful RF ablation is likely due to pathways disparate from the true annulus
7) Pathways can cross horizontal and vertical planes
B. Complications of RF catheter ablation (RFCA) (may impact surgical technique)
1) Scarring and fibrosing relate directly to the amount of energy delivered
2) Direct RF ablation to LA side of A-V groove has resulted in the destruction of planes, injury to Cx, CA and CS
3) Excessive energy to RA planes has resulted in destruction of planes
C. Surgical Treatment
1) Indications
a) Recurrent reciprocating tachycardia
b) Poorly controlled (refractory?) or toxic on medical treatment
c) failed RF ablation or require surgery for concomitant disease
d) Symptomatic, atrio-His, nodoventricular, fasciculoventricular fibers
2) Locating pathways
a) Locate preoperatively with EP studies and epicardial mapping
b) Activation sequence mapping on atrial and ventricular sides of A-V groove
c)Accessory pathways are located in: left free wall> posterior septal> right free wall> anterior septal
3) Surgical approach
a) Endocardial technique- divides ventricular end of accessory pathways
   (1) localize pathway to one of four areas
   (2) location in vertical plane may vary
   (3) endocardial dissection does nothing for atrial end of pathway
   (4) complete dissection of anatomical space (s) in every patient, regardless or localization
   (5) "Broad-Bands" may necessitate dissection in two anatomic areas
   (6) isolation of atrial rim of tissue required to retrograde conduction via juxta-annular pathway
b) Epicardial technique- divides atrial end of accessory pathways
4) Surgical Results
a) 100% success in correction of rhythm- no early or late recurrences
b) 0.5% operative mortality
c) Majority of RFCA failure secondary to anatomical abnormalities
d) Inappropriately aggressive RFCA may render patients surgically incurable due to tissue destruction in the A-V groove
3. **AV Nodal reentrant tachycardia**

   **A.** Dual A-V conduction pathways, one fast, one slow through AV node or perinodal tissues

   **B.** Anatomy

   1) Triangle of Koch
      a) Tendon of Todaro superiorly
      b) Tricuspid annulus inferiorly
      c) Coronary sinus posteriorly
      d) Apex in central fibrous body and atrial portion of membranous septum

   2) Exact position of AV node in triangle may be variable

   **C.** Surgical treatment

   1) Surgery for failure of RFCA or concomitant disease
   2) Monitor A-V conduction time during application of cryolesions
   3) Apply lesions to boundaries of Triangle of Koch
   4) Impending heart block signaled by an A-V interval of 200-300ms-"reversible knife"
   5) A-V nodal reentrant tachycardia and accessory A-V connections should undergo treatment together
   6) Nodoventricular and nodo-His corrections can be concurrently performed

   **D.** Surgical Results

   1) Only a single pathway remains
   2) No early or late recurrence
   3) Dissection of tissue anterior or posterior to A-V node has resulted in A-V block plus late recurrence

4. **Ectopic or automatic atrial tachycardias**

   **A.** More common on right than left, may be multifocal

   **B.** Surgical treatment

   1) Preoperative localization necessary
      a) GA may suppress ectopic focus
      b) Intraoperative mapping without sophisticated computerized system is difficult
      c) Ectopic tachyarrhythmias not inducible by standard programmed stimulation techniques

   2) Options
      a) Cryoablation
      b) Wide excision with pericardial patch
      c) Ablation and pericardial patch
      d) Isolation
3) Left atrial focus isolation (left atrium remains tachycardic)
   a) Option is to ablate His bundle, place pacemaker
4) Right atrial foci if circuit or focus cannot be localized
   a) Option is to isolate

C. Surgical Results
1) No recurrence
2) No sequelae

5. Atrial flutter and fibrillation
   A. Anatomy and electrophysiology
      1) 4-6 wandering, independent "wavelets" with regional entrainment
      2) Atrial reentrant circuits can become stable at short (<95ms) refractory periods
      3) Critical mass, volume, or area of atrial tissue is required to maintain fibrillation
   B. Fibrillation/Flutter is a continuum (Cox)
      1) Single, macroreentrant Right sided circuit (flutter) to
      2) Multiple, simultaneous macroreentrant circuits over left and right atria
      3) Flutter dependent upon mechanical obstacles
      4) Fibrillation shows anatomic independence, with transient circuits-not amenable
         to ablation
   C. "Surgical Cure" or Atrial Fibrillation
      1) Elimination of clinical arrhythmia
      2) Maintenance of SA nodal tissue as driving impulse
      3) Maintenance of A-V conduction
      4) Restoration of atrial transport function
      5) Items 1-4 reduce the risk of thromboembolism
   D. Idiopathic Atrial Fibrillation (Maze procedure)
      1) Drug resistant, medically refractory, symptomatic idiopathic (non-Rheumatic)
         fibrillation
      2) Mean age = 56 y.o. , concomitant procedure in 28% or patients
      3) 40% require postoperative pacemakers- atrial chronotropic incompetence
      4) Atrial transport- 100% RA, 81% LA
      5) Local effective refractory period (ERP)- shorter in LA than RA
      6) RA more susceptible to reentrant atrial flutter
      7) LA more susceptible to reentrant atrial fibrillation
   E. Atrial fibrillation associated with degenerative mitral valve disease- indications
      for Maze procedure
      1) <70 years old
      2) Normal ventricular function
3) History of H/O embolic events secondary to more than one year of atrial fibrillation
4) Medically refractory and severely symptomatic
5) LA dimension >60 mm
6) Easily reparable valve
F. Maze procedure – indications for Rheumatic Mitral valve disease
1) Modifications usually involve LA (forms of LA isolation)

Surgery for Ventricular Tachyarrhythmias

1. Patient population at risk
A. Usually related to some form of cardiac disease
B. Patients most at risk for life-threatening arrhythmias are:
   1) Those sustaining sudden cardiac death without identified cardiac disease
   2) Those with known cardiac disease (including post-MI)
   3) Those with structural heart defects with known arrhythmogenic potential
      a) Long QT, arrhythmogenic dysplasia
C. Sudden cardiac death (350,000-400,000 per year)
   1) Often during mild-to-moderate exercise
   2) More than 30% of survivors are discharged without neurologic deficit
   3) 60% chance of recurrence within 2 years
   4) Increased risk of: proximal LAD stenosis, regional LV dysfunction, LV failure (CHF)
   5) Overall 50% 5 year survival vs. 80% for age matched cohorts
6) ~70% are not MI related
   a) Greater risk of recurrence
   b) 2/3 will have significant CAD
D. Ventricular tachycardia following MI results in 40-80% mortality
   1) Prior infarct with aneurysm yields an even greater risk
E. If CAD present, CABG better than anti-anginal treatment

2. Pathophysiology
A. Wide QRS >14 msec is diagnostic of Ventricular- tachycardia (nl=<80 msec)
B. Polymorphic (vs monomorphic)
   1) No constant morphology for > 5 complexes, or
   2) No clear isoelectric baseline, or
   3) QRS complexes asynchronous in multiple leads
   4) Frequently degenerates into VF
C. Sustained tachycardia- at least 15 seconds
D. Possible mechanisms:
1) Reentry
2) Normal/abnormal automaticity
3) Triggered activity due to after-depolarization

E. Action potential
1) Resting membrane potential (electrical diastole = -85 mV)
2) Electrical, mechanical or chemical signal reduces membrane potential
3) At threshold, cell will depolarize (phase 0), reversing polarity to +30 mV

F. Automaticity
1) Resting membrane potential (phase 4) is characteristically constant
2) Some specialized cells will automatically depolarize until they reach threshold, depolarize and initiate beat
3) Depolarization is usually most rapid in SA node, which dominates rhythm
4) Peri-MI tachycardias
   a) Associated with: hypoxemia, hypocalcemia, catecholamines, drugs (digitalis)
   b) Usually responsive to:
      (1) lidocaine, procainamide, Beta- blockade, discontinuing sympathomimetics
   c) Phase 4 dependent arrhythmias are not induced or terminated by EP testing and are rarely approached surgically
5) Triggered automaticity
   a) Arises during repolarization when late after-depolarizations reach threshold

G. Re-entrant arrhythmias
1) Two or more electrically heterogenous pathways of varying conduction or refractoriness
   a) Unilateral block
   b) Slow conduction over alternative route
   c) Delayed excitation just distal to blocked tissue
   d) Re-excitation of proximal tissue upon return of the impulse

H. Pathophysiologic substrate for ventricular arrhythmias
1) Chronic CAD (ischemia)
   a) Usually gives rise to reentrant arrhythmia
   b) Alters conduction and refractoriness
2) Acute infarction
   a) Peri-ischemic areas of abnormal, viable tissue
   b) Alters conduction and refractoriness
   c) Heterogeneous infarcts are more arrhythmogenic than homogenous infarcts

I. Effect of thrombolytic therapy on then arrhythmogenic substrate
1) Canine data would predict increased arrhythmias
2) Clinically, no significant increase in life-threatening arrhythmias

J. Programmed Electrical Stimulation (EPS)
   1) Rapid ventricular pacing
      a) Burst pacing at 250 bpm
      b) Single, double or triple stimulus to terminate arrhythmia
      c) Hemodynamic instability may require instability
   2) Premature ventricular stimuli
      a) Depolarization introduced in late stimuli, then earlier, until no ventricular response is elicited
      b) In no VT, double stimuli introduced 50-100ms after refractory period
      c) S1 (fixed), S2 (premature stimulus), S1-S2 interval reduced by 10ms
      d) When S2 no longer initiates ventricular response, S3 is initiated, S2-S3 interval then decreased
      e) Reentrant arrhythmia or refractoriness of S2, S3 occurs
      f) Multiple sites studied
      g) Ventricular tachycardia secondary to automaticity, not induced my EPS

3. Surgical Treatment
   A. Indirect techniques
      1) Myocardial revascularization
      2) Blind aneurysmectomy (non-directed, without electrophysiological mapping)
      3) 50% success, 25% mortality
   B. Encircling endocardial ventriculotomy (EEV)
      1) Endocardial incision which completely encircles fibrosis (‘twilight zone’ around infarct)
      2) Isolates arrhythmogenic substrate and reentrant circuit
      3) Higher mortality than endocardial resection (incision sparing only epicardial surface induces regional ischemia)
      4) Extremely limited application
   C. Electrophysiologically directed endocardial resection
      1) Intraoperative mapping on CPB, normothermic
      2) Endocardial resection
      3) Many modifications, each with similar success to endocardial resection
         a) Cryoablation
         b) Laser
         c) Sequential resection (normothermic)
      4) Cumulative 14.4% mortality
   D. Implantable Cardioverter Defibrillator (ICD)
1) Historical controls- 26% chance of 1-year sudden death
2) ICD implantation- 98-99% one year freedom from sudden cardiac death
3) Endocardial leads have replaced (almost all) epicardial patches

E. Results of non-pharmacological therapy
1) Subendocardial resection
   a) 17%- inducible, sustained monomorphic VT post-op
   b) 11%- required antiarrhythmic medication
2) ICD
   a) 1.5% 30-day mortality
   b) 70% 5-year survival

4. Treatment Strategies
   A. LVEF is most important determinant of outcome
   B. If EPS suggests an arrhythmogenic focus can be ablated- subendocardial resection
   C. Inferior LV wall- 41% failure of subendocardial resection (difficult area); therefore, consider ICD
   D. Non-ischemic VT- subendocardial resection not applicable
   E. Arrhythmogenic events >/= 2 weeks ICD not a good choice
   F. Drug requirements following procedure
      1) Endocardial resection-- 11%
      2) ICD- ~50%
   G. ICD- restricted lifestyle

Pacemaker Therapy for Cardiac Arrhythmias

1. Anatomic principles
   A. Mature conduction system
      1) Sinoatrial (SA) node: spindle-shaped bundle with hear extending toward intra-atrial groove, tail toward IVC
      2) Preferential conduction but not anatomic pathway from SA to atrioventricular (AV) node
         a) Atrial muscle tract in ant limbus of fossa ovalis, crista terminalis and continuation to atrial septum
      3) No gross anatomical landmarks for AV node and bundle of His- located within Triangle of Koch
         a) Tendon of Todaro superiorly
         b) Tricuspid annulus inferiorly
         c) Coronary sinus posteriorly
d) Apex in central fibrous body and atrial portion of membranous septum
e) AV node is usually far removed (anterioirly) from coronary sinus
f) AV node becomes a penetrating bundle at apex of triangle, passes into ventricular septum
g) Branching and non-branching bundles are sandwiched between muscular ventricular and membranous septum
h) Compact node, penetrating bundle and branching bundle form a continuous axis of cells running the length of the ventricular septum

4) Endocardial anatomy
a) Atrial leads are designed for placement in (pectinate muscle) atrial appendage
b) Ventricular leads- apex (trabeculae)

2. Electrophysiology of cardiac pacing
A. Myocardial cells can be depolarized by artificial electrical stimulation
B. Impulse initiation and propagation
   1) Resting potential (-90 mV in ventricular tissue, -50 mV in SA and AV nodal tissue
      a) Function of intracellular and extracellular K+
      b) At rest, Na and Ca channels are closed, small number of K channels open
      c) With depolarizing stimulus, Na channels open and K channels close
   2) Na-dependent (fast response) action potential (normal atrial and ventricular myocardial cells and conduction tissue outside SA and AV nodes)
      a) Phase 0- cell depolarized to +20 millivolts
      b) Phase 1- Na influx causes Ca and K channels to open (repolarization)
      c) Phase 2- inward Ca current and persistent outward K current cause plateau
      d) Phase 3- increased outward K flow and decreased inward Ca (and Na) flow repolarization
   3) Slow response action potential
      a) Na channels are voltage-inactivated, Ca channels carry inward current
      b) Action potential with slow rate of rise
      c) Can be seen in pathologic states
   4) Propagation of cardiac impulse
      a) Nexal junction provide low-resistance intercellular pathway
      b) Anistrophy- propagation along fibers is much faster than across fibers
      c) Automaticity- the ability to generate an action potential de novo
      d) Overdrive suppression
         (1) stimulation of a cell at a rate above its intrinsic rate
         (2) suppression of the cell's pacemaker ability results
(3) cells with lower (less negative) resting potentials and less Na entry during phase 0 have a lower degree of overdrive suppression—thus the SA node is the primary pacemaker.

C. Physics/Engineering
1) $V=IR$; where $V$ = voltage, $I$ = current (mAmps) and $R$ = resistance (Kohms)
2) $E=VIt$; where $E$ = energy (Joules), $t$ = time (pulsewidth PW in msec)
3) $E= (V)^2 \times PW/R$ [??is that $V$ squared or $x2$?]
4) The size of the distal tip is inversely proportional to the concentration of the electrical charge, and therefore the amount of energy required to capture myocardium.

D. Sensing intra-myocardial electrical activity
1) Circuitry includes: sensing amplifier, bandpass filter, threshold comparator
2) Factors affecting sensing
   a) Electrode size,
   b) Unipolar/ bipolar configuration
   c) Lead position

3. Current pacemaker technology
A. Permanent leads
1) Endocardial unipolar or bipolar
   a) Active fixation leads—more stable, higher pacing thresholds
   b) Passive fixation leads—lower chronic pacing leads
2) Epicardial—historically poorer performance

B. Pulse generator

4. Clinical cardiac pacing
A. Terminology
1) Blanking period—turning off of sensor to avoid saturation by an anticipated high-voltage signal
2) Refractory periods—incorporated into pacing cycle to avoid resetting pacer in response to an appropriate signal (e.g. T-wave being interpreted as R-wave)
3) Lower rate interval—longest interval between consecutive ventricular paced events
4) A-V interval
5) Atrial escape interval—interval from ventricular pacing stimulus (or sensed beat) following atrial stimulus

B. Modes
1) VOO- risk of ventricular arrhythmia due to pacing on T-wave of intrinsic depolarization
2) VVI- lose of A-V synchrony
3) AAI- infrequently used, for chronotropic support normal AV conduction
4) DVI
   a) Committed- delivers ventricular pacing stimulus at A-V interval regardless of sensed ventricular event
   b) Noncommitted- inhibits ventricular output if ventricular activity is sensed
5) DDD- incorporates AAI, DVI and VDD modes

C. Rate responsiveness
1) Patient- improved sense of well being at rest, less tendency to develop CHF

D. Acute electrophysiologic testing of leads
1) Pacing threshold energy requirement
2) Atrial and ventricular electrogram amplitudes
3) Slew rates (if necessary)
4) P, R wave amplitude
5) Lead resistence
6) Current at the threshold level for capture of chamber paced
7) Threshold will increase in first 2-3 weeks then decrease to 2-3x initial measured level

5. Complications

A. Implantation
1) Venous access
2) Wire trauma
3) Generator

B. Post-surgical
1) Late perforation
2) Venous thrombosis
3) Loss of capture in a lead
   a) Lead fracture- high impedence
   b) Insulation break- low impedence
   c) Exit block- fibrosis around electrode inhibits conduction
4) Pacemaker mediated tachycardia- macroreentrant circuit
5) Infection- treat with generator/ lead removal
Chapter 11 - Cardiac Anesthesia

1. Anesthetic Agents for Adult Cardiac Surgery
   A. Narcotic Based: Fentanyl and Sufentanil (8 x more potent)
   B. Hemodynamic stability without myocardial depression
   C. Typical total dose during cardiac procedure
      1) Fentanyl: 10-100 mcg/kd
      2) Sufentanil: 8-15 mcg/kg
      3) Remifentanil: 1-3 mcg/kg/min
   D. Muscle Relaxation: Choice depends on desired heart rate response
   E. Pavulon: Increases heart rate- may be useful in balancing the vagolytic effect of narcotics
   F. Vercurium: No effect on heart rate of blood pressure-
      1) Other new long-acting relaxants are similar to Vercurium

2. Induction and Maintenance of Anesthesia (Adult)
   A. Induction
   B. Narcotic
      1) Remifentanil 1-2 mcg/kg
      2) Fentanyl 5-35 mcg/kg or Sufentanil 1-8 mcg/kg plus
      3) Sedative-Hypnotic
      4) Pentothal
      5) Etomidate
      6) Valium or Versed
      7) Propofol
   C. Maintenance
   D. Narcotic PLUS
   E. Propofol, Benzodiazepine, or low dose inhalation drug (Ethrane, Forane, Deslurane, Halothane, Sevoflurane)
3. Pediatric Anesthetic Agents
A. Induction is usually not intravenous
B. Induction
1) Ketamine 5 mg/kg intramuscular
2) Inhalation using Halothane or Sevoflurane
3) "Halothane sensitizes myocardium to arrhythmogenic influence of
catecholamines"
C. IV established after induction
D. Maintenance
1) Narcotic PLUS
2) Hypnotic or Inhalation

4. Anesthetic Management of Ischemic Heart Disease
A. Goal: prevent myocardial damage
B. Optimum myocardial oxygen demand : supply ration
C. MVO2 is directly related to
1) Heart rate
2) Contractility
D. Oxygen supply is directly related to
1) Coronary blood flow
2) LV wall tension

5. **Minimize Ischemia**
   A. Avoid tachycardia
   1) Increased heart rates are correlated with post-operative MI
   B. Maintain resting (ischemia-free) hemodynamics
   1) Slow: maximize diastolic time
   2) Small: minimize wall tension
   3) Well Perfused: Adequate coronary pressure

6. **Valvular Heart Disease**
   A. Aortic Stenosis
   B. LVH
   1) May have coronary artery disease
   2) Requires high filling pressures
   3) Anesthetic goals
   4) Normal heart rate (avoid tachycardia)
   5) Atrial "kick" crucial for adequate preloading of LV
   C. Aortic Insufficiency
   D. CHF common in acute AI
   E. Anesthetic goals:
      1) Decreased afterload
      2) high-normal heart rate (avoid bradycardia)
   F. Mitral Stenosis
   G. High LA pressure and volume needed to fill LV
   H. Anesthetic goals:
      1) Adequate preload
      2) Maintain diastolic filling time (avoid tachycardia)
   I. Mitral Regurgitation
   J. Volume overload leads to CHF and pulmonary hypertension
   K. Anesthetic goals:
      1) Vasodilation improve forward flow
      2) Normal to increased heart rate (avoid bradycardia)

7. **Weaning from Bypass**
   A. Establish rhythm
   1) Defibrillate
2) AV pacing
3) Control rate

B. SVR (normal to low-normal)
1) SVR = (BP-CVP/CO) x 80
2) On pump: BP-CVP = mean BP; CO = Pump flow (L/min)

C. Normalize cardiac output
1) Visual
2) Blood pressure
3) Measured CO

D. Adjust preload
1) Post-bypass heart is stiff and volume dependent

8. Heparin Reversal
A. Use calculated dose of Protamine
B. Excess Protamine will cause a prolongation of A.C.T. and coagulopathy

9. One Lung Ventilation
A. To facilitate surgery on the lung or thoracic aorta
B. Absolute indications-
1) Lung abcess
2) HeartPort
C. Useful in-
1) Pulmonary hemorrhage
2) V.A.T.
D. Hypoxemia- commonly due to increased shunt
E. Minimize hypoxemia by-
1) 100% FiO2
2) Decrease volatile agents to < 1%
3) Increase ventilation to the dependent lung (non-operative)
4) PEEP the dependent lung
5) CPAP on the operative lung
6) Occlude the pulmonary artery of the operative lung

10. Pericardial Tamponade
A. Acute drop in BP on induction
1) Decreased venous return with controlled ventilation
2) Decreased sympathetic tone due to anesthetic state
B. Management
C. Prep awake with spontaneous ventilation
D. Ketamine induction
   1) Sympathomimetic
   2) Spontaneous ventilation possible

10. Anterior Mediastinal Mass
A. Sudden inability to ventilate
B. Obstruction of major airways with
   1) Supine position
   2) Controlled ventilation
   3) Depressed ventilation
C. Management
D. Radiation therapy pre-op
E. Awake fiberoptic intubation (sitting)
   1) Spontaneous ventilation
   2) Standby cardiopulmonary bypass
1. Definition
A. A narrowing of one or more coronary arteries from atherosclerotic disease which limits myocardial blood flow. Increasing degrees of stenosis first limit reserve flow, then reduce flow at rest, and finally may totally occlude the vessel.

2. Morphology
A. The normal coronary artery layers
   1) Endothelium
   2) Intima
   3) Internal elastic lamina
   4) Media
   5) External elastic lamina
   6) Adventitia
B. Lesions of atherosclerosis
   1) Fatty streak begins in childhood
   2) Lipid laden macrophages and T-lymphocytes with smooth muscle cells cause focal intimal thickening
3) More **smooth muscle cells** and connective tissue form in the intima

4) Eccentric **fibrous plaque** develops, which is white and elevated

5) Lipid deposition in cells and connective tissue
6) A luminal fibrous cap forms
7) Zone of necrotic tissue beneath the cellular area
3. Pathophysiology
   A. Rupture and thrombosis of a plaque is the probable cause of most unstable angina and acute myocardial infarction
   B. Acute ischemia commonly develops in vessels with less than 50% stenosis
   C. More severe stenoses also occlude, but may not have acute ischemia due to protective collaterals
   D. Hemorrhage may occur suddenly within a plaque

   E. Platelet aggregation, vessel stenosis, and coronary spasm all play a role in acute narrowing/occlusion

   F. Plaque regression occasionally occurs
   G. Development of collaterals important in restoring regional perfusion

4. Vascular Anatomy
   A. CAD usually involves proximal portions of the 3 major arteries, particularly at branch points
   B. The LAD and RCA are more often involved than the CX
   C. 40% of patients studied for symptoms will have significant stenoses in all 3 vessels
D. 95% of patients with 1 completely occluded artery will have a significant stenosis in at least one other artery
E. 10-20% of patients with significant disease will have L main involvement
F. Diffuse distal disease unsuitable for CAB is uncommon

5. Diagnosis
A. Coronary angiography
1) Severity of lesions and size of distal vessels may be underestimated
2) 75% reduction in cross-section = 50% diameter reduction (moderate)
3) 90% reduction in cross-section = 67% diameter reduction (severe)
4) Ejection fraction should be considered with heart size, as the heart size can be normal even in severe LV dysfunction
B. Tests of LV function
1) Resting LV function depends on the amount of myocardium devoid of scar
2) Exercise LV function reflects loss of coronary flow reserve, and is typically depressed when compared to resting function
3) Global LV function usually visually estimated on angiography as ejection fraction
4) Can also be evaluated by CASS score, which is the sum of five segmental scores
5) Segmental LV wall function assessed by local wall motion or thickening during cardiac cycle

6. Natural History
A. Progression of Stenoses
1) Rate of progression is highly variable
2) Young age, hyperlipidemia, and presence of PVD denote more rapid progression of coronary stenoses
3) 50% of patients will develop new significant lesions within 2 years
B. Progression of LV Dysfunction
1) As areas of ischemia become more extensive, global LV systolic function will fall during exercise testing
2) LVEDV will increase from the decreased systolic function
3) LV diastolic function also falls from impaired myocardial relaxation during early diastole
4) All factors ultimately result in increased LVEDP
5) LV dysfunction at rest is usually from myocardial scarring
6) Myocardial stunning or hibernation can cause resting LV dysfunction as well

7. Unfavorable Outcomes
A. Stable angina
1) Chest pain on exertion is a common event with progression of coronary stenoses
2) Graded exercise testing helps quantify the degree of reduction in flow reserve
3) Angina typically becomes more severe with time, although some patients do not progress

B. Unstable angina
1) Definitions:
   a) Severe and persisting angina with EKG evidence of ischemia and minor CK-MB changes
   b) Severe class IV angina within 2 months of onset
   c) Severe angina lasting more than 15 minutes occurring within 10 days of presentation
   d) Severe angina within 2 weeks of acute myocardial infarction
2) Plaque fissure and/or rupture is the probable cause of unstable angina
3) These patients have increased tendency to develop myocardial infarction

C. Acute myocardial infarction
1) Severe proximal LAD disease is prone to cause acute MI
2) 30% of patients studied will have an acute MI within 5 years
3) Probability of acute MI is increased by number of previous MIs and number of vessels involved
4) Thrombolytics have reduced current hospital mortality to less than 10%
5) Death usually the result of acute cardiac failure or sudden ventricular arrhythmia

D. Death
1) The majority of patients with CAD ultimately die from cardiac causes
2) Most common cause is acute or subacute cardiac failure
3) 20% of patients have sudden death
4) 10-year survival is about 60%

8. Risk Factors
 A. Severity of reduction of regional coronary flow reserve
 B. Number of myocardial regions with reduced flow reserve
 C. Nature of plaque and internal thrombolytic/fibrinolytic state
 D. Amount and distribution of scar
 E. Hemodynamic instability
 F. Ischemic instability
 G. Ventricular electrical instability
 H. Older age
I. Diabetes  
J. Hypertension  
K. Hyperlipidemia  
L. COPD  
M. Chronic renal disease  
N. Smoking  

O. Previous CVA

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<th>Number of vessels with stenoses</th>
<th>5-year survival</th>
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<td>1 (RCA)</td>
<td>96%</td>
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<td>88%</td>
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<td>3</td>
<td>70%</td>
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<tr>
<td>Left main</td>
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Chapter 13 - Myocardial Infarction

1. Acute Myocardial Infarction
   A. Obstruction→ Thrombosis→ Occlusion
   B. Ischemic injury prolonged→ Irreversible injury

2. Location and Size
   A. Location and severity of obstruction
   B. Size of vascular bed
   C. O2 needs of myocardium
   D. Collateral development
   E. Coronary artery spasm
   F. Tissue factors
   G. Thrombotic and thrombolytic substances

3. Types of Infarction
   A. Transmural
      1) Acute coronary thrombosis
      2) Localized zone of distribution
   B. Subendothelial (non-transmural)
      1) Coronaries narrowed but patent
      2) Thrombotic occlusion→ thrombolysis
      3) Increased oxygen demand and/or decreased oxygen delivery
      4) Pulmonary embolism
      5) Hypotension
      6) Hypertension
      7) Aortic stenosis
      8) Anemia
      9) Operative procedures
      10) Cerebrovascular accident

4. Sites of Involvement
   A. Most involve LV and interventricular septum
   B. Up to 65% or IMI involve RV
   C. Isolated RV in 3-5%
1) COPD
2) RVH

5. Pathology

Gross Changes

<table>
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<th>Changes</th>
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<tr>
<td>&lt; 6 hours</td>
<td>No change</td>
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<tr>
<td>&gt; 6 hours</td>
<td>Pale, bluish, edematous</td>
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<tr>
<td>18-36 hours</td>
<td>Tan, reddish purple</td>
</tr>
<tr>
<td>&gt;48 hours</td>
<td>Gray, yellow lines at periphery</td>
</tr>
<tr>
<td>8-10 days</td>
<td>decreased wall thickness, coagulation necrosis</td>
</tr>
<tr>
<td>2-3 months</td>
<td>Thin, form scar</td>
</tr>
</tbody>
</table>

6. Coronary Artery Thrombosis

A. Coronary atherosclerosis
B. Vasospasm
C. Plaque rupture
D. Platelet actuation

7. Coronary Atherosclerosis

A. Acute occlusion =Rapidity of development/Collateral circulation
   1) Transmural
   2) Subendocardial
   3) None
B. Vasospasm
   1) Increased Thromboxane A2
C. Plaque rupture
   1) Ulceration
   2) Fissure formation
D. Platelet activation
   1) Adhesion-> aggregates-> increase Thromboxane A2
   2) Decreased Fibrinolytic activity
   3) Decreased tissue plasminogen activator

8. Collateral Circulation

A. Coronary occlusive disease
B. Chronic hypoxia
1) COPD
2) Anemia
3) Cyanotic CHF
C. LVH

9. Pathophysiology
A. Systolic Function
B. Infarcted area
1) Dyssynchrony
2) Hypokinesis
3) Akenisis
4) Dyskinesis
C. Non-infarcted areas
1) Hyperkinesis
D. Manifestations
1) Decreased diastolic compliance
2) Decreased ejection fraction (>15%)
3) CHF (>25)
4) Cardiogenic shock (>40%)

10. Infarct Size Limitation
A. O2 supply (coronary perfusion pressure)
B. O2 demand (ventricular wall tension)
C. Oxygen Supply and Demand
11. **Complications**
A. Hypotension
B. Arrhythmias
C. Congestive heart failure
D. Hypoxemia
E. Anemia
F. Infections
G. Hypertension
H. Cardiogenic shock
   1) Pharmacologic
   2) Mechanical
   3) Surgical– VSD, MR, Ventricular rupture

12. **Reperfusion of infarction**
A. Increased systolic function
B. Increased diastolic function
C. Decreased mortality

13. **Treatment**
A. Coronary thrombolysis
B. Angioplasty
C. **Coronary Atery Bypass**

14. **Coronary Thrombolysis**
A. Agents
   1) Streptokinase
   2) Plasminogen streptokinase activation complex (APSAC)
   3) Tissue-type plasminogen activator (tPA)
B. Indications
   1) Impending or evolving MI
   2) 3 hours of symptom onset
   3) Heparin (bolus ==>infusion)
   4) ASA
Duration of Coronary Occlusion

Time from Onset of Symptoms
15. Contraindications
A. Recent trauma
B. Major surgery (6 weeks)
C. GI bleeding (3 months)
D. Bleeding diathesis
E. Chronic liver disease
F. Allergy to thrombolytics
G. Stroke with residual
H. TIA (6 months)
I. Cerebral hemorrhage
J. Pregnancy

16. Angioplasty
A. Indications
  1) Thrombolytic contraindicated
  2) Thrombolytic unsuccessful
  3) Extensive ischemia

17. Summary
A. Atherosclerotic coronary artery disease
  1) Stenosis
  2) Thrombosis
3) Vasoconstriction
4) Plaque disruption
B. Segmental disease
C. Endocardium→ epicardium
D. Irreversible injury >15-20 minutes occlusion
  1) Maximal damage 4-6 hours
  2) Best salvage 1-2
E. Size depends on collateral
  1) Morbidity and mortality
  2) O2 supply/O2demand
F. RV infarct with inferior MI
Chapter 14 - Coronary Artery Bypass

1. Indications
   A. Stable angina
      1) Survival depends on all patient-specific risk factors, not just angina
      2) Class I/II if there is significant 3-vessel disease and some LV dysfunction
      3) Class I/II if there is significant 3-vessel disease, good LV function, and one or more important proximal stenoses
      4) Class III/IV if there is significant 3-vessel disease and sometimes 2-vessel disease, regardless of LV function
      5) Left main stenosis at least 50%, even if asymptomatic
      6) 2-vessel disease with severe proximal LAD stenosis or some LV dysfunction
      7) Rarely indicated for single vessel disease
   B. Unstable Angina
      1) Stabilize initially with medical therapy
      2) Same indications as for stable angina, but more urgent
      3) Strongest indications are 3-vessel disease, LV dysfunction, and angina at rest
   C. Other Situations
      1) Angina after acute MI has same indications; delay CAB for at least 1 week
      2) Emergent CAB for hemodynamic instability during acute MI can salvage over 50% of such patients
      3) Emergent CAB indicated if PTCA results in hemodynamic instability

2. Operative Technique
   A. General strategy
      1) Goal is complete revascularization by bypassing all vessels with at least 50% stenosis
      2) Patency enhanced by grafting to larger vessels with good runoff
   B. Vein graft preparation
      1) Avoid overdistension and spasm of the vein
      2) Multiple large varices render the vein unsuitable for grafting
      3) The vein should be untwisted, marked, and reversed for grafting
   C. IMA preparation
      1) Begin dissection at 6th intercostal space
      2) Either a pedicle or skeletonized artery may be used
3) Distal end not divided until just prior to anastomosis
4) Avoid probing unless there is no bleeding from the cut end

D. Distal anastomosis
1) Incise anterior wall of coronary longitudinally 4 to 6 mm
2) Bevel vein end somewhat larger than coronary opening for most distal anastomosis
3) Incise vein longitudinally 10-20% longer than coronary opening for sequential anastomosis
4) Sutures run from inside to out on the coronary and outside to in on the vein graft

E. Proximal anastomosis
1) Lateral openings on the aorta are preferred to protect the grafts during reoperation
2) Bevel vein end somewhat larger than aortic opening

3. Reoperative CAB
A. Avoid manipulating intact grafts
B. Some recommend replacing all vein grafts older than 6 years
C. Others recommend only replacing vein grafts that are occluded or stenotic
D. Left thoracotomy with femoral CPB is useful in the setting of a functional IMA-LAD graft

4. Vascular Anatomy
A. CAD usually involves proximal portions of the 3 major arteries, particularly at branch points
B. The LAD and RCA are more often involved than the CX
C. 40% of patients studied for symptoms will have significant stenoses in all 3 vessels
D. 95% of patients with 1 completely occluded artery will have a significant stenosis in at least one other artery
E. 10-20% of patients with significant disease will have L main involvement
F. Diffuse distal disease unsuitable for CAB is uncommon

5. Results
A. Survival
1) Current hospital mortality is about 3%, most from acute cardiac failure
2) 5-year survival is 88% and 10-year survival 75%
3) IMA graft favorably affects the mid- and long-term survival (after 6 years)
4) About 25% of all deaths after CAB are unrelated to ischemic heart disease or CAB

B. Risk factors for death
1) Diminished LV function
2) Unstable angina
3) Acute hemodynamic instability after MI
4) Operation within 1 week of acute MI
5) Cardiogenic shock at time of operation
6) Older age

C. Procedural risk factors for death
1) Incomplete revascularization
2) Nonuse of IMA to LAD
3) Increased myocardial ischemic time
4) Increased CPB time
5) Earlier date of operation

D. Freedom from angina
1) About 60% of patients are free from symptoms at 10 years
2) Late recurrence is due to vein graft occlusion or progression of native coronary disease
3) Risk factors for return of angina are not as powerful as those for death

E. Freedom from MI
1) Perioperative incidence is 2-5%
2) 5-year freedom is greater than 95% after CAB
3) Survival is adversely affected by any post-CAB infarction

F. Freedom from sudden death
1) Uncommon after CAB; 97% freedom at 10 years
2) Poor preoperative LV function is the most significant risk factor for sudden death postop
3) Successful CAB does not affect the incidence of existing ventricular arrhythmias, as most of these are due to scar

G. Neurologic events
1) Up to 75% of patients may have subtle neurologic deficits in the perioperative period
2) Gross neurologic defects occur in less than 1% of younger patients but up to 5% of patients over age 70

H. Functional status
1) Maximal exercise capacity is improved, particularly when complete revascularization has been performed
2) Systolic function in hypokinetic, akinetic and even dyskinetic areas can be improved
3) A preop EF of 30% or less limits recovery of LV function after CAB
4) Exercise testing at 2 weeks postop in most patients shows a normal rise in EF, a normal increase in LVEDV, and the resolution of regional wall motion dysfunction.

6. Graft History
A. Vein grafts
1) Intimal hyperplasia is a universal finding after one month, but is not progressive
2) At 1 year, the graft diameter approximates the recipient coronary diameter
3) 10% close within the first few weeks if antiplatelet therapy is not used
4) 10-year patency is about 50-60%
5) Most grafts have evidence of atherosclerotic changes at 10 years
B. IMA grafts
1) Intimal hyperplasia also develops; the IMA is highly resistant to atherosclerosis
2) 10-year patency is about 90%
3) 5-10% develop late stenoses, but most of these do not progress to occlusion
4) Controversy exist over its use as a sequential graft and for bilateral IMA grafting
C. Other conduits
1) Long-term patency not yet conclusive on gastroepiploic, inferior mesenteric, and inferior epigastric arteries
2) The free radial artery graft is being re-evaluated for long-term patency

7. Reintervention after CAB
A. Most interventions are reoperative CAB, although PTCA used in about 25% of cases
B. 90% of patients are free from reoperative at 10 years
C. Vein graft stenosis is the most common cause for reoperation
D. IMA grafting reduces reoperations and extends time to reoperation
E. Overall risk for reoperative CAB is about twice that of first CAB
F. 10-year survival after reoperative CAB is about 65%
Chapter 15 - Randomized Studies of CAB

1. Comparisons of bypass surgery with medical therapy

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<tr>
<th>Trial Cooperative</th>
<th>Patients</th>
<th>Randomized</th>
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<td>VA cooperative trial (VA)</td>
<td>686</td>
<td>1972-74</td>
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<tr>
<td>European cooperative surgical study (ECSS)</td>
<td>768</td>
<td>1973-76</td>
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<tr>
<td>Coronary artery surgery study (CASS)</td>
<td>780</td>
<td>1974-79</td>
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</table>

Survival

2. Severity of angina
   A. Objective evidence of ischemia
   B. Instability of angina (crossover 20% 6 months, 50% 5 years)
   C. Myocardial infarction
   D. Severity of stenosis (L. main, 3 vessel, proximal LAD)
   E. Left ventricular dysfunction
   F. Age

3. Summary
A. Patients with single, double or triple vessel disease, good ventricular function (>50%) and no exercise induced ischemia have a good prognosis.

B. Improved survival is seen in patients with triple vessel disease, left main disease and reduced ejection fraction (>35%, <50%) following surgery.

C. Improved surgical survival is seen in patients with any two of the following clinical risk factors: h/o hypertension, h/o myocardial infarction, resting ST- T abnormalities.

4. Comparison of bypass surgery with angioplasty
   A. The randomized interventional treatment of angina (RITA) - March 1993, Lancet (longest follow-up)
   C. The Coronary Artery Bypass Revascularization Investigation (CABRI) August 1993
   D. Argentine Randomized trial of Percutaneous Transluminal Coronary Angioplasty v/s coronary artery bypass surgery (ERACI) October 1993, JACC.

5. Rita Trial

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<tr>
<th>Inclusion Criteria</th>
<th>CABG</th>
<th>PTCA</th>
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<tr>
<td>Symptomatic or asymptomatic SVD or MVD</td>
<td>suitable for equivalent revascularization</td>
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<table>
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<tr>
<th>Baseline Characteristics</th>
<th>Class 3-4 angina 59%; hx MI 43%</th>
<th>3VD 12% &gt; 3Rx 38%</th>
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<td>Patients (n)</td>
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<td>Early outcome</td>
<td>In-hospital</td>
<td>In-hospital</td>
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<tr>
<td>Death</td>
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<td>MI</td>
<td>2.4%</td>
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<tr>
<td>Reintervention</td>
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<tr>
<td>Late outcome</td>
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<tr>
<td>MI</td>
<td>5.2%</td>
<td>6.7%</td>
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<tr>
<td>CABG</td>
<td>0.8%</td>
<td>18.8%</td>
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<tr>
<td>PTCA</td>
<td>3.2%</td>
<td>18.2%</td>
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<tr>
<td>Event-free survival</td>
<td>89%</td>
<td>62%</td>
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<td>Symptom-free</td>
<td>78%</td>
<td>69%</td>
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### 6. Gabi Trial

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<tr>
<th>Inclusion Criteria</th>
<th>CABG</th>
<th>PTCA</th>
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<tbody>
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<td>Symptomatic MVD</td>
<td>Symptomatic MVD suitable for complete revascularization</td>
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<tr>
<td>Baseline Characteristics</td>
<td>Class 4 angina, 19%; hx MI 50%</td>
<td>mean LVEF 56%</td>
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<td>Patients (n)</td>
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<td>Early outcome</td>
<td>In-hospital</td>
<td>In-hospital</td>
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<td>Death</td>
<td>2.2%</td>
<td>1.1%</td>
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<tr>
<td>MI</td>
<td>8.0</td>
<td>2.7</td>
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<tr>
<td>Reintervention</td>
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<td>NR</td>
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<tr>
<td>Late outcome</td>
<td>1 year</td>
<td>1 year</td>
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<tr>
<td>Death</td>
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<td>1.6%</td>
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<tr>
<td>MI</td>
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<tr>
<td>GABG</td>
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<tr>
<td>PTCA</td>
<td>4.5%</td>
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<tr>
<td>Event-free survival</td>
<td>94%</td>
<td>58%</td>
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<tr>
<td>Symptom-free</td>
<td>80%</td>
<td>80%</td>
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### 7. Gabri Trial

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<tr>
<th>Inclusion Criteria</th>
<th>CABG</th>
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<tr>
<td>Symptomatic or asymptomatic MVD</td>
<td>LVEF &gt; 35%</td>
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<tr>
<td>Baseline Characteristics</td>
<td>Class 3-4 angina 66%; hx MI 42%</td>
<td>3VD 40% &gt; 3Rx 26%, mean LVEF 63%</td>
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<td>Patients (n)</td>
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<tr>
<td>Early outcome</td>
<td>30 days</td>
<td>30 days</td>
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<tr>
<td>Death</td>
<td>0.9%</td>
<td>1.7%</td>
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<tr>
<td></td>
<td>MI</td>
<td>Reintervention</td>
</tr>
<tr>
<td>------------</td>
<td>-------</td>
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</tr>
<tr>
<td></td>
<td>2.9%</td>
<td>1.6%</td>
</tr>
<tr>
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<td>3.1%</td>
<td>10.1%</td>
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8. Eraci Trial

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<th>Inclusion Criteria</th>
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<tr>
<td>Symptomatic MVD</td>
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<tr>
<td>Baseline Characteristics</td>
<td>Class 3-4 angina</td>
<td>LVEF &gt; 35%</td>
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<td>Patients (n)</td>
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<tr>
<td>Early outcome</td>
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<td>In-hospital</td>
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<tr>
<td>Death</td>
<td>4.6%</td>
<td>1.5%</td>
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<tr>
<td>MI</td>
<td>6.2%</td>
<td>6.3%</td>
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<tr>
<td>Reintervention</td>
<td>NR</td>
<td>NR</td>
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<tr>
<td>Late outcome</td>
<td>1 year</td>
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<tr>
<td>Death</td>
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<td>MI</td>
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<td>GABG</td>
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<td>18.0%</td>
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<tr>
<td>PTCA</td>
<td>3.2%</td>
<td>14.0%</td>
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<tr>
<td>Event-free survival</td>
<td>83.5%</td>
<td>63.7%</td>
</tr>
<tr>
<td>Symptom-free</td>
<td>90%</td>
<td>65%</td>
</tr>
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</table>

9. Survival (older 3v disease, + 2v disease, - 1v disease)
A. Symptom free survival
B. Incidence of myocardial infarction
C. Freedom from crossover to CABG after angioplasty (5 yrs - 25%)
D. Event free survival

10. For low risk patients with two vessel disease, angioplasty may provide modest survival benefits relative to medical therapy.
   A. In single vessel disease, the primary treatment choice is between medicine and PTCA
   B. Survival benefits of surgical revascularization are magnified on the absolute scale by factors that increase overall medical risk, especially left ventricular dysfunction and advanced age. These factors tend to increase procedural risks but offer proportionately greater long-term benefits than can be expected with medical treatment

11. Summary
   A. The more extensive the coronary artery disease, the larger the benefit derived from surgical revascularization
   B. In the most severe forms of coronary artery disease (Left main, triple vessel) bypass surgery provides the best long term survival results
   C. In patients with two vessel disease, the higher the risk the more likely that patient will have improved survival with bypass surgery (eg. impaired left ventricular function, older age, co-existing vascular disease)

EXTENDED OUTLINE
Surgical Indications for Coronary Revascularization

1. Objectives of CABG
   A. relieve ischemia
   B. prolong survival
   C. prevent MI
   D. preserve LV function
   E. improve exercise tolerance

2. Assessing CABG Candidates
   A. degree of symptoms
   B. associated medical problems
   C. evidence of reversible ischemia
   D. Documentation of abnormal coronaries
   E. LV function

3. Angina
A. Chronic Stable Angina defined as stable pain pattern for 4-6 weeks
B. Canadian Cardiovascular Society Classification
1) Class I. Angina: occurs with strenuous activity
2) Class II. Angina: pain with rapid walk or climbing multiple stairs
3) Class III Angina: pain with walking < 2 blocks on level ground @ a normal pace or climbing one flight of stairs
4) Class IV. : pain with minimal activity or @ rest if it last < 15 min.
5) Unstable Angina: pain @ rest that last more than 15 min.

4. Studies
A. General
1) three major studies of medical vs. surgical treatment
2) use of early CABG techniques
3) no LIMA
4) no wide spread use of cardioplegia
5) no postop antiplatelet therapy
B. VA Study (1970)
1) 686 patients
2) criteria
a) > 50% lesion in one or more vessel
b) graftable vessels
c) acceptable LV function
3) results:
a) 36 month survival was 87% in the medical group and 88% in the surgical arm
(1) patients with a left main lesions were the only group to show a survival advantage with surgery
b) 7 year survival 70% with medical and 77% with surgical
c) beyond 7 years any survival advantage with surgery begins to disappear except in patients with three vessel disease and decreased LV function
C. European Cooperative Surgical Study (ECSS)
1) 768 men, < 65 yrs old, > 3 month hx of angina, @ least 2 vessel disease, and LV function > 50%
2) results:
a) survival @ 16 months was 93.5% in the surgical group and 84.1% in the medical group
b) survival advantage was greatest in patients with three vessel disease, left main disease, or two vessel disease with a proximal LAD lesion

3) Conclusion:
   a) symptomatic stable angina with left main, three vessel, or two vessel disease including a proximal LAD lesion benefit from surgery

D. Coronary Artery Surgery Study (CASS)
1) 2099 patients, 780 truly randomized the other chose their therapy
2) set out to answer the question which was the best therapy for patients with minimal symptoms - most patients had class I and II angina
3) results:
   a) survival @ 5 yrs was equal in medical and surgical groups
   b) medical group had a 5%/yr. conversion to surgery
   c) increased survival @ 7 yrs for patients with decreased EF and three vessel disease
4) Conclusion:
   a) mild angina with an EF between 35 - 50%, and three vessel disease had increased survival @ seven years
   b) incidence of MI was the same in both groups

5. Indications for CABG
   1) failure of medical therapy
   2) unstable angina
   3) Left main disease
   4) symptomatic three vessel disease
   5) post infarction angina
   6) acute MI with shock
   7) failed PTCA
   8) reoperation for recurrent symptoms
   9) congenital anomalies
   10) Kawasaki’s disease

A. Failure of medical therapy
1) CASS:
   a) patients with three vessel disease and class III - IV angina had increased survival and decreased MI @ 5 years regardless of LV function
   b) patients with one or two vessels with decreased LV function

B. Unstable Angina
1) surgery provides increased relief of symptoms, but no survival benefit compared to medical therapy

C. Left main
1) survival increased for 60% - 90% @ 4 yrs with surgery

D. 3 Vessel disease and decreased LV function
1) VA and CASS studies support

E. Post-infarction Angina
1) 5-10% incidence of MI with surgery

F. Acute MI with Shock
1) mortality > 80% in all comers
2) 30% mortality with surgery

G. Failed PTCA
1) incidence 3-4%
2) 5% mortality
3) 30-40% incidence of MI

H. Reop with recurrent symptoms
1) factors associated with decreased reop survival
   a) failure to use the LIMA
   b) decreased age
   c) incomplete revascularization
   d) smoking

2) Survival

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<tr>
<th>Survival</th>
<th>5 Years</th>
<th>10 Years</th>
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<tbody>
<tr>
<td>first surgery</td>
<td>90%</td>
<td>75%</td>
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<tr>
<td>reop</td>
<td>80%</td>
<td>60%</td>
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Chapter 16 - Non-surgical Revascularization

1. History
   A. Developed by Andreas Gruentzig in 1977
   B. Original series
      1) 169 patients
         a) 133 successfully balloononed
         (1) 95% ten year survival with one lesion
         (2) 81% ten year survival with more than one lesion
         b) 23% went to surgery in the ten year period
   C. 1981 series
      1) 427 patients
         a) 88% had single vessel disease
         b) 94% successfully balloononed
         (1) 91% ten year survival
         (2) 30% redo PTCA in ten year follow-up
         (3) 23% required surgery
         (4) 55% freedom from MI, death, and surgery @ ten years

2. PTCA after CABG
   A. 94% success with PTCA of SVG
      1) depends on location
         a) distal anastamosis: good results secondary to intimal hyperplasia
         (1) 24% restenosis rate
         b) restenosis rate increases in mid and proximal lesions, and in vein grafts over two years old

3. Primary Angioplasty in Myocardial Infarction
   A. most beneficial in older patients and in AWMI
      1) AWMI mortality 1.4% with PTCA
         vs. 11.9% with lytic therapy
      2) Age > 65 yrs mortality 5.7% with PTCA
         vs. 15% with lytic therapy

4. New Interventional Devices
A. Rotablator
B. Transluminal Extractor Atherectomy Catheter (TEC)
C. Excimer Laser
D. Stents
   1) indications widening, but the text states for use
      a) after a dissection secondary to PTCA,
      b) acute closure after PTCA
      c) reduce restenosis
   2) Benestent Trial and STRESS
      a) each trial had >1000 randomized patients
      b) end point was luminal diameter @ 6 months
      c) restenosis (defined as 50%) was 42% in PTCA vs. 32% with PTCA and stenting
      d) reintervention was 15% in PTCA vs. 10% with PTCA and stenting
   3) cost:
      a) increased bleeding
      b) increased hospitalization

5. PTCA vs. CABG
   A. Emory Angioplasty Surgery Trial (EAST)
      1) single center trial
      2) 392 patients randomized and 458 non randomized patients
      3) 60% had double vessel disease and 40% had triple vessel disease
      4) excluded left main lesion, occluded vessels, and severe LV dysfunction
      5) results:

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<td>Event mortality</td>
<td>1%</td>
<td>1%</td>
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<td>3 year mortality</td>
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<td>freedom from subsequent surgery</td>
<td>79%</td>
<td>99%</td>
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<tr>
<td>freedom from subsequent PTCA</td>
<td>60%</td>
<td>88%</td>
</tr>
<tr>
<td>Class I, II, III symptoms</td>
<td>20%</td>
<td>12%</td>
</tr>
</tbody>
</table>

6) Conclusion: PTCA can be safely done but will require repeat procedures

B. Bypass Angioplasty Revascularization Investigation (BARI)
   1) largest trial (1829 patients), followed for 5.4 years
   2) multicenter
   3) results:
<table>
<thead>
<tr>
<th></th>
<th>CABG</th>
<th>PTCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Event mortality</td>
<td>1.3%</td>
<td>1.1%</td>
</tr>
<tr>
<td>Q-wave</td>
<td>4.6%</td>
<td>2.1%</td>
</tr>
<tr>
<td>Stroke</td>
<td>0.8%</td>
<td>0.2%</td>
</tr>
<tr>
<td>5 yr survival</td>
<td>89.3%</td>
<td>86.3%</td>
</tr>
<tr>
<td>Revascularization @ 5 yrs.</td>
<td>8%</td>
<td>54%</td>
</tr>
<tr>
<td>Diabetic's survival</td>
<td>80.6%</td>
<td>65.5%</td>
</tr>
</tbody>
</table>

C. RITA (United Kingdom)
1) single and multivessel disease, although 50% were single
2) required complete revascularization and were more compulsive regarding randomization

D. CABRI (Europe)
1) need for surgery in one year in the PTCA group was 20%

E. GABI (Germany)
1) need for surgery in one year in the PTCA group was 21%

6. Indications for PTCA
A. Nomenclature
1) Class I: general agreement that PTCA is indicated, but not the treatment
2) Class II: Divergence of opinion
3) Class III: agreement that PTCA not indicated

B. Symptomatic patients
1) Class I and II:
   a) amenable lesions
   b) ischemic on maximal therapy
   c) angina on maximal therapy
   d) side affects of medical therapy

C. Asymptomatic patients
1) severe ischemia on testing
2) rescue from angina
3) in need of high risk surgery

D. Myocardial Infarction
1) Class I and II:
   a) AWMI with duration less than 6 hrs.
   b) persistent pain within 12 hrs.
c) cardiogenic shock or continued ischemia following lytic therapy
2) Class III. : following lytic therapy

Chapter 17 - Post-Infarct Left Ventricular Aneurysm

1. Definition
A. an area of thin scar devoid of muscle that occurs after myocardial infarction. This area is well-delineated and both walls bulge outward during systole.

2. Morphology
A. The fibrous scar is transmural and delineated from surrounding myocardium
B. Underlying endocardium is smooth and non-trabeculated
C. The aneurysm is thin, devoid of muscle, and often large
D. The walls are akinetic or dyskinetic during systole
E. LVEF is usually depressed to 35% or worse

3. Pathophysiology
A. Fibrous scar tissue develops in about one month after infarct
B. Early aneurysms (7-10 days after infarct) are mostly necrotic muscle and therefore not true aneurysms
C. Overlying pericardium is usually adherent
D. Mural thrombus is present in about 50%, but rarely produces thromboembolism
E. Calcification of thrombus and/or pericardium is common
F. The non-aneurysmal portion of the LV gradually increases in both volume and thickness, resulting in depressed LVEF

<table>
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<th>Location</th>
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<tbody>
<tr>
<td>Anterolatera</td>
<td>85%</td>
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<tr>
<td>Posterior</td>
<td>5-10%</td>
</tr>
<tr>
<td>Lateral</td>
<td>less than 5%</td>
</tr>
</tbody>
</table>

G. 50% of posterior aneurysms are false aneurysms
H. True posterior aneurysms are associated with post-infarct mitral insufficiency

4. Clinical Features
A. Small and moderate sized aneurysms often have no specific associated symptoms
B. Classic presentation is history of previous MI and CHF
C. Ventricular arrhythmias are present in 15-30%, more often when the septum is involved
D. Thromboembolism is infrequent

5. Diagnosis
A. ECG: ST elevation, loss of R wave anteriorly, or evidence of previous infarction
B. CXR: enlarged heart, may show convexity if aneurysm is large and profiled
C. ECHO: demonstrates aneurysm, evaluates LV function and mitral insufficiency
D. Catheterization: look for following features -
1) systolic akinesia or dyskinesia
2) permanent outward bulging
3) thinning of wall
4) loss of trabeculations
5) clear demarcation of aneurysm area
6) concomitant CAD
7) segmental and global LVEF
8) presence of LV thrombus
9) presence and degree of mitral insufficiency

6. Natural History
A. Incidence
1) 10-30% after significant myocardial infarction if untreated
2) The incidence has been reduced by thrombolytic therapy, HTN control, and avoidance of corticosteroids
3) The aneurysm evolves over 6 months and is unlikely to enlarge after 1 year
B. LV function
1) There is global cardiac remodeling and dilation
2) Systolic efficiency is reduced due to paradoxical movement of the aneurysm
C. Survival (non-operative)
1) Larger size of the aneurysm is a risk factor for premature death
2) With small aneurysms, survival is related to concomitant CAD risk factors rather than the aneurysm
3) The prognosis is poorer with dyskinesia and poor function of the LV

<table>
<thead>
<tr>
<th>Function</th>
<th>5-year survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>Akinesia</td>
<td>69%</td>
</tr>
</tbody>
</table>
7. Operative Indications
A. Large aneurysm, with or without symptoms (angina, CHF)
B. Recurrent ventricular tachycardia
C. Risk of late rupture
D. Evidence of thromboembolism
E. A small aneurysm may be a possible indication when undergoing concomitant cardiac procedure
F. Avoid operation with diffuse hypokinesis and no discrete aneurysm
G. Patients with severe LV dysfunction may be candidates for transplant

8. Operative Technique
A. Basic Considerations
1) Avoid clot dislodgement and thoroughly remove all thrombus
2) Remove all LV free wall that has smooth endocardium
3) Excise entire aneurysm, leaving thin rim of scar for closure
B. Methods
1) Incise anterior aneurysm longitudinally and preserve LAD if possible
2) Incise posterior aneurysm along long axis, avoiding papillary muscle
3) Objective is to preserve geometry and maintain LVEF
4) Classic linear closure does cause some distortion and is best used for small or apical aneurysms
5) Remodeling ventriculoplasty (Dor repair) uses patch to recreate wall architecture and is probably the optimum repair
6) Additional procedures as indicated (CAB, arrhythmia surgery)

9. Results
A. Symptoms
1) Symptomatic improvement occurs in most patients
2) Paradoxical wall movement is usually eliminated in the border zones
3) Symptomatic improvement is not always associated with improved LV function
4) Most evident in patients with preoperative CHF
B. Operative Mortality
1) About 5%, most from acute cardiac failure
2) Preoperative risk factors:
a) residual untreated CAD
b) resting LV dysfunction
c) chronic CHF
d) ventricular tachycardia
e) reduced cardiac output
f) elevated LVEDP
g) decreased septal systolic function
h) poor NYHA class
i) poor segmental wall motion

C. Late Mortality
1) 65% 5-year survival; particularly evident in patients with 3-vessel disease
2) One-third die from progressive CHF
3) One-third die from another myocardial infarction
4) Ventricular arrhythmias and sudden death in 15%

10. Special Situations
A. Pseudoaneurysm
1) Develops after acute rupture of contained area
2) Usually fatal, but hemopericardium can be small and contained
3) Small neck distinguishes this from large, wide neck of true aneurysm
4) The wall consists of pericardium and adhesions and gradually expands
5) More often located posteriorly or laterally
6) More likely to rupture than true aneurysm
7) Resection is indicated when the diagnosis is made

B. Post Infarct Free Wall Rupture
1) Occasionally massive with sudden death from exsanguination
2) Usually a more gradual process of dissection through the myocardium
3) Sudden death then occurs from pericardial tamponade
4) Surgical salvage is possible if LV has good function

C. Congenital Left Ventricular Aneurysm
1) Very rare
2) Long, finger-shaped projection projects into epigastrium
3) Rupture is not uncommon; can be excised without CPB

D. Traumatic Left Ventricular Aneurysm · Severe localized contusion causes probable pseudoaneurysm · Should be resected due to thin wall and propensity to rupture
Chapter 18 - Post-infarct VSD and MR

Post-infarct VSD And MR

1. Morphological Features
   A. Location: 60% anterior, 40% posterior
   B. Associated with total occlusion coronary artery, few collaterals
      1) Large loss of myocardium
   C. May be multiple; staged appearance
   D. Posterior VSD- can have MR
   E. Late complication- aneurysm

2. Clinical Features & Diagnosis
   A. Murmur, pansystolic, LLSB
      1) (Also consider acute MR murmur)
   B. Chest X-Ray- pulmonary venous hypertension, large pulmonary blood flow
   C. ECHO- site, size, ?MR
   D. Swan-Ganz- Qp:Qs >/= 2, hemodynamics
   E. Cardiac catheterization (optional??)
      1) Coronary angiography
      2) Left ventriculography (only if condition permits)

3. Natural History
   A. Occurrence- 1-2% of MI
      1) (Decreased since thrombolytics)
   B. Timing- 2-3 days post MI up to 2 weeks
   C. Early death is common

4. Indications for Operation
   A. Indication = presence of VSD
   B. Timing
      1) Urgent- for hemodynamic or end-organ decline
      2) Delayed (2-3 weeks) - if stable
5. Operative Considerations
A. Urgency, IABP
B. Approached through LV
C. Patch technique
   1) 2 patches unless apical
D. Concomittant procedures
   1) CABG
   2) MV replacement
   3) Aneurysm resection
   4) Free wall perforation (especially posterior)

6. Results or Repair
A. Survival: 35% early mortality
B. Functional status: good
C. Modes of death
   1) 50% CHF, acute
   2) 10% sudden death
   3) 5% CHF, chronic, intractable
   4) CVA
D. Risk factors
   1) Hemodynamic status & RV function preoperatively
   2) Extent of myocardial necrosis
   3) Posterior VSD >> anterior VSD
Chapter 19 - Combined Coronary Amp Carotid Disease

1. Coronary Surgery

<table>
<thead>
<tr>
<th>Carotid Stenosis &gt; 50%</th>
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<tbody>
<tr>
<td><strong>CABG</strong></td>
</tr>
<tr>
<td>5-8%</td>
</tr>
<tr>
<td><strong>CABG &gt; 65</strong></td>
</tr>
<tr>
<td>17%</td>
</tr>
<tr>
<td><strong>CABG + Left main</strong></td>
</tr>
<tr>
<td>50%</td>
</tr>
</tbody>
</table>

2. Risk Factors for Stroke Following CABG
A. Overall stroke risk 1-3.5%
B. Mural thrombi in the left ventricle
C. Atheromatous lesions in the ascending aorta
D. Air embolism
E. History of previous stroke

3. Carotid Artery Stenosis and CABG
A. Carotid stenoses are less of a risk factor for stroke with CABG because with CPB:
   1) Cerebral vascular resistance lowered
   2) Hypothermia reduces brain metabolism and oxygen requirement
   3) Hemodilution
   4) Auto-regulation of cerebral blood flow is related more to flow than MAP
B. Indications for combined coronary and carotid procedures are limited
C. Indications for combined coronary and carotid artery procedures
   1) Severe CAD: unstable angina, left main stenosis or 3 vessel CAD with poor LV function and
   2) An actively symptomatic carotid artery stenosis

4. Indications for Staged Operations for Coronary and Carotid Artery Disease
A. Significant 1, 2 or 3 vessel CAD requiring CABG in a patient with asymptomatic high grade CAS with medically controlled symptoms
B. Patient with actively symptomatic carotid artery stenosis with stable angina and adequate LV function

5. Combined Coronary and Carotid Artery Disease
   A. Controversial Areas
   1) Stable angina requiring CABG and coexistent asymptomatic high grade (> 80%) bilateral carotid stenosis
   2) Redo CEA or CABG with coexistent lesions in the other vascular system

6. Operative Strategies for Combined Procedures
   A. Ensure adequate exposure of neck in addition to chest and legs
   B. Pre-bypass vs. on bypass CEA
   C. After CEA, wound left open until systemic heparinization reversed

7. Results of Combined Procedures
   A. Morbidity and mortality for patients requiring combined procedures is higher than for either procedure alone
   1) Mortality 4%
   2) Post-operative stroke 9%
   3) Peri-operative MI 6%
   B. Therefore: Only 1-3% of patients requiring CABG or CEA will be candidates for combined procedures

Duplex

Management of Patients with Suspected Combined Coronary and Carotid Artery Disease

CAD +/- Carotid Disease

Duplex Scan

Negative
CABG

Positive
Cerebral Angiography
Angiography

Management of Patients with Suspected Combined Coronary and Carotid Artery Disease

Cerebral Angiography

Positive
- Unstable angina
- Left main stenosis
- Poor LV function

Combined CABG and CEA

Positive
- Stable angina
- Good LV function

Staged CABG and CEA

Negative
- CABG
Section III
Valvular and aortic disease

Chapter 20 - Aortic Valve Disease

1. Morphology
A. Calcified Aortic Stenosis
1) Congenitally bicuspid or unicuspid, fused commissures, heavy calcification, age 50-70

B. Rheumatic Aortic Stenosis
1. Fibrous thickening, 3-cusp valve, mild calcification, rheumatic fever history
C. Degenerative Aortic Stenosis
1) Diffuse nodular calcification, 3-cusp valve, no commissural fusion

2. Aortic Valve Incompetence
A. Cusp prolapse or cicatricial shortening of cusps with rolled edges

B. Annulo-aortic ectasia is a disease of the aorta rather than the valve itself
C. Dilation of sinus aorta, cystic medial necrosis, failure of coaptation of cusps

3. **Symptoms and Diagnosis and** indications for surgery

A. Aortic Stenosis
1) Dyspnea, angina, syncope in 1/3
2) Angina more common with CAD
3) Severe AS = LV to Ao gradient greater than 50 mmHg or aortic valve area less than 1.2 cm²/M²

B. Aortic Incompetence
1) CHF symptoms, angina 1/4, syncope rare
2) Severe AI = LV enlargement, calculated LV end systolic pressure greater than 50 mm Hg, EF less than 40%, calculated fiber shortening less than 0.6 cm/sec

4. **Natural History -** Stenosis

A. Hemodynamically severe, symptomatic or asymptomatic
1) Sudden death risk high
2) Immediate operation is indicated

B. Hemodynamically mild or moderate, asymptomatic
1) 50% event free for 4 years
2) Operation is not urgent, but patients should be followed carefully as the disease advances rapidly
C. Hemodynamically mild or moderate, symptomatic
   1) One-third will die within 4 years
   2) Prompt operation is indicated

5. Natural History - Incompetence
A. Latent period to cardiac decompensation is long
   1) Sudden death is not common
   2) Once deterioration begins, the LV fails rapidly
C. Symptomatic patient with CHF, angina, syncope
   1) Prompt operation is indicated
C. Asymptomatic patient
   1) Follow carefully for LV enlargement or decreased LV function by ECHO or MUGA
   2) Operate at an appropriate time

6. Associated Coronary Artery Disease
A. Treat significant coronary artery disease at the time of surgery even if asymptomatic
B. CABG reduces risk of AVR and improves long-term survival
C. Coronary angiography is indicated in all patients older than 45 years who will be having AVR

7. Ventricular Performance After AVR
A. AVR may improve LV performance
B. Pre-op LV dysfunction is the strongest predictor of post-op dysfunction (60%)
C. Microscopic changes in myocardium may persist despite improvement in symptoms and reduction in heart size

8. Age and AVR
A. Advanced age most common predictor of survival and cardiac events
B. AVR very effective treatment even in patients over age 70 or 80
C. Even the best patients over age 80 have reduced reserve

9. Choice of Replacement Device
A. Age less than 55 years - Aortic allograft or pulmonary autograft
B. Age between 55-75 years - Mechanical prosthesis
C. Age greater than 75 years - Porcine heterograft, stented or stentless
D. Allografts and autografts enlarge the orifice by about 2 mm, porcine heterografts reduce valve size by about 2 mm, and mechanical valves reduce valve size by about 5-8 mm

10. Size of Prosthesis for AVR
A. 19 mm
1) Prohibitively high LV/Ao gradient
2) Enlarge the aortic root or perform Ross procedure instead
B. 21 mm
1) Adequate size if BSA 1.5-1.7 M2 and patient is sedentary
2) If BSA greater than 1.7 M2 = enlarge the aortic root (10 year survival 80% vs 60%)
C. 23 mm or larger
1) Acceptable LV/Ao gradient in all patients

11. Survival After AVR
A. Early (hospital) death - 3-6%
B. Time-related survival
1) 5 years - 75%
2) 10 years - 60%
3) 15 years - 40%
C. Mode of death
1) Early due to CHF, hemorrhage, infection, CVA
2) Sudden - 20%
3) Device related - 20%

12. Risk Factors for Survival after AVR
A. Advanced age
B. Functional status (NHYA class)
C. Depressed LV function (aortic incompetence)
D. Coronary artery disease
E. Presence of endocarditis
F. Aneurysm of ascending aorta
G. Mismatch of prosthesis and body size
Chapter 21 - Mitral Valve Disease

1. Surgical Anatomy of the Mitral Valve
   A. Leaflet
      1) Anterior leaflet inserts on about 1.3 of the annulus
      2) Posterior leaflet inserts into about 2/3 of the annulus
      3) Posterior leaflet area is significantly larger than anterior leaflet area
      4) The combined leaflet area is twice the mitral orifice
   B. Chordae
      1) Primary attachment to free margin
      2) Secondary & tertiary attachment away from free margin
   C. Papillary Muscles
      1) Anterolateral and posteromedial supplying both leaflets

2. Mitral Stenosis
   A. Etiology
      1) Rheumatic
   B. History
      1) Dyspnea, fatigue, palpitations, hemoptysis
   C. Physical exam
      1) Loud 1st heart sound, diastolic, rumble, opening snap
   D. Chest X-Ray
      1) Left atrial and right ventricular enlargement

3. Cardiac Catheterization
   A. Mitral valve area = diastolic flow ÷ %pressure gradient (Gorlin formula)
      1) Normal Mitral valve area 4.0-5.0 cm²
      2) Symptomatic mitral stenosis 1.4-2.5 cm²
      3) Critical mitral stenosis <1.0 cm²

4. Natural History
   A. Mitral Stenosis
      1) Continuous progressive, life-long disease
      2) Slow, stable early course, latent period of 20-40 years from Rheumatic fever to onset of symptoms
3) Onset of symptoms to disability- 10 years
4) Atrial fibrillation 30-40%
4) More common in older patients

B. 10 year survival-- Overall 50-60%
1) Asymptomatic => 80% (60% no progression of symptoms)
2) Symptomatic 0-15%
3) Severe pulmonary hypertension <3%
4) Older patients with atrial fibrillation 25%
5) Normal sinus rhythm 46%

C. Causes of death
1) CHF 60-70%
2) Systemic embolism 20-30%
3) Pulmonary embolism 10%
4) Infection 1-5%

5. Indications for Intervention
A. Mitral stenosis- reparable valve
1) Prominent opening snap, no calcification
2) Pliable leaflets, commissural fusion
3) Chordae and papillary muscle normal

B. Balloon valvuloplasty vs open commissurotomy
1) Experience of operator
2) Left atrial thrombus or mitral insufficiency = open commissurotomy

C. Symptomatic patients (NYHA Functional Class III or IV)
1) MV area <1.5 cm²
2) PA pressure > 50 mmHg at rest- >60 mmHg exercise

6. Indications for Surgery
A. Mitral valve stenosis- Mitral valve replacement

B. Symptomatic patients
1) NYHA functional class III-IV
2) MV area >1.5 cm²

C. Asymptomatic patients
1) PA pressure >60 mmHg at rest
7. **Mitr al Incompetence**
   
   **A. Etiology**
   1) Myxomatous degenerations
   2) Mitral valve prolapse
   3) Ruptured chordae
   
   **B. History**
   1) Asymptomatic
   2) Dyspnea on exertion
   3) Congestive heart failure
   
   **C. Physical exam**
   1) Holosystolic at apex radiates to axilla
   
   **D. Chest X-Ray**
   1) LV and LA enlargement
   2) Echocardiography
   
   **E. Best diagnostic tool for Mitral valve prolapse**
   
   **F. Quantitative regurgitation**
   
   **G. Direction of jet**
   1) Anterior (septal) = posterior leaflet prolapse
   2) Cardiac Catheterization
   
   **H. Quantitative regurgitation**
   
   **I. Assess function of pulmonary hypertension**
   1) ? Exercise
   
   **J. Coronary angiography**
   
   **K. Natural history**
   
   **L. Mitral valve prolapse is most common form of valvular heart disease**
   1) Affecting 2-6% of population
   2) Probably overdiagnosed
   
   **M. Gradual progression of Mitral regurgitation results in enlarged LA and LV**
   
   **N. Enlarged LA may result in atrial fibrillation**
   
   **O. Moderate to severe Mitral regurgitation results in LV dysfunction, CHF, pulmonary hypertension**
   
   **P. Prolonged asymptomatic phase ÷ accelerated phase, ruptured chordae tendinae**
   
   **Q. Men age >45 are subject to complications**
   
   **R. Sudden death rare <1% per year**
   
   **S. Infective endocarditis - incidence extremely low, risk controversial, antibiotic prophylaxis advised**
   
   **T. Occasionally presents as acute severe Mitral regurgitation requiring urgent operation**
8. Mitral Incompetence- Indications for Operation
   A. Acute symptomatic mitral regurgitation
   B. Symptomatic or Asymptomatic Patients with LV Dysfunction

<table>
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<tr>
<th>TYPE</th>
<th>EF</th>
<th>Systolic Dimension</th>
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<tbody>
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<td>Mild</td>
<td>0.5-0.6</td>
<td>40-50 mm</td>
</tr>
<tr>
<td>Moderate</td>
<td>0.3-0.5</td>
<td>50-55 mm</td>
</tr>
<tr>
<td>Severe</td>
<td>&lt;0.3</td>
<td>&gt;55 mm</td>
</tr>
</tbody>
</table>

C. LV dysfunction will persist, symptoms diminish, risk increase
D. Asymptomatic patients with atrial fibrillation or pulmonary hypertension
   1) PA = >50 mmHg at rest, >60 mmHg exercise

9. Surgical approaches to the Mitral Valve
   A. Left thoracotomy
      1) Rarely used, redo
   B. Right thoracotomy
      1) For isolated redo MVR
   C. Median sternotomy
      1) Traditional through Waterston’s groove
      2) Through Waterston’s groove with SVC detachment
      3) Superior via dome of left atrium transseptal
   D. Partial/mini-sternotomy

10. Surgical Procedures for Mitral Valve Disease
    A. Stenosis
        1) Closed mitral commissurotomy
        2) Open mitral commissurotomy
        3) Mitral valve replacement-- likely with thick anterior leaflet, calcification, mitral regurgitation, thick short chordal
    B. Regurgitation
    C. Mitral valve repair
        1) Repair likely with posterior leaflet prolapse or ruptured chordal
        2) Repair less likely with anterior leaflet prolapse
    D. Mitral valve replacement with preservation of chordae tendinae
        1) Mechanical bioprosthesis
        2) Bioprosthesis (stented porcine aortic)
        3) Mitral homograft
11. Risk Factors for Mitral Valve Replacement
A. Type of prosthesis is not a risk factor
B. Previous valvotomy or commissurotomy not a risk factor
C. NYHA Class (MR, LV size, LA size)
D. Age
E. Tricuspid valve disease
F. Coronary artery disease (3 x risk)
G. Chordal preservation reduces risk

EXTENDED OUTLINE

1. Structure and Pathology
A. crucial to understand the anatomy of the mitral valve in order to perform valve repair
B. mitral valve is composed of five separate components
   1) valvular leaflets
   2) annulus
   3) chordae tendinae
   4) papillary muscles
   5) left ventricular wall

2. Ischemic Mitral Valve Disease
A. myocardial ischemia from coronary artery disease affects mitral valve function in many ways
   1) ischemia leads to loss of contractility which affects mitral valve competence
   2) lateral ventricle wall and papillary muscle dysfunction
      a) anterior papillary muscle is supplied usually by the LAD but can be from a diagonal, ramus or proximal marginal arteries
      b) posterior papillary muscle is usually supplied by RCA or distal CX
      c) ischemia in these distributions can lead to papillary muscle dysfunction
   3) papillary muscle necrosis and rupture leads to acute cardiac decompensation
   4) left ventricular aneurysm may lead to valvular incompetence
   5) the chordae tendinae and valve leaflets are avascular and not directly affected by ischemia
   6) annular dilatation can lead to MV incompetence
      a) up to 20% of patients undergoing surgery for CAD will have some MV regurgitation
      b) often with correction of underlying CAD with improve MV regurgitation
3. Rheumatic Disease
A. mitral leaflets are the most common structures involved
B. mitral stenosis occurs distant from initial episode
C. rheumatic heart disease can manifest itself as mitral stenosis, insufficiency or both
D. rheumatic process includes:
   1) leaflet thickening, calcification and retraction
   2) periannular calcification with limitation of annular motion
   3) leaflet fusion (esp. at the commissural regions) and “fish-mouthing”
   4) chordal thickening, shortening, and fusion
   5) papillary muscle inflammation

4. Myxomatous Degeneration
A. primarily affects the chordae and leaflets in older patients
B. chordae elongate leading to MV regurgitation
C. myxomatous degeneration with prolapse is a common cause for mitral valve operation

5. Endocarditis
A. leaflet tissue is commonly involved resulting in vegetations and destruction of leaflet
B. may result in annular or periannular abscess
C. destruction of leaflets, chordae, or papillary muscle may result in rupture and massive MV regurgitation
D. annular involvement of one valve may result in involvement of the other valve (aortic)

   Symptoms

6. Mitral Stenosis
A. rheumatic fever is most common cause
B. symptoms are usually insidious occurring over several years after infection
C. symptoms include decreased exercise tolerance, dyspnea, orthopnea and PND
D. pulmonary edema is a late sign
E. hemoptysis
F. the onset of atrial fibrillation often worsens the symptoms of mitral stenosis
   1) thromboembolism occurs in 20% patients
   2) may occur without presence of atrial fibrillation
   3) incidence of thromboembolism correlates with size of the left atrial appendage
G. pulmonary hypertension can occur and is usually reversible after valve replacement

7. Mitral Regurgitation
   A. symptoms depend on the acuteness of onset
   B. if acute in onset secondary to papillary muscle rupture or leaflet disruption then patient will present with pulmonary edema and right heart failure
   C. patients with chronic mitral regurgitation with remain asymptomatic for several years until left ventricular failure develops at which time dyspnea occurs

Physical Examination

8. Mitral Stenosis
   A. loud first heart sound, diastolic murmur, and sometimes
   B. an opening snap murmur is best heard over the apex
   C. opening snap occurs when the leaflets are mobile
   D. when leaflets are rigid and calcified there is no opening snap
   E. may be evidence of peripheral arterial embolism
   F. signs of right ventricular failure may be present
      1) RV heave
      2) tricuspid regurgitation
      3) hepatomegaly, ascites
   G. normal sized ventricle

9. Mitral Regurgitation
   A. left ventricular enlargement
   B. high pitched apical systolic murmur that radiates to the axilla
   C. in a prosthetic valvular leak, the murmur may radiate in any direction
   D. holosystolic murmurs are indicative of severe MR
   E. in ischemic regurgitation the murmur may vary in intensity depending on the presence of ischemia and papillary muscle dysfunction
   F. findings of right ventricular failure may occur in advanced disease

10. Laboratory Examinations
    A. EKG may reveal atrial fibrillation and/or enlargement
    B. CXR may reveal ventricular enlargement, pulmonary edema or annular calcification
    C. ECHO- mainstay of mitral valvular pathology diagnosis
       1) reveals leaflet thickening and abnormal excursion
2) doppler ECHO can estimate transvalvular gradient
3) detection of atrial thrombi and valvular vegetations
D. cardiac catheterization
1) completed if coronary artery disease is suspected
2) can calculate valve area utilizing the Gorlin formula

Indications for Operation

11. Mitral Stenosis
A. asymptomatic patients are generally not recommended for operation
B. patients with few symptoms that are otherwise healthy should undergo operation
C. patients with severe mitral stenosis should undergo operation
1) normal orifice is 4-6 cm²
2) 2-4 cm² is mild
3) < 1 cm² is severe

12. Mitral Regurgitation
A. indications for operation are more complex than mitral stenosis
B. endocarditis and acute ischemic mitral regurgitation are clear indications
C. patients with MR secondary to myxoid degeneration or rheumatic disease typically have an insidious onset of symptoms after several years of quiescent disease
1) patients with MR become symptomatic only after left ventricular function has been irreversibly damaged at which time, results are less favorable
2) ejection fraction is a poor measure of function because it may be preserved even after irreversible LV failure has occurred
3) when the ejection fraction is 40% the left ventricular function is severely impaired
4) it is important to assess status of the LV for prognostic reasons and to determine optimal timing for operation
   a) measurements of end-systolic volume or diameter have been found to be reliable indices for LV function
   b) patients with end-systolic volume <30 mL/m² or an end-systolic diameter of < 40 mm will have normal LV function post-op
   c) patients with end-systolic volume > 90 mL/m² or end-systolic diameter > 50 mm LV function is irreversibly impaired and surgical mortality is higher
13. Operation General Considerations
A. three classes of techniques
1) valve repair
2) valve replacement
3) transcatheter
B. patient-specific considerations
1) presence of cardiogenic shock
2) is valve repair is feasible
3) presence of atrial fibrillation
4) ability to take anticoagulants

14. Choice of Incision and Cannulation
A. median sternotomy- most common
B. right thoracotomy
C. left thoracotomy
D. dual or single caval cannulation
E. antegrade or retrograde cardioplegia

15. Left Atrial Incision
A. "standard approach" - incision parallel to intraatrial groove in to lateral atrium posterior to SVC and IVC
B. superior septal- incision in roof of left atrium between aorta and SVC
C. transseptal- incision in right atrium and through intraatrial septum

16. Chordal Preservation
A. controversy exist on how to deal with native mitral valve tissue
B. in endocarditis with infected tissue, or with heavily calcified valvular apparatus, complete excision is necessary
C. there is some evidence to suggest preservation of chordae and the posterior leaflet is important in maintaining the annuloventricular apparatus and normal left ventricular function
D. techniques
1) preservation of posterior valve
2) elliptical excision of the anterior leaflet
3) excision and re-attachment of the chordae

17. Atrioventricular Groove Disruption
A. occurs with over aggressive resection of valvular apparatus
B. usually a fatal complication
C. requires re-institution of bypass, removal of valve, repair of disruption and valve replacement
D. retention of the posterior leaflet had decreased the incidence

18. Associated Operations
A. when coronary bypass is also required, the distal anastamoses are completed first followed by valve replacement in order to avoid atrioventricular disruption
B. when tricuspid valve procedures must be completed then a transseptal approach can be utilized
   1) the tricuspid procedure can be completed after the mitral valve has been replaced and the left atrium closed with the aortic cross clamp removed
C. with combined aortic valve replacement, care must be taken when excising the intra-annular region to avoid damaging the aortic annulus

Choice of Valve

19. Bioprosthetic Valves
A. low incidence of thromboembolism
B. average durability is 10-15 years
C. porcine valves may be chosen in females who desire to become pregnant
D. glutaraldehyde-preserved stented porcine tissue valves are the most common
E. bovine pericardial valves were found to degenerate rapidly
F. structural deterioration
   1) mitral stenosis secondary to calcification, esp. in young patients
   2) mitral insufficiency form cuspal tearing and detachment
G. when bioprosthetic valve degeneration is detected, repair should be completed before the onset of symptoms due to the possibility of rupture and embolism
H. some recommend patients should receive 3 months of anticoagulation therapy until endocardial healing is completed

20. Mechanical Valves
A. durable with valve life up to 20 years
B. requires anticoagulation (INR 2.5 -3.0)
C. usually indicated in young patients or patients with chronic atrial fibrillation
D. three types of mechanical valves
   1) caged- ball (Starr-Edwards)
      a) first implanted in 1965
      b) incidence of thromboembolism is higher than bileaflet valves
c) long-term durability
d) high profile and contraindicated in patients with a small left ventricle
2) tilting disc (Medtronic, Omniscience)
a) low profile and useful in patients with small ventricles
b) orifice larger than caged-ball
c) meticulous surgical technique is required during implantation to avoid subvalvular interference
3) bileaflet (St. Jude, Carbomedics)
a) most common mechanical valve used in the U.S.
b) surgical technique important - no subvalvular interference
c) incidence of valve thrombosis is low

Results

21. Hospital Mortality
A. higher mortality than aortic valve replacement
B. the Society of Thoracic Surgeons National Cardiac Surgery Database is the largest database of cardiac surgical procedures in the U.S.
1) contains 345,000 cases with 9,000 mitral valve replacements
2) results of univariate analysis of the Database with the 1991 to 1993 experience (3625 patients)
a) operative mortality 2.5% for males and 3.9% for females for first time elective cases
b) coincident CAD increases operative risk (mortality 6.1% men, 12.2% women)
c) left ventricular end-systolic diameter is the most sensitive indicator of irreversible LV dysfunction from mitral regurgitation and predicts mortality

22. Overall Survival and Function
A. two most important factors are postoperative left ventricular function and age of patient
B. patients with impaired left ventricular function have decreased long-term survival
C. actuarial 5-year survival after mitral valve replacement in recent series is 80%, with a 10 year survival between 50 and 87%
D. a recent study demonstrated that in patients with combined coronary bypass and mitral valve replacement the actuarial 5-year survival to be 66% and 10-year survival of 31%
23. Bioprosthetic Valve Failure
A. a major risk is structural valve failure
B. infants, children and patients with chronic renal failure have a high incidence of structural failure
C. valves in the mitral position degenerate faster than those in the aortic position
D. follow-up is important to detect any structural failure
E. the two most common valves (Hancock and Carpentier-Edwards) show no difference in structural failure at 10 years with freedom from failure at 10 years between 60 and 78%
F. at 14 years, freedom from operation is between 27 and 43%

24. Thromboembolism and Bleeding
A. the percentage of patients free from thromboembolism at 10 years is similar whether mechanical or bioprosthetic valves are implanted with a rate of 1.6 to 2.9% per patient year
B. thromboembolism is higher with Starr-Edwards valves with only 55% of patients free of thromboembolism at 10 years
C. the incidence of anticoagulant-related hemorrhage is between 0.18 and 2.2 per patient year
D. bleeding is most common in the CNS, GI and GU tracts

25. Mechanical Valve Thrombosis and Structural Failure
A. the tilting disc valve is most susceptible to valve thrombosis
B. Bjork-Shiley valve has a thrombosis rate of 0.28% per patient year
C. St. Jude valve has a thrombosis rate between 0.09 and 0.3%
D. structural failure is rare in mechanical valves with three studies demonstrating no structural failure with St. Jude valves in a 10-year follow-up

26. Paravalvular Leak
A. presence of active native valve endocarditis is a risk for developing a paravalvular leak
B. patients with annular and atrial wall calcifications also have a higher incidence of leak
C. prosthetic valve hemolysis is most often related to paravalvular leaks
D. some valves (Bjork-Shiley) have a higher basal state of hemolysis
E. bileaflet valves have been found to be relatively free of chronic hemolysis
27. Prosthetic Valve Endocarditis
A. most important factor is the presence of native valve endocarditis
B. several series have reported rates of endocarditis of 0.06 to 0.4%
C. early mortality as high as 75%
D. indications for prosthetic valve rereplacement include septic emboli, persistent sepsis, and hemodynamic instability
E. infections caused by Staphylococcus aureus, gram negative organisms, and Candida albicans should lead to early consideration of valve rereplacement
Chapter 22 - Tricuspid Valve Disease

1. Pathology
   A. Congenital
      1) AV canal
      2) VSD
      3) Ebstein’s
      4) Myxoma

2. Acquired
   
<table>
<thead>
<tr>
<th>Structural</th>
<th>Functional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rheumatic disease</td>
<td>Cor-pulmonale</td>
</tr>
<tr>
<td>Endocarditis</td>
<td>Inferior MI</td>
</tr>
<tr>
<td>Carcinoid</td>
<td>Left-sided lesion</td>
</tr>
</tbody>
</table>

3. Normal Anatomy
   A. Septal, posterior and anterior leflets
   B. Annulus- sphincter-like function
   C. Septal annulus- fixed
   D. Dilatation only in anterior and posterior annulus

4. Functional Incompetence of the Tricuspid Valve
   A. Most common form of tricuspid dysfunction
   B. No leaflet or subvalvular abnormality
   C. RV dilatation (secondary to left-sided lesion)
   D. RV volume overload
   E. Pulmonary hypertension- "Pop-Off" safety feature

5. Rheumatic disease
   A. Functional TR due to left-sided lesion
   B. Structural- never isolated
      1) Stenosis- rare
      2) Mixed- stenosis/regurgitation
C. Most common cause for tricuspid replacement

6. Endocarditis
A. Usually IV drug abusers
B. Pseudomonas/ Staph. Aureus
C. Gram negatives, fungal
D. TR, septic pulmonary emboli
E. Antibiotics highly successful

7. Clinical-- Tricuspid stenosis
A. Prominent jugular "a-wave" or atrial fibrillation
B. +/- systolic murmur
C. Enlarged liver
D. Right atrial enlargement
E. Cath >4mm enlargement

8. Clinical-- Tricuspid regurgitation
A. Cannon waves in jugular pulse
B. Pansystolic murmur
C. Pulsatile hepatomegaly/ascites/edema
D. Catheterization- not accurate
E. Echocardiography
   1) Reversal of flow in IVC
   2) Paradoxical atrial septal shift
   3) Annular dilatation
F. Intraoperative- digital exam

9. Indications for Surgery
A. Tricuspid stenosis
   1) Gradient > 4 mmHg
   2) Commissurotomy vs replacement
B. Tricuspid regurgitation
   1) Clinical decision- improvement with repair of left-sided lesion
   2) Moderate to severe TR or any structural TR
   3) RV volume overload
   4) Right-sided heart failure
   5) Repair vs replacement
C. Endocarditis
1) Severe TR
2) Persistent sepsis
3) Recurrent PE
4) Excision vs replacement vs repair

10. Repair
A. Ring annuloplasty
   1) Shorten anterior-posterior annulus
   2) Avoid septal annulus
B. Sewn annuloplasty
   1) Kay
   2) DeVeiga
C. Can be done after cross-clamp removal

11. Replacement
A. Bioprosthetic valve if $\geq 28$ mm
B. Smaller annulus consider prosthetic valve
C. Septal sutures in base of leaflet
D. Epicardial permanent pacemaker electrodes

12. Excision
A. If IV drug abuser ceases abuse
B. Second-stage replacement

13. Results
A. Annuloplasty
   1) Addition adds minimal risk to MVR
   2) Freedom from moderate/severe TR about 85% for 6 years
   3) Results poorer with pulmonary hypertension
   4) Reoperation for TR recurrence- rare
B. Replacement
   1) Early mortality 7%
   2) Porcine valve longer life than mitral position
   3) Thrombosis: bileaflet $<$ disc $<$ ball/cage
   4) Mortality- multi-valve-disease, EF, co-morbidities
C. Excision
   1) Early mortality 12%
   2) Survival 63% at 15 years
3) 50% right sided heart failure
4) RV overload, septal shift, arrhythmias

14. Complications
A. Annuloplasty failure- related to pulmonary hypertension
B. Bioprosthetic calcification in younger age
C. Complete heart block
1) 10% with MVR and TR early postoperatively
2) 25% at 10 years
3) Rare after repair

15. Risk of premature death
A. Excision
B. Prior valve surgery
C. Older age at operation
D. Preoperative functional class
Chapter 22 - AV Valve Repair

1. The Perfect Valve
   A. Excellent hemodynamics
   B. Non-thrombogenic
   C. Durable
   D. Unrestricted availability
   E. Easily implantable
   F. Silent function
   G. Low cost

2. Selection of Valve Prosthesis
   A. Primarily based on hemodynamic need, risk of anticoagulation and required durability
   B. Small aortic root
   C. Elderly
   D. Multiple medical conditions
   E. Child-bearing female
   F. Lifestyle precluding anticoagulation
   G. Ability or desire to undergo reoperation

3. Hemodynamic performance
   A. Aortic
      1) Homograft / autograft
      2) Stentless heterograft
      3) Mechanical prosthesis
      4) Stented heterograft
   B. Mitral
      1) Valve repair
      2) Mechanical prosthesis
      3) Stented bioprosthesis

4. Thromboembolism and Hemorrhage
   A. Homograft / autograft
   B. Bioprosthesis
C. Mechanical prosthesis

5. Durability
   A. Mechanical prosthesis
   B. Autografts
   C. Homografts
   D. Bioprosthesis

6. Infection
   A. Important when operating on endocarditis
   B. Homograft / autograft most resistant to infection
   C. Stented bioprosthesis = mechanical prosthesis

7. Valve Repair
   A. Successful valve repair is always more preferable than valve replacement
   B. Aortic
      1) Leaflet plication, commissure re-suspension
   C. Mitral
      1) Posterior quadrangular resection
      2) Chordal transfer
      3) Ring annuloplasty
   D. Require training and experience for good result

8. Aortic Homograft
   A. Sir Donald Ross- 1962
   B. Performance
   C. Freedom from failure 80-90%- 10 years
   D. Risk of grade III/IV AI @ 7 years:
      1) 26% with subcoronary implant- 22% reoperation
      2) 12% with inclusion/root implant- 5% reoperation
   E. Freedom from thromboembolism 97% @ 14 years
   F. Freedom from endocarditis 94% @ 14 years
   G. 71% actuarial survival @ 14 years (J Card Surg 1991 6:534)
   H. Implant Techniques
      1) Subcoronary
      2) Inclusion
      3) Root replacement
I. Immunologic responses
1) Cryopreservation maintains collagen but not cellular viability
2) Antibody production related to ABO type, HLA
3) Matching and immunosuppression

A. Advantages
1) Viable tissue, excellent hemodynamics
2) Near 0% thromboembolism, growth potential
3) Non-antigenic
4) Pulmonary valve equal in strength as aortic valve
B. Disadvantage
1) Creating 2-way valve pathology from single valve disease
C. Results
1) Freedom from re-operation 81% @ 8 years
2) 5-10% annular dilatation and regurgitation
3) Pulmonary homograft deterioration
D. Technique
1) Root replacement preferred
2) Tailoring of aortic/pulmonary size mismatch
3) Bolstering ring with Dacron strip
E. Long-term follow-up still accruing

10. Porcine Bioprosthesis
A. Introduced in 1972
B. Indications
1) Elderly, child-bearance, intolerance of anticoagulation, bleeding diatheses
C. Disadvantages
D. Structural deterioration
1) Less common in older patients
2) Faster in mitral vs aortic positions (55% vs 37% @ 15 years)
E. Calcification
1) Children, adolescents, renal failure, pregnancy?
F. Obstructive in smaller sizes
1) 19 mm: Porcine 0.8-1.2 cm2, Mechanical 1.6 cm2
2) Supra-annular: 2.1 cm2
11. Stentless Porcine Bioprosthesis
A. Stent is the major factor governing stress
B. Advantages
1) Better hemodynamics than stented prosthesis
2) Availability (full range of sizes)
C. Implant technique
1) Subcoronary/ inclusion/ root replacement
D. Long-term follow-up pending

12. Mechanical Prosthesis
A. Most commonly used prosthesis
B. Excellent durability
C. Higher incidence of anticoagulation related complications
D. Flow characteristics Flow Characteristics
1) ball/cage < tilting disc < bileaflet

E. Thrombogenic potential
1) ball/cage > tilting disc > bileaflet
2) Aortic < Mitral < both

13. Atrial Fibrillation and Valvular Disease
A. Anticoagulation substantially reduces stroke
B. Large immobile atrium with valve disease increases stroke risk
C. Anticoagulation should be maintained after valve replacement
D. No benefit to bioprosthesis

14. Anticoagulation Management
A. TIA is most common event
B. Standardization of coagulation management (INR)
C. Narrow therapeutic range - balance between thrombolic and bleeding risk
D. ACCP recommendations: INR 2.5-3.5
   1) Aortic: 2.5-3.0
   2) Mitral: 3.0-3.5
   3) Both: 3.5-4.0
E. Appropriate use of antiplatelet therapy

15. Moderate Aortic Stenosis with Coronary Artery Disease
A. Treatment plan
B. Life expectancy in the 7th decade
   1) Male - 10 years
   2) Female - 13 years
C. Valve area of 0.8
   1) 1.5 cm² - moderate stenosis
   2) >1.5 cm² - mild stenosis
D. Gradient
   1) <25 mmHg is mild stenosis

16. Natural History
A. Moderate aortic stenosis - 10 years - 30% need or AVR
B. (0.8-1.5 cm²) - 15 years - 50% need AVR
C. Aortic gradient increases by 7 mmHg/year when base gradient is 10 mmHg or more
D. Valve area decreases by 11 cm²/year
E. Progression of moderate to severe stenosis mean duration is 5-7 years

EXTENDED OUTLINE

1. Surgical Anatomy of Cardiac Valves And Techniques of Valve Reconstruction
   I. Mitral Valve
      A. Anatomy
         1) Leaflets - surface area is twice that of the MV orifice
            a) anterior
(1) common attachment with left coronary and 1/2 of the noncoronary cusps
b) posterior
2) Commissures'''
a) anterolateral
b) posteromedial
c) corresponding PM underneath
3) Annulus
a) insertion of atrial and ventricular muscle
b) attached to fibrous trigones
c) right trigone junctions between the MV, TV, AV & membranous septum
d) sphincter like function causing a 26% narrowing during systole
4) Chordae tendinae
a) insert into the distal part of the valve on the rough zone
b) anterior leaflet
c) main, paramedian, paracommissural
d) posterior leaflet
e) basal, rough zone, cleft
5) Papillary Muscles
a) anterolateral and posteromedial
6) Arterial Supply
a) leaflets
(1) anterior - Kugal’s artery from the RCA or Circ.
b) PM
(1) anterolateral - LAD, Diagonal, Circ.
(2) posteromedial - Circ. and RCA
B. Mitral Valve Repair
1) leaflet motion is either normal, prolapsed, or restricted
2) if the leaflets move normally and there is MR then the annulus is dilated or there is leaflet perforation
3) goal is to improve movement of the leaflets and remodel the annulus
4) Repair of Prolapse
a) quadrangular resection
b) gap repaired by:
(1) annular plication
(2) sliding plication
5) Repair of Anterior Leaflet
a) chordal rupture
(1) fix to secondary chordae
(2) chordal shortening
(3) chordal transposition (post. to ant.)
(4) chordal replacement
b) chordal shortening
6) Papillary Muscle
a) sliding plasty
b) cuneiform resection
c) concertina technique
7) Restricted Leaflet Motion
a) resection of secondary chordae
b) triangular resection of fused elements
C. Results
a) 72 % 5 year survival
b) 94 % freedom from embolic event
c) 97 % freedom from endocarditis
d) 87 % without reop @ 15 years
e) 2. 5 % with signs of MR

2. Tricuspid Valve
A. Anatomy
1) Leaflets
a) anterior, septal, posterior
2) Commissures
a) anteroseptal, anteroposterior
3) Annulus
a) attached only to the right fibrous trigone between the septal leaflet and the anteroseptal commissure, elsewhere the valve inserts directly into the myocardium
4) Chordae Tendinae
a) similar to the MV with the addition of free edge @ deep chordae
5) Papillary Muscles
a) anterior
b) largest
c) send chordae mainly to the anterior leaflet
d) posterior
e) may have more than one belly
f) chordae of the posterior and a few to the septal
g) septal leaflet supported with chordae directly from the septum
B. Tricuspid Valve Repair
1) indications for repair
   a) annular size > 34 in women and > 36 in men
   b) organic lesions
2) annuloplasty mainly works in the posterior leaflet
3) organic lesions
   a) division of fused commissures
   b) prolapse treated the same as MV
C. Results
1) .6 % reop rate with ring vs. DeVega

3. Aortic Valve
A. Anatomy
1) leaflets
   a) tricuspid
      (1) all insert into annulus
   2) fibrous skeleton
      a) does not change during the cardiac cycle
   3) sinuses of valsalva
B. Repair
1) Annular dilatation
   a) circular annuloplasty
   b) commissural annuloplasty
2) Repair of leaflets
   a) prolapse
      (1) triangular resection
      (2) leaflet resuspension
   b) restricted
      (1) commissurotomy
C. Results
1) 20 % reop rate
Chapter 24-Selection of Prostheses

1. Mechanical valves
   A. Selection
      1) <70 yo
      2) no h/o bleeding
   B. Survival - over ½ of late deaths are related to valve complications
   C. Hemodynamics
      1) Tilting disc and bileaflet are "low-profile"
      a) Tilting disc - 6-7mmHg gradient
      2) Caged ball is "high-profile"
   D. Thromboembolism
      1) Highest risk is in first 14 months
      2) Steady level after - 0.5%/pt-yr
      3) INR 2.5 = therapeutic
      4) Coumadin for all - antiplatelet agent for high-risk (a-fib, h/o embolus, etc.)
      5) Thrombolytic therapy - never for patients in a low-output state
   E. Hemorrhage
      1) Incidence the same for aortic and mitral position
      2) Associated w/high anticoagulation levels (INR >4.5)
      3) At INR 2.5-3.5, anticoagulation-related death = 0.2%/pt-yr
   F. Endocarditis
      1) PVE - mortality = 23-69%
      2) Most commonly in first several months
      3) After initial period = 0.17%/pt-yr
   G. Periprosthetic leakage (see Table 122-2)
      1) Predisposing factors
         a) Annular calcification
         b) Infection
         c) Annuloprosthetic mismatch
         d) Excessive tension on sutures, annulus or both
         e) Technique
         f) Abnormal annulus tissue
   H. Structural valve degeneration
      1) Rare
2) Leaflet fracture - may be due to mishandling à scratches

I. Nonstructural valve degeneration
1) Pannus formation

2. Bioprosthetic Cardiac Valves
   A. Features
   1) No indication for anticoagulation
   2) Survival
   B. Glutaraldehyde-preserved porcine valves
   C. Hemodynamics
   1) Central unimpeded flow
   2) In aortic position, small (19-21mm) valves are stenotic
   3) Supraannular bioprosthesis improves flow
   D. Thromboembolism
   1) INR 2.0-3.0 for a-fib
   E. Hemorrhage—see Table 122-4
   F. Structural valve dysfunction
   1) Progressive degeneration
   2) Reasons
      a) Calcification
      b) Collagen degeneration-associated cuspal defect
      c) Time-dependent - accelerated failure after 8-10 years
      d) Valve failure and calcification accelerated in children à young adults
      e) Mitral > aortic failure
   G. Endocarditis
   H. Periprosthetic leak

3. Pericardial Valves
   A. Better flow (than porcine bioprostheses)
   B. Newer designs more durable

4. Homograft Valve Prostheses
   A. Patient survival 85-90% @ 7.5yr // 71% @ 14yr
   B. Durability
   1) Early homografts - calcification & cusp rupture
   2) Cryopreservation (vs irradiation & chemical processes)
      a) 95-98% freedom from structural deterioration (10yr)
   C. Thromboembolism
   1) ? Role of endothelium
D. Endocarditis
1) S. aureus a major player
2) Many respond to Abx
3) Failure to respond to Abx = surgical indication
Chapter 25 - Acute Aortic Dissection

Definition
Dissection of the aorta is an event that results in the separation of the layers of the media by blood, producing a false channel with variable proximal and distal extension.

1. Etiology
   A. Cystic medial necrosis - 20%
   B. Marfan syndrome - 20-40%
   C. Other causes: hypertension, bicuspid aortic valve/aortic stenosis, atherosclerosis, coarctation, pregnancy, trauma, aortic cannulation, aortic cross-clamping, cardiac catheterization

2. Morphology
   A. Blood leaves the normal aortic channel through intimal tear, rapidly dissecting through the media to produce a false channel
   B. The intimal tear is sometimes absent; possible rupture of vasa vasorum with medial hemorrhage
   C. Usually the dissection proceeds distally; 38% dissect proximally and 10% in the transverse arch
   D. Dissection may shear off or extend into branch arteries
   E. False channel characteristics:
      1) Thickens and gradually enlarges with time
      2) May interrupt blood supply of branches by external compression
      3) Outer wall thin - media + adventitia
      4) May rupture to pericardium or pleural space
      5) May thrombose
3. **Classification**

<table>
<thead>
<tr>
<th>DeBakey I</th>
<th>Ascending + arch</th>
<th>Stanford A</th>
</tr>
</thead>
<tbody>
<tr>
<td>DeBakey II</td>
<td>Ascending only</td>
<td>Stanford A</td>
</tr>
<tr>
<td>DeBakey IIIa</td>
<td>Descending only</td>
<td>Stanford B</td>
</tr>
<tr>
<td>DeBakey IIIb</td>
<td>Descending + abdom</td>
<td>Stanford B</td>
</tr>
</tbody>
</table>

4. **Clinical Features**
   A. Severe pain - tearing, interscapular, precordial, neck, migrating, persisting
   B. Signs of occlusion of major vessel
      1) Arch - stroke, syncope
      2) Intercostal - paraplegia
      3) Renal - oliguria-anuria
      4) Iliac - ischemic leg
   C. Sudden death
      1) Rupture to pericardium, pleural, peritoneal space
      2) Shear off coronary artery
   D. Hypovolemic Shock
      1) Blood in periaortic tissues
      2) Acute aortic valve insufficiency
      3) Cardiac tamponade
5. Diagnosis
A. Imaging
1) Chest X-ray - widened mediastinum, cardiomegaly, pleural effusion, intimal calcification separated more than 6mm from the edge
2) Echo - identifies intimal flap/false channel, noninvasive, no contrast media, performed at bedside
3) TEE is best for the descending aorta; TTE best for the ascending aorta and arch
4) Aortography - conventional method of diagnosis (gold standard), shows origin of arteries from true or false lumen
5) CT Scan - identifies intimal flap rapidly, requires contrast media
6) MRI - multiple planes, cine for AI
B. Main points of interest
1) Involvement of the ascending aorta
2) Location of the intimal tear
3) Status of perfusion in the major branches
4) Size of the aorta and presence of AI
5) Extent of the false lumen
6) Pericardial effusion

6. Treatment Overview
A. Type A and complicated type B dissections are managed surgically
B. Uncomplicated type B dissections are managed medically
C. The goals of surgical therapy are to prevent extension, excise the intimal tear, and replace the segment of aorta which is susceptible to rupture
D. The goals of medical therapy are to prevent extension, control blood pressure, and relieve pain

7. Treatment - Ascending Aorta
A. Immediate operation is indicated because rupture is likely
B. Contraindications: ? advanced age, incurable coexisting disease, paraplegia
C. Note: new stroke may resolve, not a contraindication
D. Replace ascending aorta and the aortic valve if insufficient; the valve may be worth preserving if normal
E. Replace arch if false channel leaking or site of tear
F. Operative strategy (elephant trunk)
1) Use circulatory arrest if indicated

<table>
<thead>
<tr>
<th>TEMP.</th>
<th>OXYGEN CONSUMPTION</th>
<th>SAFE PERIOD FOR TOTAL CIRCULATORY OCCLUSION</th>
</tr>
</thead>
<tbody>
<tr>
<td>37° C</td>
<td>100%</td>
<td>4-5 min.</td>
</tr>
<tr>
<td>29° C</td>
<td>50%</td>
<td>8-10 min.</td>
</tr>
<tr>
<td>22° C</td>
<td>25%</td>
<td>16-20 min.</td>
</tr>
<tr>
<td>16° C</td>
<td>12%</td>
<td>32-40 min.</td>
</tr>
<tr>
<td>10° C</td>
<td>6%</td>
<td>64-80 min.</td>
</tr>
<tr>
<td>6° C</td>
<td>3%</td>
<td>128-160 min.</td>
</tr>
</tbody>
</table>

2) Incise in a longitudinal fashion, avoiding the phrenic and recurrent nerves

3) Follow the dissection from inside the aorta to determine extent and remove damaged intima and media
4) Invert the graft into the distal aorta and approximate only the aortic adventitia to the inside of the graft

5) Pull the graft out and anastomose the arch vessels as a group

6) Once the distal repair is completed, the proximal repair can be performed with the graft clamped in a fashion that allows reperfusion and rewarming of the body
while the proximal aspect of the repair is completed (with continued protection of the heart with cardioplegia)

8. Treatment - Descending Aorta
A. Medical treatment indicated unless complications of dissection have occurred
1) NTP + beta-blocker to maintain normal blood pressure
2) 80% survive 1 year
3) Close follow-up required, 50% die in 3-5 years
B. Complications dictate immediate operation (interposition graft or fenestration)
1) Hemothorax, persisting pain, limb ischemia, acute renal failure, paraparesis (malperfusion syndrome)
2) Paraplegia NOT an indication for operation because not likely to resolve

9. Results After Operation
A. Early (hospital) death
1) Ascending aorta - 5-10% (up to 30%)
2) Arch - 10-25% (up to 50%)
3) Descending - 10% (up to 25-60%)
B. 10 year survival - 46%
1) 1/3 late death related to residual old false channel or redissection
C. Aneurysm of false channel
1) Uncontrolled hypertension - 50%
2) Controlled blood pressure - 10-20%
D. Redissection - 10% (Marfan higher)
Chapter 26 - Aortic Aneurysm

1. Morphology
A. Atherosclerotic (degenerative) aneurysm: most common cause (1/2) of localized aortic enlargement
B. Chronic aortic dissection: persistent false channel of outer media and adventitia gradually enlarges
C. Chronic traumatic aortic transection: false aneurysm contained only by aortic adventitia

D. Annulo-aortic ectasia: aneurysmal dilation of sinuses of Valsalva (Marfan, cystic medial necrosis)
**E. Aortitis: granulomatous or syphilis**

2. **Location**

<table>
<thead>
<tr>
<th>Location</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ascending aorta</td>
<td>45%</td>
</tr>
<tr>
<td>Arch</td>
<td>10%</td>
</tr>
<tr>
<td>Descending thoracic</td>
<td>55%</td>
</tr>
<tr>
<td>Thoracoabdominal</td>
<td>10%</td>
</tr>
</tbody>
</table>

3. **Symptoms**
   A. Usually asymptomatic
   B. Pain implies sudden extension or rupture of aneurysm
      1) Ascending aorta - neck, jaw
      2) Descending aorta - back, inter-scapular
      3) Thoracoabdominal aorta - low back
   C. Compression of adjacent structures
      1) SVC syndrome
      2) Hoarseness, laryngeal nerve

4. **Associated Atherosclerotic Disease**

<table>
<thead>
<tr>
<th>Disease</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coronary arteries</td>
<td>16%</td>
</tr>
<tr>
<td>Cerebrovascular</td>
<td>10%</td>
</tr>
<tr>
<td>Peripheral vascular</td>
<td>10%</td>
</tr>
<tr>
<td>Abdominal aortic aneurysm</td>
<td>10%</td>
</tr>
</tbody>
</table>

5. **Diagnosis**
   A. Chest X-ray - enlarged aortic shadow
   B. Aortography - most valuable for assessment of aorta proximal and distal to aneurysm
C. **Echocardiography** - is useful in the assessment of aortic valve function and can demonstrate an intimal flap.

D. Computed axial tomography - real size of aneurysm and relation to adjacent structures
E. Magnetic resonance imaging - multiple planes possible, cine loop

6. **Natural History**
   A. Aortic aneurysms enlarge, eventually rupture (74%)
   B. Large aneurysms (>6 cm) tend to rupture
   C. Symptoms herald rupture (2 years)
   D. Aneurysm with chronic dissection have worst prognosis

7. **Operations - Ascending Aorta and Arch**
   A. Conventional cardiopulmonary bypass is utilized
   B. Aortic valve replacement with valved conduit (**Bentall procedure**) or repair/resuspension if feasible

   C. Arch anastomosis by tailoring or arch vessel reimplantation
D. **Reimplant** the coronary arteries as buttons

E. Do *not* cover the graft, as this will increase the risk of false aneurysm

F. Elephant trunk

G. Cerebral perfusion antegrade ? retrograde

H. Deep hypothermia - circulatory arrest

8. **Operation - Descending Thoracic Aorta**
   A. Clamp and go is the traditional method
   B. **Incise** the aneurysm to work inside
C. There are many approaches to protect the spinal cord and kidneys, including:
1) NTP and spinal fluid drainage are somewhat controversial
2) LV or ascending aorta to descending aorta shunt (Gott)
3) LA to femoral artery bypass
4) Femoral-femoral cardiopulmonary bypass

5) Deep hypothermia and circulatory arrest may be the most controlled approach
D. The proximal anastomosis should be precisely matched to the aorta
E. **Reattach** the intercostal arteries as an island; this is particularly important in the distal portion of the repair

F. The **distal anastomosis** may be fashioned either end-to-end or as an elephant trunk
9. Operation - Thoracoabdominal Aorta
A. Spinal cord and renal protection are essential
B. Hemorrhage remains a challenging problem
C. Thoracoabdominal incision with a retroperitoneal approach
D. There are also various approaches to these aneurysms:
   1) Clamp and go with or without heparinization
   2) Deep hypothermia with circulatory arrest
E. Reimplant the visceral and intercostal-lumbar arteries when involved

10. Results

<table>
<thead>
<tr>
<th>Death (hospital) - bleeding, neuro, MI</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ascending aorta</td>
<td>4-10%</td>
</tr>
<tr>
<td>Arch</td>
<td>5-50%</td>
</tr>
<tr>
<td>Descending</td>
<td>5-15%</td>
</tr>
<tr>
<td>Thoracoabdominal</td>
<td>up to 50%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Survival - new aneurysm, CHF, renal</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5 years</td>
<td>60%</td>
</tr>
<tr>
<td>10 years</td>
<td>40%</td>
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</tbody>
</table>
Section IV
Miscellaneous cardiac disease

Chapter 27 - The Pericardium and Tamponade

1. Definition
Pericardial disease can be divided into constrictive pericarditis and effusive pericarditis. Constrictive pericarditis involves thickening of both the fibrous and serous layers of the pericardium. Effusive pericarditis is the accumulation of fluid within the pericardial sac. Both entities are the result of inflammatory processes, may present acutely or have a chronic course, and produce a varying degree of cardiac compression.

2. Mechanisms of Cardiac Compression
A. Acute Tamponade
1) Pericardial pressure is normally subatmospheric and becomes more negative during inspiration
2) Transpericardial pressure is highest at end diastole, when ventricular volume is greatest
3) The pressure-volume curve for the pericardium rises steeply after a certain volume is exceeded, so that removal of small amounts of fluid will result in significant reduction in pressure
4) A rapid increase in intrapericardial fluid produces acute tamponade, with pressures reaching 20-30 mmHg
5) Systemic venous pressure rises, heart volumes are reduced, and systemic arterial pressure falls = Beck’s triad
6) This compression also causes pulsus paradoxus, which is a decrease in arterial pressure of more than 10 mmHg during inspiration
7) The x descent is accentuated, but the y descent is flattened or absent, as cardiac filling is severely restricted during diastole

B. Chronic Constrictive Pericarditis
1) The fibrous envelope reduces end-diastolic volume and causing inadequate preload
2) The right ventricular pulse wave during diastole demonstrates an early drop followed by a high plateau = square-root sign
3) Mean venous pressure is elevated and the x and y descents are steep and deep
4) Pulsus paradoxus is infrequent and may be difficult to detect in the setting of atrial fibrillation
5) Systolic left ventricular function is preserved, but the heart may still have impaired contractility

**C. Chronic Effusive Pericarditis**

1) The increased fluid volume presents initially as acute tamponade
2) Pericardial fluid drainage, however, does not resolve the compression, as the thickened pericardium continues to restrict diastolic filling
3) Like chronic constrictive pericarditis, the y descent is steep and deep, and pulsus paradoxus is infrequent

**CHRONIC CONSTRICTIVE PERICARDITIS**

1. **Pathophysiology**
   A. **Morphology**
   1) Inflammation affects both the parietal and visceral pericardium
   2) The pericardial space accumulates both fluid and fibrinous deposits
   3) Both layers of the visceral pericardium eventually fuse, and the heart is surrounded by a thick fibrous envelope
   4) This entire process may calcify and become adherent to the underlying myocardium
   
   B. **Etiology**
   1) In most patients, the underlying cause is unknown
   2) 10% have progression of acute pericarditis
   3) Less than 5% of cases are the result of cardiac surgery, and the time interval is widely variable
   4) Other causes include mediastinal radiation, rheumatoid disease, sarcoidosis, tuberculosis, and trauma
   
   C. **Natural History**
   1) Factors affecting disease progression and development of symptoms are incompletely known
   2) Atrial fibrillation is a common occurrence and causes sudden clinical deterioration
   3) When ascites is present, progression is more rapid

2. **Clinical Presentation**
A. Symptoms are classically delayed for several years after the initial episode of acute pericarditis
B. Fatigue, dyspnea on exertion, and jugular venous distension are early symptoms
C. Hepatomegaly, ascites, and peripheral edema are late findings, but dyspnea at rest and orthopnea are not common
D. On examination, there may be systolic retraction and a pericardial knock (produced by rapid ventricular filling in early diastole)

3. Diagnosis
A. Protein-losing enteropathy may be present, with severe hypoproteinemia
B. CXR demonstrates pericardial calcification in about 40% of patients and suggests compression in about 60%
C. EKG will show non-specific ST-T changes in the majority of patients; some will have a low QRS voltage or atrial arrhythmia
D. Echocardiography is most useful in acute tamponade, but can be helpful in assessing restrictive disease
E. CT and MRI can identify thickened pericardium, but give little additional information
F. Catherization characteristically shows equal end-diastolic pressures in the right atrium, pulmonary artery, and left atrium
G. Rapid infusion of volume can reproduce these features if catheterization findings are equivocal
H. A small anterolateral thoracotomy for pericardial biopsy can be used to distinguish between constrictive pericarditis and restrictive cardiomyopathy

4. Indications for Operation
A. Diagnosis is a general indication
B. Patients with minimal physiologic alteration and serious concomitant disease may be delayed until more significant pericardial symptoms develop
C. Patients with radiation-induced pericarditis should only undergo operation when symptoms are advanced

5. Operative Technique
A. Left anterolateral thoracotomy
1) Dissect off phrenic nerve and incise pericardium through area of minimal calcification over left ventricle
2) Create longitudinal incision anteriorly and posteriorly
If a pericardial space is present:
   1) An anterior pericardial flap is developed as far as the right AV groove and resected
   2) A posterior flap is developed far posteriorly and excised
   3) Care must be taken to resect bands off the pulmonary trunk to prevent postoperative RV hypertension
   4) Any fibrous plaques adherent to the epicardium are now resected
   5) If the epicardium is thin, it should not be disturbed; if thickened, it should be either removed entirely or in a number of areas

If no pericardial space is present:
   1) Deepen the longitudinal incision over an area of myocardium
   2) Carefully dissect flaps, leaving islands of scar and calcification attached to the myocardium where dissection is not possible
   3) Retain long flaps until dissection is complete to help control bleeding
   4) Care must be taken over the coronary vessels, and plaques may be left undisturbed here

B. Median sternotomy
   1) Cardiopulmonary bypass may be used and may be most convenient through the femoral vessels
   2) The pericardium is opened vertically and flaps dissected in a similar manner
   3) The pericardial flaps are excised about 1 cm anterior to the phrenic nerves, and dissection resumed posterior to the nerves
   4) The outer pericardial layer may then be separated from the pleura which contains the phrenic nerves

6. Results
A. Hospital mortality is about 5%
B. Most early deaths are from acute cardiac failure
C. 1-year, 5-year, and 10-year survival is about 90%, 75%, and 65%
D. Most late deaths are from chronic heart failure
E. Risk factors for death include poor preoperative functional status, ascites, peripheral edema, and previous radiation
F. Most patients have good results for functional status and reoperation is very infrequent

CHRONIC EFFUSIVE PERICARDITIS
1. Pathophysiology
   A. Morphology
   1) Inflammation causes secretion of excessive amounts of fluid as well as fibrin
   2) Strands of fibrin may accumulate within the layers, known as “bread and butter” pericarditis
   3) Both layers may be thickened and adherent
   4) The fluid may be loculated
   B. Etiology
   1) Common underlying diseases included advanced renal disease, dialysis, malignancy, and trauma
   2) The exact mechanisms are unknown
   3) Infection is rarely the cause of effusive pericarditis
   4) It is more common in young women
   C. Natural History
   1) Effusive pericarditis occurs in about 15% of patients on hemodialysis, and tends to occur early
   2) The course from malignancy is unpredictable
   3) The long-term course is unknown

2. Clinical Presentation
   A. Some patients present with fever, elevated white blood cell count, and a pericardial rub
   B. Others may have chest pain ranging from mild to severe
   C. Few patients develop acute tamponade
   D. Clinical examination demonstrated jugular venous distension; Beck's triad and pulsus paradoxus may or may not be present

3. Diagnosis
   A. CXR may demonstrate the classic enlarged, globular cardiac silhouette
   B. EKG shows widespread ST elevation when the effusion is acute; in chronic effusion, the EKG findings are similar to those of constrictive pericarditis
   C. Echocardiography is very accurate in the diagnosis and allows ultrasound-guided aspiration

4. Indications for Operation
A. Pericardial window is indicated for acute tamponade or when significant symptoms do not resolve after 7-10 days of intensive medical therapy. 
B. Subtotal or total pericardiectomy is indicated when effusion recurs or cannot be drained satisfactorily.

5. Operative Technique
A. Pericardiocentesis
1) Echocardiographic guidance is safe and effective.
2) Drainage of loculations may be difficult.
B. Subxiphoid Pericardial Window
1) Perform 4-8 cm vertical midline incision over xiphoid process and upper abdomen.
2) Remove or retract xiphoid process upward and dissect diaphragm off undersurface of sternum.
3) Open pericardium, aspirate fluid and excise a large portion of the pericardium.
4) Insert suction drain and close wound loosely.
C. Left Anterolateral Pericardial Window
1) Perform small anterolateral thoracotomy.
2) Create window anterior to the phrenic nerve.
D. Subtotal/Total Pericardectomy
1) See #5 above for chronic constrictive pericarditis.

6. Results
A. Long-term survival is considerably lower in patients who have underlying malignancy than with other diseases.
B. Relief of symptoms is generally excellent.

PURULENT PERICARDITIS
A. Most commonly caused by S. aureus or H. influenzae.
B. Pericarditis indicated if the effusion is not loculated.
C. Recurrent effusions should be treated with pericardial window.
D. Loculations or development of continued sepsis are indications for pericardectomy.

TUBERCULOUS PERICARDITIS
A. Occurs in about 1% of patients with tuberculosis.
B. Medical therapy alone is sufficient when the effusion is moderate and there is minimal pericardial thickening.
C. Pericardial window is indicated for persistent effusion, recurrent effusion after aspiration, thickened pericardium, or signs of pericardial constriction
D. Development of chronic constrictive pericarditis is an indication for pericardectomy

Chapter 28 - Cardiac Tumors

1. Definition
A. Any benign or malignant neoplasm arising primarily from the myocardium or within a cardiac chamber
B. Approximately 70% are benign and 30% are malignant
C. Metastatic tumors are not classified as cardiac tumors

<table>
<thead>
<tr>
<th>Benign</th>
<th>Malignant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myxoma</td>
<td>Angiosarcoma</td>
</tr>
<tr>
<td>Lipoma</td>
<td>Rhabdomyosarcoma</td>
</tr>
<tr>
<td>Papillary fibroelastoma</td>
<td>Mesothelioma</td>
</tr>
<tr>
<td>Hemangioma</td>
<td>Fibrosarcoma</td>
</tr>
<tr>
<td>Mesothelioma</td>
<td>Lymphoma</td>
</tr>
<tr>
<td>Fibroma</td>
<td>Osteosarcoma</td>
</tr>
<tr>
<td>Teratoma</td>
<td>Thymoma</td>
</tr>
<tr>
<td>Granular cell tumor</td>
<td>Neurogenic sarcoma</td>
</tr>
<tr>
<td>Neurofibroma</td>
<td>Leiomyosarcoma</td>
</tr>
<tr>
<td>Lymphangioma</td>
<td>Liposarcoma</td>
</tr>
<tr>
<td>Rhabdomyoma</td>
<td>Synovial sarcoma</td>
</tr>
</tbody>
</table>

2. Myxoma
A. Morphology
1) Usually pedunculated with a short, broad-based attachment
2) Characteristically polypoid, project into cardiac chamber, and about 5-6 cm in diameter
3) Gelatinous/mucoid texture and covered with endothelium
4) Arises from endocardium as small, uniform cells in myxomatous stroma
5) Rarely metastasizes

B. Location
1) Left atrium: 75%
2) Right atrium: 20%
3) Atrial myxomas usually arise from the atrial septum
4) Ventricles: less than 10%
5) Multicentric: 5%
6) Valve: rare

C. Clinical Presentation
1) Hemodynamic impairment
   a) Flow obstruction of venous drainage or across atrioventricular valves
   b) Obstruction is usually progressive
   c) Intermittent obstruction can cause syncope or sudden death in 1/4 to 1/2 of patients

2) Embolism
   a) Occurs in 30 to 45% of left atrial myxomas and over 50% of left ventricular myxomas
   b) About 50% of emboli will affect the CNS
   c) Right-sided tumors have a lower frequency of embolism

3) Constitutional Symptoms
   a) Occur in 30% of patients, most commonly with left atrial tumors
b) Include fever, weight loss, clubbing, Raynaud's, myalgias/arthritis, hemolytic anemia

c) Laboratory tests may reveal elevated IgM or IgA globulins, ESR, and C-reactive protein

4) Familial Myxoma

a) Familial occurrence in 5% of patients
b) Usually found in young men, more often multiple, and less common in left atrium
c) 20% associated with other conditions: Sertoli cell tumors, Cushing syndrome, centrofacial/labial lentigenosis, cutaneous myxomas
d) Abnormal ploidy pattern in almost all familial cases
e) Strong tendency to recur

D. Diagnostic Tests

1) Echocardiography easily demonstrates the tumor mass and can often demonstrate the site of wall attachment
2) CT and MRI may have a role
3) Cineangiography demonstrates left atrial lesions on the venous phase after right heart injection

E. Indications for Operation
1) At the time of diagnosis
2) Presence of obstructive or embolic symptoms
3) Death occurs within 1 to 2 years after onset of obstructive symptoms
4) Up to 10% of patients will die from embolic complications prior to surgery
5) Natural history with constitutional symptoms only is unknown

F. Surgical Management
1) **Complete resection** with adequate margin, which usually results in only a small wall defect

2) Left atrial tumors are resected using a **trans-septal approach**

3) Right atrial tumors are resected through the right atrium
4) Ventricular tumors are resected through the atria
5) Tumor manipulation should be avoided to prevent embolization, and every effort made to remove the tumor intact

G. Results
1) Operative mortality is less than 3%
2) Slightly higher mortality with ventricular tumors
3) 30 to 75% of familial tumors recur

3. Papillary Fibroelastoma
   A. Usually small, frond-like tumor that characteristically develops on an aortic or mitral leaflet
   B. Core of dense connective tissue that resembles chordae tendinae
   C. Produces embolism by fragmentation or thrombus formation
   D. Affected valve can often be repaired at surgery
   E. Incidental tumors found on the aortic or mitral valves during other surgery should probably be removed

4. Rhabdomyoma
   A. Yellow-gray tumor that occur invariably in the ventricles, commonly in multiple locations
   B. Altered myocytes, often not discrete from surrounding normal myocardium
   C. Associated with tuberous sclerosis
   D. Most common primary cardiac tumor in children
   E. Cause cardiac failure from obstruction of conduction pathways and ventricular tachycardia
   F. Over 90% present before age 15, usually in the first few days of life
   G. May require EPS to locate tumors that do not project into ventricular cavity
   H. Tumors may be unresectable at surgery
   I. About 50% of survivors will eventually develop tuberous sclerosis

5. Fibroma
   A. Large, bulky tumors that occur exclusively in the ventricles or ventricular septum
   B. Characteristic whorled appearance from fibroblasts, collagen, and elastic fibers
   C. Usually present in childhood
   D. Free wall tumors can be enucleated without entering the ventricular cavity
   E. Results are good, although few patients available for followup
6. Lipoma
A. Well-encapsulated tumors, usually found incidentally
B. Consist of mature fat cells
C. Most commonly occur in atrial septum as part of lipomatous hypertrophy of the interatrial septum
D. Incidental tumors should probably be resected
E. Results are generally good

7. Pheochromocytoma
A. Soft, fleshy tumors occurring in the pericardium and epicardial surface
B. Functionally active chromaffin cells produce large amounts of catecholamines
C. Presents with severe hypertension
D. Diagnosed by urinary catecholamines, CT scanning, and scintography
E. Preoperative alpha- and beta-blockade is mandatory
F. Carefully dissect tumor away from underlying cardiac structures
G. Outcome favorable unless malignant

8. Teratoma
A. Pale, cystic tumor with heterogenous features
B. Up to 20% have malignant features
C. Typically present in very young patients
D. Presence is an indication for operation
E. Results unknown, as very few cases reported

9. Sarcoma
A. Malignant tumor with wide variety of types, originating from mesenchyme
B. Subtypes include angiosarcoma, rhabdomyosarcoma, fibrosarcoma, osteosarcoma, neurogenic sarcoma, leiomyosarcoma, liposarcoma, and synovial sarcoma
C. Most commonly occur in right atrium and in mid-adulthood
D. Operation indicated to obtain accurate diagnosis
E. Prognosis is poor, as most patients have distant metastases at presentation
F. Adjuvant therapy may have some role

10. Metastatic Tumors
A. Most common neoplastic process involving the heart
B. Common tumors that metastasize to the heart include leukemia, lymphoma, melanoma, lung cancer, and breast cancer
C. Most frequently metastasize to pericardium, then myocardium and endocardium
D. Clinical presentations include pericardial effusion, tamponade, failure, and arrhythmias
E. Prognosis depends on treatment of primary malignancy

11. Right Atrial Extension of Infradiaphragmatic Tumor
A. Most commonly occurs with renal tumors extending up inferior vena cava
B. Usually do not cause cardiac symptoms
C. Combined median sternotomy/midline laparotomy with cardiopulmonary bypass
D. Remove IVC and right atrial portions of tumor prior to primary renal mass
Chapter 29 - Endocarditis

1. Infective endocarditis:
   A. Invasion of the endothelial surface of the heart by microorganisms
   B. Infective microorganism may be:
      C. Bacteria
      D. Fungus
      E. Rickettsia
      F. Chlamydia
      G. Virus
   H. Commonly affects heart valves; also shunts (PDA), septal defects (VSD), coarctation of aorta

2. Predisposing Factors
   A. Congenital lesions
   B. Ventricular septal defects
   C. Tetralogy of Fallot
   D. Aortic stenosis
   E. Complex cyanotic anomalies
   F. Patent ductus arteriosus
   G. Systemic to pulmonary arterial shunts
   H. Acquired lesions
   I. Rheumatic valvular disease
   J. Degenerative cardiac lesions

3. Acute Infective Endocarditis
   A. Toxicity marked
   B. Progresses in days or weeks to valvular destruction and metastatic infection
   C. Typically due to staphylococcus aureus

4. Subacute Infective Endocarditis (SBE)
   A. Toxicity modest
   B. Progresses over weeks to months, metastatic infection rare
   C. Likely caused by streptococcus viridans, enterococci, staphylococcus epidermis, gram negative coccobacilli
5. Characteristic lesion: The Vegetation

6. Native valve endocarditis - occurs on normal, congenitally deformed, or diseased valves
   A. Aortic valve most common
   B. Prosthetic valve endocarditis
   C. 10-20% of cases of endocarditis
   D. Greatest risk during initial 6 months after valve surgery
   E. Staphylococcus epidermis most common cause
   F. Often extends beyond the valve into anulus and cardiac tissues

7. Pathogenesis
   A. Intact endothelium is resistant to infection
B. Injury to heart valve endothelium leads to deposition of platelets and fibrin (nonbacterial thrombotic endocarditis)
C. Platelet - fibrin complex receptive to bacterial colonization
D. Bacteremia originates most commonly from oral mucosa, genitourinary or gastrointestinal tract
E. Fibronectin binds bacteria to platelet - fibrin complex (or to normal endothelium) - The vegetation grows, sheds organisms or fragments and embolizes

8. Pathophysiology
A. Constitutional symptom of infection
B. Locally destructive effects of infection
C. Embolization of vegetation
D. Continuous bacteremia with remote infection
E. Antibody response with tissue injury (eminent complex or antibody - complement reaction)

9. Constitutional Symptoms
A. Fever 80 - 85%
B. Chills 42 - 75%
C. Anorexia 25 - 55%
D. Malaise 25 - 40%
E. Weight loss 25 - 35%

10. Locally Destructive Effects of Infection
A. Perforation of valve leaflets
B. Perforation of fistula between blood vessels or cardiac chambers
C. Abscesses
D. Disruption of conduction system

11. Signs
A. Fever 80 - 90%
B. Murmur 80 - 85%
C. Changing or new 10-40%
D. Peripheral signs
E. Petechiae 10 - 40%
F. Splinter hemorrhages 5 - 15%
G. Osler's nodes 7 - 10% (tender subcutaneous nodules in pulp of digits)
H. Janeway lesions 6 - 10% (erythematous, nontender lesions on palm or sole)
I. Roth spots 4 - 10% (retinal hemorrhage with pole center)

12. Emboli
A. Systemic emboli with infarction occur in 40%
B. Splenic (LUQ pain)
C. Renal (flank pain)
D. Cerebral (stroke 10 - 15%)
E. Coronary (common at autopsy, transmural infection rare)
F. Mesenteric (abdominal pain, ileus)
G. Retinal (blindness 3%)
H. Pulmonary emboli, often septic, occur
I. In 75% with tricuspid valve endocarditis

13. Diagnosis
A. High index of suspicion
B. Valvular heart disease
C. Prosthetic heart valve
D. Fever
E. Murmur
F. Positive blood culture
G. Echocardiogram (TEE = 82 - 94% +)
H. Vegetation
I. Dehiscence of prosthetic valve
J. New valvular regurgitation

14. Fungal Endocarditis
A. 5% of cases of NVE
B. 10% of cases of PVE
C. Most common in IV drug abuse or underlying systemic disease
D. Diagnosis difficult, because many patients are afebrile with normal WBC

15. Fungus often difficult to culture, blood cultures typically negative
A. Large vegetations, systemic embolization, myocardial invasion, extremely resistant to medical therapy
B. Early surgical intervention warranted because medical mortality approaches 100% ->C. Anti-fungal therapy for life
16. **Surgical Treatment - Absolute Indications**
   A. Congestive heart failure due to valve dysfunction
   B. Unstable valve prosthesis
   C. Uncontrolled infection
   D. Persistent bacteremia
   E. Fungal endocarditis
   F. Relapse after optimal therapy (prosthesis)
   G. *Vegetation in Situ*

17. **Surgical Treatment - Relative Indications**
   A. Perivalvular extension of infection
   B. Staphylococcal infection of prosthesis
   C. Persistent fever (culture negative)
   D. Large vegetation (> 10 mm = increased embolism)
   E. Relapse after optimal therapy (native valve)

18. **Treatment of Extracardiac Complications**
   A. Splenic abscess (3 - 5%)
   B. Antibiotics
   C. Percutaneous catheter drainage
   D. Splenectomy
   E. Mycotic aneurysm (2 - 10%, 1 - 5% cerebral)
   F. Antibiotics
   G. Surgery for aneurysm which expand or persist
   H. Emerging operation for rupture

19. **Principles of Surgical Management**
   A. Excision of all infected valve tissue
   B. Drainage and debridement of abscess cavities
   C. Repair or replacement of damaged valves
   D. Repair of associated pathology: Septal defects, fistulas

20. **Aortic Valve - Surgical Options**
   A. Infection limited to leaflets
   B. Aortic valve replacement
   C. Infection extends to anulus or beyond
D. Debride infected tissues
E. Drain abscesses to pericardial sac (? obliterate)
F. Replace aortic root

21. Atrioventricular Valve - Surgical Options
A. Infection limited to leaflets
B. Vegetectomy
C. Repair perforations
D. Reduction annuloplasty
E. Infection extends to anulus or beyond
F. Valve replacement
G. Debride and obliterate abscesses
H. ? Tricuspid valve excision
I. (20 - 30% develop CHF)

22. Results of Surgery
A. Mortality (operative) = 15 - 20%
B. Infection of prosthetic valve during operation for native valve endocarditis = 4%
C. (12 - 16% if active endocarditis)
D. Late survival (5 years)
E. Native valve = 70 - 80%
F. Prosthetic valve = 50 - 80%
Chapter 30 - Hypertrophic Cardiomyopathy

1. Definition
   A. Unknown etiology
   B. Genetically determined
   C. Primary cardiac muscle hypertrophy
   D. Dynamic LVOT obstruction
   E. Myocardial fiber disarray

2. Morphology
   A. Asymmetric septal hypertrophy
   B. Systolic anterior motion (SAM) mitral valve
   C. Small LV cavity
   D. Myocardial fiber disarray
   E. Left atrial enlargement
   F. Distortion right ventricle
   G. Large diameter coronary arteries
   H. Impaired coronary perfusion

3. Clinical features
   A. Symptoms
   B. Dyspnea Diastolic dysfunction
   C. Syncope <===== Arrhythmias
   D. Angina Myocardial ischemia
   E. Outflow obstruction
   F. Signs
   G. Rapid pulse upstroke
   H. Jugular a-wave
   I. Double LV impulse (S4)
   J. S3 at apex
   K. Mid-systolic precordial murmur

4. Diagnostic Criteria
   A. Electrocardiography
   B. LV strain
C. RBBB, LBBB, left anterior hemiblock
D. Chest radiography
E. Cardiomegaly
F. Increased pulmonary vascular markings
G. Echocardiography
H. LVOT obstruction
I. Early aortic valve closure
J. Small LV cavity
K. SAM

5. Cardiac catheterization
A. Right sided pressures - normal or increased
B. LVOT obstruction
C. Increased LVEDP
D. Post-PVC gradient potentiation (Brockenbrough)
E. Dynamic gradient (provocative)
F. Mitral regurgitation
G. Coronary arteriography

6. Natural History
A. Asymptomatic ASH ==> clinical HOCM
B. Ages 20-30 most common
C. Obstruction in only 20%
D. Progressive symptomatic course
E. Mortality without operation
F. 15% at 5 years
G. 25% at 10 years

7. Operative Treatment
A. Indications for Operation
B. NYHA class III or IV
C. Symptoms not relieved by medical treatment
D. Gradient (rest or provocative) > 50 mmHg
E. Goals of Operation
F. Relieve gradient
G. Abolish SAM
H. Enlarge LVOT
I. Abolish MR
8. Technique
   A. Myotomy - Myectomy
   B. Aortic root
   C. Aortic root and LV
   D. Modified Konno
   E. LV-Ao conduit
   F. MVR
   G. Myectomy and MVR
   H. DDD pacemaker

9. Complications
   A. Complete heart block (3-5%)
   B. Myocardial infarction (3-4%)
   C. Embolism
   D. Iatrogenic
   E. VSD (3%)
   F. Aortic valve injury
   G. Mitral valve injury
   H. LV pseudoaneurysm
   I. Results
   J. Early death (5-8%)
   K. Late death - CHF, arrhythmias, stroke
Chapter 31—Minimally Invasive Cardiac Surgery

1. History
A. Beating heart anastomosis
1) Alexis Carrell on dog
2) Kolessov 1967 first LIMA to LAD (6 pts)
3) Banned/ Buffalo 1990/1991
4) Subramanian/Acuff/Mack/Calafiore - MIDCAB

2. Port Access Cardiac Surgery
A. CABG -- Stevens 1996 (Stanford)
B. MVR -- Schwartz, Ribakove (NYU)
C. MIDCAB --
D. Exposure thru 4th ICS
E. 1 or 2 vessel bypass
F. 5-20% stenosis rate
G. Anterior wall revascularization only
H. Less use of resources
I. Eliminates CPB and sternotomy

3. OPCAB
A. Exposure median sternotomy
B. Bypass multiple targets
C. Patency unknown
D. No CPB
E. Port access
F. 4th ICS
G. Femoral cannulation CPB
H. Still heart
I. Total revascularization
J. Can use SVG for proximals
K. Over 2000 cases done similar results as open

4. Endoscopic CABG
A. LIMA taken down with scope only
B. Then conventional MIDCAB or Port Access

5. MIDCAB or OPCAB
   A. Use in patients you might not want to use CPB
   B. Calcified aorta, poor LVEF, severe PVD
   C. Severe COPD, CRF, coagulopathy
   D. Transfusion issues, i.e., Jehovahs witness
   E. Good target vessels not diffuse disease
   F. Anterior/lateral wall revascularzation
   G. Target revascularzation in older sicker patients

6. Port Access
   A. More universal use
   B. Multi-vessel revascularization
   C. Redo cases
   D. Where sternum healing is problem
   E. Obese, DM, steroids

7. Aortic Valve surgery
   A. Approach
      1) Right parasternal first used by Cosgrove 2nd and 3rd costal cartilages
         removed try to preserve RIMA
      2) Mini sternotomy (Gundry) upper sternotomy T off to the right 3rd or 4th
         ICS better for homograft root replacement
      3) Transected sternum (Cosgrove) transect at 3rd ICS level both RIMA and LIMA
         divided

8. Mitral Valve Surgery
   A. Approach
   B. Right parasternal
   C. Lower mini sternotomy
   D. Right anterior lateral thoracotomy
   E. CPB has been accomplished with Heartport system
   F. Fem-fem CPB
   G. Direct cannulation of aorta and atrium

9. Advantages
   A. Decreased length of stay (average 4 days)
B. Decreased blood transfusions (Cohn, et al)
C. Return to activity sooner
D. Less atrial fibrillation (5-10% incidence vs 20-30% open CPB)

10. Pediatric Cardiac Surgery
A. Ligation of PDA and division of vascular rings via thorascopic technique (Burke)
B. Open procedures VSD, Tetralogy via mini-sternotomy (Gundry)
C. ASD closure with Heartport port access

*Mini L-Shaped Sternotomy*
Mini T-sternotomy

Mini- Parasternal & Mini-Thoracotomy
D. Graphs

**AF Incidences**

**Patency Rates**
Long-Term Results
Angiographic Results

Qualitative Angiographic Result
Gill et al., 1997

<table>
<thead>
<tr>
<th></th>
<th>% Grade A</th>
<th>% Grade B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beating Heart (thoracotomy or sternotomy)</td>
<td>81%</td>
<td>19%</td>
</tr>
<tr>
<td>Heart arrested</td>
<td>96%</td>
<td>4%</td>
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</tbody>
</table>

Postoperative AF

<table>
<thead>
<tr>
<th>Study</th>
<th>n</th>
<th>Patients with AP</th>
<th>Increase of LOS (Days)</th>
<th>Reported Mean Cost Increased per Patient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kowey et al., 1997</td>
<td>157</td>
<td>28%</td>
<td>3 (median, 7 to 10)</td>
<td>21,394</td>
</tr>
<tr>
<td>Crosswell et al., 1993</td>
<td>3983</td>
<td>34.6%</td>
<td>2.3 days in ICU 3.4 days in ward</td>
<td>-</td>
</tr>
<tr>
<td>Aranki et al., 1996</td>
<td>570</td>
<td>23%</td>
<td>4.5 (Adjusted LOS)</td>
<td>10,065</td>
</tr>
</tbody>
</table>
**Decision Grid**

**Sternotomy vs No Sternotomy**

**Off-Pump Indications**
11. Future robotics
A. 3-D imaging
B. Total closed chest still experimental
C. What to do?
D. All will become tools to be used
E. Each will find a niche
F. How to define role for each tool
G. Balance co-morbidities with complete revascularization
Recipient Selection

1. Cardiomyopathy definition
   A. Any myocardial disease process that leads to clinically significant myocardial dysfunction

2. Cardiomyopathy classification
   A. Dilated cardiomyopathy
   B. Hypertrophic cardiomyopathy
   C. Restrictive cardiomyopathy
   D. Arrhythmogenic right ventricular dysplasia
   E. Dilated, characterized by dilation and impaired contraction of left or both ventricles
      1) Idiopathic
      2) Familial/genetic
      3) Viral and/or immune
      4) Alcoholic/toxic
      5) Presentation with heart failure, often progressive, arrhythmias, thromboembolism, and sudden death
   F. Hypertrophic, characterized by left and/or right ventricular hypertrophy
      1) Usually asymmetric with normal or reduced LV volume
      2) Systolic gradient common
      3) Familial disease with predominantly autosomal dominant inheritance
      4) Myocyte hypertrophy and disarray surrounding areas of increased loose connective tissue
      5) Arrhythmias and premature sudden death are common
G. Restrictive, characterized by restrictive filling and reduced diastolic volume of either or both ventricles with normal or near-normal systolic function and wall thickness
1) Idiopathic
2) Associated with other disease (amyloidosis; endomyocardial disease with or without eosinophilia

H. Arrhythmogenic right ventricular dysplasia, characterized by progressive fibrofatty replacement of right ventricular myocardium, initially with typical regional and later global right and some left ventricular involvement with relative sparing of the septum
1) Familial disease common, autosomal dominant inheritance and incomplete penetrance
2) Presentation with arrhythmias and sudden death is common, particularly in the young

3. Specific cardiomyopathies: heart muscle diseases that are associated with specific cardiac or systemic disorders
   A. Ischemic
   B. Valvular
   C. Hypertensive
   D. Inflammatory (e.g., myocarditis, Chagas' disease, HIV, etc.)
   E. Metabolic (e.g., thyrotoxicosis, hypothyroidism, storage diseases, etc.)
   F. General system disease (e.g., SLE, sarcoidosis, etc.)
   G. Muscular dystrophies (e.g., Duchenne, Becker-type, etc.)
   H. Neuromuscular disorders (e.g., Friedreich's ataxia)
   I. Sensitivity and toxic reactions (e.g., anthracyclines, irradiation, alcohol)
   J. Peripartal

4. Prognosis
   Factor Possibly Predictive Not Predictive
   \[
   \begin{array}{|c|c|c|c|}
   \hline
   \text{Factor} & \text{Predictive} & \text{Possibly Predictive} & \text{Not Predictive} \\
   \hline
   \text{Clinical} & \text{Symptoms} & \text{Alcoholism, Peripartum, Family History} & \text{Age, Duration, Viral Illness} \\
   \hline
   \text{Hemodynamic} & \text{LVEF, CI} & \text{LV size, LAP, RAP} & \text{Viral Illness} \\
   \hline
   \text{Dysrhythmia} & \text{IVCD, Complex} & \text{AV block} & \text{Simple ectopy} \\
   \hline
   \end{array}
   \]
<table>
<thead>
<tr>
<th>ectopy</th>
<th>Histologic</th>
<th>Myofibril volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neuroendocrine</td>
<td>PI, NE, ANF, Serum Na</td>
<td></td>
</tr>
</tbody>
</table>

**Cumulative Mortality**

![Cumulative Mortality Graph](image)

*Figure 1. Cumulative Mortality from the Time of Randomization in the Three Treatment Groups.*

**Probability of Death**
Probability of Survival

5. Pharmacological Treatment of Heart Failure
A. Digoxin*
B. Diuretics
C. Afterload Reduction
D. Isosorbine dinitrate/hydralazine**
E. Angiotensin Converting Enzyme Inhibitors
F. Enalapril**
G. Captoril**
H. Lisinopril
I. Angiotensin II Receptor Inhibitors
1) Losartan
J. Calcium Channel Blockers
1) Amlodipine

6. Beta Blockers
A. Carvedilol**
B. Metoprolol*
C. Inotropic Agents
D. Beta Agonists
1) Dopamine
2) Dobutamine
E. Phosphodiesterase Inhibitors
1) Amrinone
2) Milrinone
F. Anticoagulation
1) *Decreases risk of hospitalization or decompensation
2) **Decreases mortality

7. Pharmacologic Treatment of Heart Failure

<table>
<thead>
<tr>
<th>Improves Survival</th>
<th>Decreases Hospitalization</th>
<th>Decreases Survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enalapril</td>
<td>Digoxin</td>
<td>Dobutamine</td>
</tr>
<tr>
<td>Captopril</td>
<td>Metoprolol</td>
<td>Milrinone</td>
</tr>
<tr>
<td>Isosorbide dinitrate</td>
<td></td>
<td>Vesnarinone</td>
</tr>
<tr>
<td>Carvedilol</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8. Recipient Selection Process
A. Inclusion criteria
B. Exclusion criteria
C. Ongoing re-evaluation process

9. Inclusion Criteria
   A. Absence of reversible or surgically amenable heart disease
   B. NYHA Class III - IV symptoms despite optimal medical management
   C. Maximal oxygen consumption < 14 ml/kg/minute
   D. Estimated 1 year survival without transplant < 50%

10. Insufficient Indications for Cardiac Transplantation
   A. Ejection fraction < 20%
   B. History of NYHA Class III - IV symptoms
   C. Low maximal oxygen consumption

11. Candidate exclusion criteria

<table>
<thead>
<tr>
<th>Criteria</th>
<th>High Risk</th>
<th>Moderate Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulmonary Hypertension</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVR &gt; 8 Wood Units, unresponsive to nitroprusside</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>PVR &gt; 8 Wood Units, decreasing in response to nitroprusside, but not below 3 Wood Units</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Pulmonary artery systolic pressure &gt; 70 mmHg despite nitroprusside</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Transpulmonary gradient &gt; 15-20 mmHg (mean PAP - PCWP)</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Infection - active, untreated</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Irreversible hepatic disease</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Irreversible renal disease</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Irreversible pulmonary disease</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEV1 &lt; 1 L</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Condition</td>
<td>Mark</td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------------------------------------------------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>FEV1 &lt; 1.5 L</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Recent pulmonary infarction</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Age &gt; 65 years</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Diabetes mellitus, Type 1, with significant end-organ damage</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Cerebrovascular disease</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Symptomatic</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Asymptomatic</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Peripheral vascular disease</td>
<td></td>
<td></td>
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<tr>
<td>Symptomatic</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Peptic ulcer disease</td>
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<tr>
<td>Active bleeding</td>
<td>X</td>
<td></td>
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<tr>
<td>Diverticulitis, recent</td>
<td>X</td>
<td></td>
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<tr>
<td>Chronic Active Hepatitis</td>
<td>X</td>
<td></td>
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<tr>
<td>HIV positive</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Malignancy, recent</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Malignancy, remote</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Psychiatric disease</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acute, unresolved</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Recent, resolved on treatment</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Substance abuse</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active, unresolved</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Recent, resolved</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

12. Panel Reactive Antibody (PRA) Screen
A. AKA: HLA antibody or white blood cell antibody screen
B. Technique: Recipient sera placed in 40-60 wells containing lymphocytes with a wide variety of HLA antigens
C. Use: Determine presence of preformed antibodies
D. If > 10%: Prospective crossmatch

13. Management of Transplant Candidate While Waiting
A. Close follow-up
B. Low threshold for hospitalization
   1) IV diuretics
   2) Inotropic support
   3) Mechanical assistance
C. Ongoing re-evaluation of candidacy

14. Ongoing Re-evaluation for Candidacy
A. Periodic assessment for degree of illness (VO2, EF, right heart pressures)
B. Periodic assessment of acceptability (development of a new or worsening of a pre-existing illness)
C. Periodic PRA determinations

15. Conditions Which Generally Preclude the Use of a Donor Heart
A. HIV positivity
B. Significant ventricular arrhythmia
C. Echocardiographic abnormalities
D. Significant global hypokinesis
E. Significant valvular abnormality
F. Significant coronary disease by arteriography or documented previous myocardial infarct
G. Any acute malignancy, except primary brain cancer
H. Inadequately treated systemic infection
I. HbsAG positive, unless recipient is also positive
J. Hepatitis C positivity, unless recipient is also positive
K. Death from carbon monoxide poisoning, with carboxyhemoglobin level > 20%
L. Significant cardiac contusion
M. Severe left ventricular hypertrophy by echo
N. History of intravenous drug use

16. Donor-recipient Matching
A. Size: Greater than 80% of recipient body weight
B. Blood type: Identical or compatible
C. HLA-matching: Generally not done
Chapter 33 - Cardiac Transplantation

1. Clinical Advances
   A. 1960 - Surgical technique reported
   B. 1967 - Successful human transplant
   C. 1970 - Recipient selection criteria standardized
   D. 1973 - Surveillance endocardial biopsy
   E. 1977 - Distant donor heart procurement
   F. 1980 - Cyclosporine A

Causes of Death

Cardiovascular diseases are the most common causes of death

Transplant Volume
2. Etiology or End-Stage Heart Disease

<table>
<thead>
<tr>
<th>Etiology</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ischemia</td>
<td>44.8</td>
</tr>
<tr>
<td>Cardiomyopathy</td>
<td>46.2</td>
</tr>
<tr>
<td>Valvular</td>
<td>3.5</td>
</tr>
<tr>
<td>Congenital</td>
<td>1.8</td>
</tr>
<tr>
<td>Rejection</td>
<td>2.1</td>
</tr>
<tr>
<td>Other</td>
<td>1.6</td>
</tr>
</tbody>
</table>

3. Recipient Criteria
A. Terminal heart disease
B. Reasonable physiological
C. No renal or hepatic dysfunction
D. No acute infections
E. No recurrent pulmonary infections
F. Psychosocial stability
G. No alcohol, tobacco or drug abuse

4. Contradictions
A. Fixed pulmonary vascular resistance
B. Peripheral vascular disease
C. Acute malignancy
D. COPD of chronic bronchitis
E. Morbid obesity
F. ABO incompatibility

5. Donor Criteria
A. Brain death declared
B. Age <45 (special exceptions)
C. No re-existent heart disease
D. Few CAD risk factors
E. No untreated acute infections
F. No systemic malignancy
G. No cardiac trauma
H. Normal ECG
I. Normal echocardiogram
J. Negative HIV and Hepatitis screen

6. Unique Features of Cardiac Recipient
A. Prone to infection (opportunistic)
B. Denervated heart physiology
C. Rejection at any time- few symptoms

7. Immunosuppressive Therapy
A. Cyclosporine A
B. Adrenocortical steroids
C. Azathioprine
D. OKT3
E. Anti-thymocyte globulin (ATG)

Immunosuppression
8. Rejection
A. Endomyocardial biopsy
B. Acute rejection
   1) Hospital
   2) Out-patient

9. Registry Database
A. Fifteenth Report- 1998
B. Total Transplants Reported- 45,993
C. Total Centers Reported- 257
D. Survival
   1) 1 year- 79%
   2) Thereafter- 4% per year mortality

Total Survival
Survival by ERA
Survival by Age
Survival with Retransplant
10. Risk Factors (p value < 0.001)
A. Previous cardiac transplant
B. Ventricular support
C. Mechanical support (VAD)
D. Recipient < 5 years of age
E. Recipient > 60 years of age
F. Donor > 40 years of age
G. Donor female
H. Ischemic time >3.5 hours

11. Causes of Death after Transplantation
A. Rejection
B. Infection
C. Technical
D. CNS
E. Malignancy

Cause of Death Post Transplant
F. After First year
1) Graft Atherosclerosis
2) Infection
3) Malignancy- Lymphoma
4) Rejection

12. Improved Survival
A. Cyclosporine
B. Lower chronic steroid dose
C. Earlier diagnosis of rejection
D. Better patient selection
E. Diagnosis of infection
F. New antimicrobial agents
G. Medical and surgical experience

13. Functional Status Following Heart Transplant
A. Post Transplant Functional Status

HEART TRANSPLANT RECIPIENT FUNCTIONAL STATUS

No Activity Limitations  Performs with Assistance  Total Assistance

1 Year Followup
- 8.5%
- 1.4%
- 90.1%

3 Year Followup
- 5.8%
- 0.8%
- 93.5%

B. Post Transplant Work Status

HEART TRANSPLANT RECIPIENT WORK STATUS

Working Full Time  Working Part Time  Not Working  Retired

1 Year Followup
- 15.0%
- 47.7%
- 8.1%

3 Year Followup
- 19.1%
- 39.8%
- 8.6%

C. Post Transplant Rehospitalization
1. Candidate Selection
   A. Most often from idiopathic dilated or ischemic cardiomyopathies
   B. "End stage...failure to respond to maximal therapy"; need to identify those who are likely to have sudden death or progressing heart failure
   C. Adequacy of therapy prior to evaluation is key
   D. Some guidelines for selection of candidates:
      1) EF < 20%
      2) Peak O2 consumption (VO2) < 10cc/kg/min

2. Cardiac Donor
   A. Only 10-20% of brain dead patients with suitable hearts become donors; cardiac transplantation is currently limited by donor availability
   B. Initial screening done by a local organ procurement agency
   C. Hep C generally OK
   D. Level of inotropic support
   E. Cardiovascular risk factors
   F. Substance abuse
   G. Ideally, donor body weight 80-120% of recipient's weight
   H. Age limits
I. Intensive fluid management of the donor is important; often these people are hypovolemic from trauma or diabetes insipidus

3. Donor Cardiectomy
   A. Visualize/palpate the heart
   B. Divide the:
      1) SVC
      2) Left superior pulmonary vein
      3) Incise IVC
   C. Clamp aorta
   D. Administer cardioplegia
   E. Avoid coronary sinus injury during liver procurement
   F. Divide aorta and pulmonary artery

4. Recipient Operation
   A. Open RA along the AV groove anteriorly
   B. Extend this incision to CS inferiorly and to the right atrial appendage posteriorly
   C. Aorta and main pulmonary artery are divide at the valve commissures
   D. Incise roof of the left atrium between the aorta and SVC
   E. Connect the atrial incisions and extend the incision to the left atrial appendage
   F. Incision is then extended along the AV groove posteriorly to the CS
   G. Check donor heart for PFO
   H. Donor pulmonary veins are connected to fashion a left atrial cuff
   I. Left atrial anastomosis is completed and a vent is placed
   J. Right atrial anastomosis is completed
   K. Great vessels are anastomosed; PA first
   L. Deair, pacing wires, choronotropic/inotropic support

Herotopic Cardiac Transplantation

5. Posttransplant Concerns
   A. Immunosuppression
      1) as detailed previously
      2) use of tacrolimus as both maintenance therapy and rescue therapy;
      3) Pittsburgh group has evidence to prove that there are fewer repeat episodes of rejection and it is an effective agent for refractory rejection
   B. Transvenous myocardial biopsy
1) IJ approach
2) 3-5 specimens
3) weekly for the first 4 weeks
4) grading system developed by Billingham
C. Coronary graft vasculopathy
D. Infection
1) bacterial are most common followed by viruses, fungi, and protozoans
2) viral most common between months 1-6
3) fungal most common between months 1-2
4) protozoal infections peaked months 3-6
5) in the first 6 weeks of transplant, CMV, Herpes, or bacterial are equally likely; >2yrs is usually bacterial pneumonia is the most common infection
6) CMV can be cultured from almost all recipients; consider active infection in anyone with fever, fatigue, lymphocytosis, elevated LFT's, neutropenia, and thrombocytopenia; 25% will develop invasive GI or pulmonary disease; most severe infections seen in those seronegative prior to operation; Gancyclovir is used to treat, but its use should be prophylactic
7) HSV usually causes mucocutaneous infections
8) Ebstein-Barr infection seems to be related to the development of posttransplant proliferative disorder; most effective treatment appears to be reduction of immunosuppression
9) Candidiasis is the most common severe fungal infection seen posttransplant; aspergillosis also has a significant cause of death
10) PCP usually presents with fever, dry cough and dyspnea and may be slow to respond to therapy; TMP-SMX or pentamidine prophylaxis can usually prevent it; diagnosis is usually confirmed by methenamine silver stains on BAL fluid; rapid reduction in immunosuppression may exacerbate the process in the lung

6. Renal Failure
Most important side effect of cyclosporin—from afferent arteriolar vasoconstriction and direct tubular cell injury; is dose related to some extent and will improve with reduction in the Cyclosporin dose; oliguria occurs in the early form of renal failure—late nephrotoxicity is characterized by a slow rise in serum creatinine

7. Other
Hirsutism, tremor, gingival hyperplasia, gout, elevated cholesterol, hyperglycemia, osteoporosis, and abdominal surgical complications
8. Survival

A. One year: >80%

B. 3-5 years: 70%

C. 12 years: ~40%

D. Bridge to transplant > 90% survival

E. Risk factors: previous transplant, preoperative ventilator dependence, age <5 or >60 recipient)

F. Risk factors: age >40, female sex, ischemic time >3.5 hours (donor) most common causes of early death: cardiac complications (40%); rejection (19%); infection (16%).

G. Infection is the most significant factor in late deaths, accounting for 40%
Chapter 34 - Heart/Lung and Lung Transplantation

1. History
   A. Alexis Carrel- 1907
   B. Demikhov- 1940s
   C. Lower/ Shumway- 1960s
   D. Clinical heart/lung transplantation
      1) Cooley- 1968
      2) Lillehei- 1969
      3) Barnhard- 1971
      4) Modern-era- Reitz
   E. 1963- first human lung transplant
   F. 1983- Cooper- first successful lung transplant
   G. 1985- Cooper / Patterson- double lung transplant

2. Donor Selection
   A. Age <60 years
   B. No history of pulmonary disease
   C. Smoking history < 20 packs/year
   D. Normal chest x-ray
   E. Adequate gas exchange
   F. Normal bronchoscopy
   G. Acceptable sputum gram stain
   H. Normal serology
   I. ABO compatibility
   J. Adequate size matching

3. Absolute Donor Criteria
   A. Adequate gas exchange
      1) PO2 >300 on FiO2 1.0
      2) PO2 >100 on FiO2 0.4
   B. Absence of significant infiltrates
   C. Normal serology
   D. ABO compatibility
4. Indications of Thoracic Transplantation
   A. Single lung transplant
      1) Pulmonary fibrosis
      2) Emphysema
   B. Primary pulmonary hypertension
   C. Double lung transplants
      1) Septic lung disease
      2) Cystic fibrosis
      3) Bronchiectasis
   D. Emphysema
      1) Primary pulmonary hypertension
   E. Heart / Lung transplant
      1) Irreversible disease of both heart and lung

5. Recipient Selection
   A. Age <65
   B. Other disease processes
   C. Previous surgery
   D. Steroids
   E. Smoking
   F. Nutrition
   G. Ventilator dependence
   H. Timing of transplant
   I. Psychosocial factors

6. Lung Preservation for Transplantation
   A. Hypothermia
   B. Lung inflation
   C. Pulmonary artery vasodilation- PGE1
   D. Pulmonary artery flush- solutions include:
      1) Modified eurocollins solution
      2) Belzer’s (Wisconsin) solution
      3) Low potassium Dextran
   E. Low potassium, colloids, free radical scavengers

7. Early Complications of Lung Transplantation
   A. Reperfusion pulmonary edema
   B. Primary graft failure
C. Hemorrhage
D. Bronchial dehiscence
E. Non-infectious pleural space problems

8. Infection in Lung Transplantation
A. Transplanted organ exposed to external environment
B. Target organ for CMV
C. Bacterial, viral (CMV), fungal Protozoan (PCP)
D. Infection increases expression of
   1) HLA antigens
   2) Adhesion molecules (ICAM-1)
E. Can trigger rejection
F. Transbronchial biopsy / bronchoalveolar lavage to differentiate

9. Rejection in Lung Transplantation
A. Routine screening
B. Lung allografts more antigenic and more vulnerable to rejection
C. Symptoms: malaise, shortness of breath, lung infiltrate
D. Differentiating infection from rejection difficult
E. Transbronchial biopsy, bronchoalveolar lavage useful
F. Serial daily spirometry (FEV1)

10. Bronchiolitis Obliterans
A. Primary factor limiting long-term survival
B. Exact etiology unknown (chronic rejection/infection)
C. Most important cause of mortality and morbidity after lung transplantation
D. Affects 50% of long-term survivors
E. 50% will respond to enhanced immunosuppression
F. The remainder will have progressive deterioration of lung function

11. Pediatric Lung Transplantation
A. Higher incidence of bypass
B. May be more vulnerable to bronchiolitis obliterans
C. Immune advantage has not been clearly documented in pediatric population
12. Survival after Lung Transplantation

By Diagnosis

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>30 Days</th>
<th>1 Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emphysema (SL)</td>
<td>93%</td>
<td>78%</td>
</tr>
<tr>
<td>A1A (SL)</td>
<td>90%</td>
<td>75%</td>
</tr>
<tr>
<td>Cystic fibrosis (BL)</td>
<td>90%</td>
<td>70%</td>
</tr>
<tr>
<td>Pulmonary fibrosis (SL)</td>
<td>82%</td>
<td>65%</td>
</tr>
<tr>
<td>Pulmonary htn. (BL)</td>
<td>80%</td>
<td>75%</td>
</tr>
</tbody>
</table>

By Transplant

<table>
<thead>
<tr>
<th>Transplant</th>
<th>1 Year</th>
<th>5 Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single (SL)</td>
<td>70%</td>
<td>40%</td>
</tr>
<tr>
<td>Bilateral (BL)</td>
<td>70%</td>
<td>48%</td>
</tr>
</tbody>
</table>

EXTENDED OUTLINE

1. Introduction
A. 1963-Hardy @ U Mississippi 1st human lung transplant à 18d survival
B. 1963-83 - 44 lung transplants w/o success [bronchial anastomosis/MOF]
C. 1983 - Toronto Lung Transplant Group @ 6-yr survival

2. End-Stage lung disease
A. Obstructive lung disease
1) Chronic elevation in airway resistance
   a) Decreased exp flow rates (FEV1, FVC, FEV1/FVC)
   b) Air trapping (TLC and FRC)
2) Prognostic factors = age, degree of airway obstruction (FEV1)
3) COPD
   4) Alpha-1 antitrypsin deficiency emphysema
      a) Lack protection against neutrophil elastase in distal airways
      b) Severe bullous emphysema by 4th or 5th decade
B. Cystic fibrosis (CF) (1/2,000 live births)
   1) Most common end-stage obstructive disease 1st-3rd decades
   2) Thick secretions, poor ciliary fxn => mucus plugging, pulm sepsis
C. Restrictive lung disease - idiopathic pulmonary fibrosis (IPF)
   1) Decreased Lung volumes and exp flow
   2) Decreased diffusing capacity
D. Pulmonary hypertension
1) Primary pulmonary hypertension (PPH): Mortality correlates with CVP >10mmHg, PA(mean) >60mmHg, CI<2L/min
2) Eisenmenger’s syndrome: Ca-channel blockers may [increase or decrease???] PA pressures
E. Others: sarcoidosis, chemo/RT-induced fibrosis, lymphangiomatosis

3. Recipient selection
A. Mean waiting time 9-12 mo. (Wash U) 13.5 mo. (US)

4. Preoperative evaluation and management of recipients
A. All pts enrolled in cardiopulmonary rehab

5. Choice of procedure
A. Obstructive lung disease
1) Early single lung transplant (SLT)à hyperinflating native lung, crowding, V/Q mismatch
   a) Oversizing donor lung
   b) Proper preservation technique
2) SLT for: >55yo, high risk), prior surgery, asymmetric dz
3) Bilateral lung transplant (BLT) for: younger, bilat dz, small donor
B. CF (and other septic lung disease)à BLT due to infection risk in native lung
C. IPF
   1) SLT theoretically ideal- decrease compliance and PA pressures in native lung favor allograft ventilation and perfusion
   2) BLT for large individual, especially with nl lung volumes
D. PPH - HT-lung transplant, traditionally
   1) SLT has been successful
      a) Post-op management difficult, nearly all pulm flow to allograft
      b) Late graft problem=severe V/Q mismatch
   2) BLT may provide better long-term result

6. Timing of transplantation
A. Pts w/life expectancy 12-24 mo
B. ~30% will receive transplant w/in 1 year
C. Risk of dying on the waiting list: PPH, IPF, CF >> COPD

7. Other criteria
A. Age (not absolute): BLT=55, SLT=65
B. Ventilatory support- no longer an absolute contraindication (already listed)
C. Corticosteroid therapy - data suggest:
   1) low-dose prednisone does not airway complications
   2) low-dose steroids may allograft bronchial circulation
D. Prior surgery - no longer a contraindication, in general

7. Criteria for donor lung suitability
   A. 20-25% of multiple organ donors have suitable lungs
   B. Size - TLC, VC estimated by height/weight - oversize 20% for SLT
   C. Donor lung scarcity
      1) Use "marginal" lungs
      2) Single lung assessment (2-lumen ETT, PA clamping)
      3) Living related donor (for pediatric CF patients)

Technique of Lung Preservation and Extraction

1. Lung preservation
   A. Prostaglandin E-1 before inflow occlusion (vasodilatation + other benefits)
   B. PA flush w/3L cold Euro-collins
   C. Extraction of lungs semi-inflated w/100% O2 (grafts use it)
   D. Transport under hypothermia (0-1°C)
   E. Topical cooling during implantation

2. Donor lung extraction
   A. Median sternotomy, dissection
      1) Isolate SVC and IVC
      2) Separate aorta and PA-Cardiopleg. cannula in aorta, cannulate distal PA
      3) Incise posterior pericardium, exposing distal trachea
   B. Graft flushing
      1) Bolus PGE-1 (500 mg)
      2) Inflow occlusion (ligate SVC, clamp IVC)
      3) Vent R heart - transect IVC
      4) X-C aorta, administer cardioplegia
      5) Amputate tip of LA appendage, start lung flush
      6) Flood chest w/ iced saline, ventilate w/100% O2
   C. Extract heart
      1) Transect cavae and aorta
2) LA incision is last, leaving a cuff of atrium
D. Extract lungs
1) Divide trachea between two firings of TA-30
2) (Divide esophagus superiorly and inferiorly)
3) Transect descending thoracic aorta
4) Transport on ice

Lung Transplantation Procedure

1. Anesthetic considerations
A. PA catheter
B. Left-sided 2-lumen ETT
C. Initial bronchoscopy and aspiration for CF patients
D. Avoid “pulmonary tamponade”
E. CPB for:
1) Hemodynamic instability
2) Pulmonary vascular dz
3) Poor allograft function in BLT

2. Technique
A. Incision
1) SLT-posterolateral thoracotomy
2) BLT- bilateral transverse thoracosternotomy ("clamshell") {5th IC space for COPD, 4th for CF}
B. Choice of side - avoid surgery, remove better lung - in BLT, worse lung transplanted 1st
C. R/O PFO in PPH-intra-op TEE
D. In SLT, CPB is selective - trial of PA clamping

3. Lung implantation
A. Divide 1st PA branch between ligatures, the staple PA trunk
B. Mobilize both pulmonary veins (PV) intrapericardially
C. Transect bronchus-R=just proximal to RUL takeoff, L=1-2 rings above bifurcation- hemostasis
D. Topical cooling - iced gauze around graft
E. Bronchial anastomosis
1) Continuous 4-0 mono-absorbable for membranous
2) Telescope cartilaginous arches figure-of-8 interrupted sutures
3) Ometopexy no longer used

F. PA anastomosis - 5-0 mono-non

G. LA anastomosis - 4-0 mono-non

H. De-air

1) Antegrade (release PA clamp)
2) Retrograde (release LA clamp)

I. Bronchoscopy

4. Post-operative Management

A. ICU post-op - quantitative perfusion scan

B. Pain control - epidural

C. Ventilator

1) SLT: COPD=no PEEP, PPH=10cm PEEP x 36h
2) Weaning - PPH=sedated, paralyzed x 36h, others=early wean

D. Postural drainage (lat x 24h), chest PT

E. Hemodynamics: dopamine for diuresis, PGE-1

F. Bronchoscopy - OR, POD1, pre-extubation, and prn

G. Infection

1) Abx prophylaxis: CF - per recipient cultures; others, per donor, or ancef x 3-4d
2) HSV prophylaxis: acyclovir 200mg BID for ≥ 2 yr
3) PCP: Septra-DS - one bid q M-W-F
4) Candida: nystatin

5. Follow-up strategies

A. Clinical f/u - remain in town x 3 months

B. PFTs - primarily FEV1 - Monthly in 1st year

C. CXR - schedule similar to PFTs + prn

D. Bronchoscopy (FOB) with transbrochial bx (TBLB)

1) 3-4wk post-op, 3mo, 6mo, 1yr, then annually
2) Direct TBLB to areas w/infiltrates

E. Open lung bx - when TBLB inconclusive in face of clinical, physiologic deterioration
6. Problems (clinical-pathologic entities encountered in the lung transplant recipient)

A. Acute rejection - more common than other solid-organ allografts
   1) Incidence unknown - "virtually all" in 1st 3-4wks post-tx
   2) From 1st 3-5 days post-op to years later
   3) Clinical manifestation variable - malaise, mild dyspnea, fever, decreased FEV1, decreased PO2
   4) Dx: FOB, TBLB => 84% sens, 100% spec (Ht-lung tx)
   5) Tx: High-dose steroids, maintenance prednisone, ATGAM or OKT3 for refractory episodes

B. CMV infection
   1) May mimic rejection
   2) Dx by TBLB
   3) Tx w/gancyclovir (documented infection)

C. Chronic rejection/Bronchiolitis Obliterans syndrome (BOS)
   1) Inflammatory disorder of the small airways - histologically, dense fibrosis and scar obliterating bronchial wall and lumen
   2) Prevalence as high as 50%
   3) Dry or productive cough, dyspnea refractory to bronchodilators
   4) Airflow obstruction with progressive \( \bar{\text{in}} \) FEV1
   5) Tx: Immunosuppression (empiric) - most pts will progress

D. Bronchial anastomotic complications
   1) Usually result from ischemia which =>
      a) Air leak or mediastinal collection (early)
      b) Stenosis or malacia (late)
   2) New dyspnea, stridor or wheeze
   3) W/U=CXR, FOB, chest CT
   4) Tx:
      a) Early (dehiscence) = drainage and conservative measures
      b) Late (striction or malacia) - stent

7. Results

A. Survival
   1) 92% hospital survival
   2) 70% 1-yr, 43% 5-yr
   3) Small benefit of BLT vs SLT (not significant)

B. Functional results
   1) FEV1, ABG, 6-minute walk improved
2) FEV1, PaO2, significantly better after BLT vs SLT
3) **BLT** associated w/ higher complication rate

**C. Pulmonary vascular dz**
1) Decreased PAS, CVP, PVRI
2) NYHA class III-IV => I-II
Chapter 35 - Medical Complications of Cardiac Transplant

1. Cardiac
   A. Ventricular dysfunction
   B. Sinus node dysfunction
   C. Tricuspid regurgitation
   D. Allograft rejection
   E. Allograft coronary artery disease
   F. Decreased exercise tolerance
   G. Infection
      1) Bacterial
      2) Viral
      3) Parasitic
      4) Fungal
   H. Non-cardiac, Non-infectious
      1) Renal insufficiency
      2) Hypertension
      3) Osteoporosis
      4) Hyperlipidemia
      5) Malignancy
      6) Psychologic/behavioral/societal
      7) Glucose intolerance
      8) Pancreaticobiliary disease
      9) Obesity

2. Cardiac Allograft Rejection
   A. Propensity decreases with time
   B. Types
      1) Hyperacute
      2) Acute
      3) Chronic (ACAD)
      4) Cellular
      5) Vascular (Humoral)
C. Diagnosis
1) Endomyocardial biopsy
2) Non-invasive
3) Clinical
D. Treatment

**Insertion of Bioptome**

### 3. International Society for Heart & Lung Transplantation Endomyocardial Biopsy Grading Scheme

<table>
<thead>
<tr>
<th>Grade</th>
<th>Finding</th>
<th>Rejection Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No infiltrates</td>
<td>None</td>
</tr>
<tr>
<td>1A</td>
<td>Focal (perivascular of interstitial infiltrates without necrosis</td>
<td>Mild</td>
</tr>
<tr>
<td>1B</td>
<td>Diffuse but not sparse infiltrate without necrosis</td>
<td>Mild</td>
</tr>
<tr>
<td></td>
<td>Description</td>
<td>Severity</td>
</tr>
<tr>
<td>---</td>
<td>-----------------------------------------------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>2</td>
<td>One focus only with aggressive infiltrate and/or myocyte damage Focal</td>
<td>Moderate</td>
</tr>
<tr>
<td>3A</td>
<td>Multifocal addressive infiltrates and/or myocyte damage</td>
<td>Moderate</td>
</tr>
<tr>
<td>3B</td>
<td>Diffuse inflammatory infiltrates with necrosis</td>
<td>Borderline severe</td>
</tr>
<tr>
<td>4</td>
<td>Diffuse aggressive polymorphous infiltrate with edema, hemorrhage and vasculitis, with necrosis</td>
<td>Severe</td>
</tr>
</tbody>
</table>

**Cellular biopsy Cellular biopsy Cellular biopsy Angiogram Vascular biopsy**

4. **Allograft Coronary Artery Disease**
   A. Leading cause of death > 1 year after transplantation
   B. Equivalent to:
   1) "Chronic rejection" in renal allografts
   2) "Vanishing bile ducts" in hepatic allografts
   3) "Bronchiolitis obliterans" in pulmonary allografts
   C. Prevalence of angiographically detectable disease
      1) 1 year: 10-20%
      2) 5 years: 30-50%
   D. Potential risk factors
   E. Non-transplant specific
      1) Age
      2) Sex
      3) Family history
4) Hypertension  
5) Diabetes mellitus  
6) Smoking  
7) Hyperlipidemia  
F. Transplant specific  
1) HLA mismatch, at DR locus  
2) Immunosuppressant drugs  
3) CMV infection  
4) Donor age  
G. Symptomatic  
1) Angina  
2) Acute myocardial infarction  
3) Sudden death  
H. Asymptomatic  
1) Coronary angiography  
2) Nuclear (thallium/sestamibi)  
3) Dobutamine stress echocardiography  
4) Intravascular ultrasound  

**Vascular Lesion Survival post Angiogram Survival post Transplant Infection post Transplant**

---

5. Infectious Complications  
A. Phases  
B. Early (< 1 month), Nosocomial Phase
1) Wound
2) Catheter-related
3) Hospital acquired pneumonia

C. Middle (2-5 months), Opportunistic Phase
1) Toxoplasmosis
2) Herpes viruses (cytomegalovirus, herpes simplex)
3) Pneumocystis carinii
4) Nocardia
5) Fungi

D. Late (> 6-12 months), "Normal" Phase

6. Infectious Prophylaxis

<table>
<thead>
<tr>
<th>Pathogenic Organism</th>
<th>Prophylactic Agent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cytomegalovirus</td>
<td>Gancyclovir, Acyclovir, IVIg</td>
</tr>
<tr>
<td>Herpes simplex</td>
<td>Acyclovir</td>
</tr>
<tr>
<td>Toxoplasmosis</td>
<td>Pyrimethamine and Leucovorin</td>
</tr>
<tr>
<td>Pneumocystis</td>
<td>TMP/SMX, Dapsone, Pentamidine</td>
</tr>
<tr>
<td>Oral candidiasis</td>
<td>Nystatin, Mycelex troches</td>
</tr>
</tbody>
</table>

Malignancy

Malignancy after Heart Transplantation

1 YEAR FOLLOWUP

- No: 96.1%
- Yes: 3.9%

2 YEAR FOLLOWUP

- No: 95.0%
- Yes: 5.0%

(U.S. data 4/94 to 12/96).
7. Malignancy
   A. Incidence 1-2 %/year
   B. Cutaneous Malignancy
      1) Squamous cell carcinoma
      2) Basal cell carcinoma
   C. Lymphoma (PTLD)
      1) Frequency: Most common tumor in cyclosporine-based immunosuppression
      2) Timing: 12-18 months post transplant
      3) Location: Intraabdominal most common
      4) Etiology: B cell origin induced by Epstein-Barr virus
      5) Treatment: Reduce immunosuppression
      6) Acyclovir
      7) Chemotherapy/radiation

8. Cyclosporine-induced Nephrotoxicity
   A. Characteristics
      1) Major decline in renal function in first 6 months
      2) Disproportionate azotemia
      3) Hyperkalemia
      4) Increased uric acid levels
      5) Mild proteinuria
      6) Decreased fractional excretion of sodium
   B. Pathogenesis
   C. Renal vasoconstriction (afferent arterioles)
      1) Prostaglandins
      2) Endothelin
      3) Direct effect on smooth muscle
   D. Direct tubular toxicity
9. **Cyclosporine-induced Hypertension**
   A. Incidence: 50-90% of heart transplant recipients
   B. Occurrence: Weeks to months
   C. Treatment goal: BP < 140/90 mmHg
   D. Moderate limitation of salt intake
   E. Maintenance of ideal body weight
   F. Moderate exercise
   G. ACE inhibitors (captopril, enalapril, lisinopril)
   H. Calcium channel blockers (diltiazem, nifedipine, verapamil, amlodipine, and others)
   I. Diuretics
   J. Others (Clonidine, B-blockers, hydralazine, prazocin)
10. **Hypercholesterolemia**  
A. Incidence: 60-80% of heart transplant recipients  
B. Occurrence: - 8 months  
C. Magnitude: Increase of 30-80 mg/dl  
D. Positive relationship to:  
   1) Prior history of ischemic heart disease  
   2) Preexisting lipid abnormalities  
   3) Cumulative dose of corticosteroids  
   4) Cyclosporine  
E. Treatment goals: Serum cholesterol > 240 mg/Dl (or LDL cholesterol > 160 mg/dl)  
   1) Moderate limitation of fat intake
2) Maintenance of ideal body weight
3) Moderate exercise
4) Minimize corticosteroid dose
F. Gemfibrozil
G. HMG-CoA reductase inhibitors
1) Lovastatin
2) Simvastatin
3) Pravastatin
4) Fluvastatin
H. Bile acid sequestrants (Cholestyramine, Colestipol)
1) Nicotinic Acid
2) Probucol
3) Fish oil (Omega-3 Free Fatty Acids)

11. Osteoporosis
A. Incidence:
1) 10% of heart transplant recipients
B. Risk factors:
1) Corticosteroids
2) Older age
3) Lower bone mass before transplantation
4) Low cardiac output states
5) Prolonged use of loop diuretics
6) Physical inactivity
7) Cardiac cachexia
8) Heparin administration
9) Postmenopausal status
Chapter 36 - Transplant Immunology

Allograft Rejection

Th Cell Events
1. Phases of Immunosuppression
   A. Early rejection prophylaxis
   B. Maintenance rejection prophylaxis
   C. Treatment of established rejection

2. Mechanism of Action of Immunosuppressive Agents
   A. Inhibitors of Interleukin-2
   B. Production
      1) Cyclosporine A
      2) Tacrolimus
   C. Action
      1) Rapamycin (Sirolimus)
      2) SDZ RAD
      3) Interleukin-2 Receptor Blockers
   D. Daclizumab
   E. Basiliximab
   F. Inhibitors of purine or pyrimidine biosynthesis
   G. Purine
      1) Azathioprine
      2) Methotrexate
      3) Mycophenolate mofetil
      4) Mizoribine (bredinin)
H. Pyrimidine
1) Brequinar sodium
2) Leflunomide
I. Both purine and pyrimidine
1) Cyclophosphamide
J. Opsonization of lymphocytes
1) Murine monoclonal anti-CD-3 antibody (OKT3)
2) Polyclonal antibodies (horse, rabbit)
I. Multiple mechanisms or not clearly defined mechanisms
1) Adrenocorticosteroids
2) 15-Deoxyspergualin

3. Murine Monoclonal CD-3 Antibody (OKT3)
A. Identification: IgG2a Murine Immunoglobulin
B. Mechanism: Inhibits signal transduction of antigen recognition, opsonizes CD-3 lymphocytes
C. Dose/route: 5-10 mg/day, IV
D. Side effects: First dose reactions, HAMA formation
E. Interactions: None
F. Use: Early rejection prophylaxis, treatment of rejection
G. Monitoring: CD-3 Counts, OKT3 levels

Total Lymphocytes
4. Polyclonal Antibodies
A. Identification: Horse (ATGAM) or rabbit (Thymoglobulin) immunoglobulin
B. Mechanism: RES-mediated removal of opsonized cells
C. Dose/route: ATGAM 10-20 mg/kg/day IV; Thymoglobulin 1.5mg/kg IV
D. Side effects: Leukopenia, thrombocytopenia, fever, arthralgias, serum sickness
E. Interactions: None
F. Use: Early rejection prophylaxis, treatment of rejection
G. Monitoring: CD-2 counts

5. Cyclosporine
A. Identification: Metabolite of tolypocladium inflatum gams
B. Mechanism: Inhibits m-RNA transcription of interleukin-2
C. Dose/route: 3-6 mg/kg/day orally; IV:Oral = 1:3
D. Side effects: Nephrotoxicity, hypertension, tremor, headache/paresthesias, hirsutism, gingival hyperplasia
E. Interactions: Increase clearance of cyclosporine
  1) Rifampin
  2) Isoniazid
  3) Phenytoin
  4) Phenobarbital
F. Decrease clearance of cyclosporine
  1) Erythromycin
  2) Ketoconazole
  3) Diltiazem
  4) Verapamil
  5) Nicardipine
  6) Cimetidine
E. Use: Maintenance immunosuppression
F. Monitoring: Blood or serum level determination

Cyclosporine Formulations

<table>
<thead>
<tr>
<th>1. Sandimmune Liquid</th>
<th>Liquid &amp; Capsules</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Neoral (microemulsion) Liquid</td>
<td>Liquid &amp; Capsules</td>
</tr>
<tr>
<td>3. Sang CYA (microemulsion) Liquid</td>
<td>Liquid</td>
</tr>
</tbody>
</table>

6. Tacrolimus (FK-506)
A. Identification: Fermentation product of Streptomyces tsukubaensis
B. Mechanism: Inhibits mRNA transcription of interleukin-2
C. Dose/route: 0.05 - 0.075 mg/kg orally q 12 hours 0.03 mg/kg intravenously q 24 hours
D. Side-effects:
   1) Nephrotoxicity
   2) Hyperglycemia
   3) Neurotoxicity
   4) Hypertension
E. Interactions: Believed similar to cyclosporine
F. Use: Maintenance immunosuppression
G. Monitoring: Blood level determination

7. Azathioprine
   A. Identification: Precursor to 6 mercaptopurine
   B. Mechanism: Disrupts normal purine incorporation into ribonucleic acids
   C. Dose/route: 1 - 4 mg/kg/day; IV:Oral = 1:1
   D. Side effects: Hematologic, pancreatitis, cholestatic jaundice, hepatitis, interstitial pneumonitis
   E. Interactions: Increased levels with allopurinol
   F. Use: Maintenance immunosuppression
   G. Monitoring: White blood cell count

8. Mycophenolate Mofetil (RS-61443)
   A. Identification: Morpholinoethylester of mycophenolic acid, a fermentation product of Penicillium species
   B. Mechanism: Inhibits inosine monophosphate dehydrogenase in the de novo pathway of guanine nucleotide biosynthesis
   C. Dose/route: 1,000 - 1,500 mg orally q 12 hours
   D. Side-effects: Leukopenia, Nausea, vomiting, diarrhea
   E. Interactions: Probably with acyclovir
   F. Use: Maintenance immunosuppression
   G. Monitoring: None

9. Corticosteroids (Prednisone, hydrocortisone, methylprednisolone)
   A. Mechanism:
   1) Inhibit transcription of IL-1 and IL-6 encoding m-RNA in macrophages
   2) Block antigen recognition, decrease IL-1 AND IL-6 driven effects
3) Redistribution of lymphocytes
B. Dose/route: Prednisone 1 mg = hydrocortisone 4 mg = methylprednisolone 0.8 mg
C. Side effects:
1) Cushing’s syndrome, osteoporosis, myopathy, cataracts, peptic ulcers
2) Glucose intolerance, hypercholesterolemia, skin fragility, adrenal suppression
D. Interactions: None clinically significant
E. Use: Maintenance immunosuppression, rejection treatment

10. Immunosuppression: Early Rejection Prophylaxis
A. Standard Triple therapy
B. Preoperative
1) Cyclosporine: 2-6 mg/kg po based on renal function
2) Azathioprine: 4 mg/kg IV
C. Intraoperative
1) Methylprednisolone: 500 mg
D. Postoperative
1) Cyclosporine: 2-6 mg/kg po bid based on trough levels and renal function
2) Azathioprine: 2 mg/kg/day
3) Methylprednisolone: 125 mg IV every 8 hours for 3-4 doses, followed by prednisone
4) Prednisone: (beginning after Methylprednisolone)1 mg/kg/day tapering over 1 week to 0.5 mg/kg/day, followed by further tapering over 2-3 months to 0.2-0.3 mg/kg/day
E. Quadruple Therapy - OKT3 *
F. Preoperative
1) Cyclosporine: None
2) Azathioprine: 4 mg/kg IV
G. Intraoperative
1) Methylprednisolone: 500 mg
2) OKT3: 5-10 mg (or administer first dose of OKT3, 5 mg IV 24-48 hours postoperatively)
H. Post operative
1) OKT3: 5 mg/day IV for 7-10 days post operative
2) Cyclosporine: Beginning on the fourth post operative day, 2-6 mg/kg po bid based on trough levels and renal function
3) Azathioprine: 2 mg/kg/day
4) Methylprednisolone: 25 mg IV every 8 hours for 3-4 doses, followed by prednisone
5) Prednisone: (beginning after Methylprednisolone) 0.25 mg/kg/day during the time of OKT3 administration. After OKT3 course completed, increase to 1 mg/kg/day for 7 days, then taper either completely off over 4 weeks or to 0.2-0.3 mg/kg/day by 1-3 months.

I. * OKT3 should be premedicated daily for three days with diphenhydramine 50 mg IV, acetaminophen 650 mg po or per rectum, and ranitidine 100 mg IV. OKT3 should be post-medicated every 6, 12, and 18 hours after the first 3 doses with diphenhydramine 25 mg IV, acetaminophen 650 mg po or per rectum, and ranitidine 50 mg IV.

J. Quadruple Therapy - ATG/ALG/ALS**

K. Preoperative
1) Cyclosporine: None
2) Azathioprine: 4 mg/kg IV

L. Intraoperative
1) Methylprednisolone: 500 mg

M. Post operative
1) ATG/ALG/ALS: Daily dosing for 7-10 days, Dose depends on preparation
2) Cyclosporine: Beginning on the second or third post-operative day, 2 - 6 mg/kg po bid based on trough levels and renal function
3) Azathioprine: 2 mg/kg/day
4) Methylprednisolone: 125 mg IV every 8 hours for 3-4 doses, followed by prednisone
5) Prednisone: (beginning after Methylprednisolone) 0.25mg/kg/day during the time of ATG/ALG/ALS, followed by 1mg/kg/day for 7 days, then taper either completely off over 4 weeks or to 0.2-0.3 mg/kg/day by 1-3 months.

N. ** ATG/ALG/ALS should be pre-medicated daily with diphenhydramine 25-50 mg IV and acetaminophen 650 mg po or per rectum

11. Maintenance Immunosuppression Goal

A. Lowest overall level of immunosuppression to prevent rejection

B. Cyclosporine levels
1) Low therapeutic after 1-2 years

C. Azathioprine
1) 1-2 mg/kg/day after 1-2 years

D. Prednisone
1) 0 - 0.1 mg/kg/day after 1 year

12. Treatment of Rejection - Considerations
A. Histologic grade of biopsy  
B. Allograft function  
C. Time after transplantation  
D. Past rejection history  
E. Concomitant immunosuppression  
F. Optimize cyclosporine/azathioprine

13. TREATMENT OF REJECTION

<table>
<thead>
<tr>
<th>GRADE</th>
<th>Mild</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate</td>
<td>None or oral corticosteroid augmentation</td>
</tr>
<tr>
<td>Moderate</td>
<td>Oral corticosteroid augmentation or IV</td>
</tr>
<tr>
<td>Severe</td>
<td>corticosteroids</td>
</tr>
<tr>
<td>TREATMENT</td>
<td>IV corticosteroids and ATG/ALG OR OKT3</td>
</tr>
</tbody>
</table>

Immunosuppression Flow-chart

14. Other options
A. Alteration of maintenance regimen  
1) Change from cyclosporine to Tacrolimus  
2) Change from azathioprine to mycophenolate mofetil  
3) Change from azathioprine to cyclophosphamide (vascular rejection)  
B. Methotrexate course (2.5 - 7.5 mg, Q 12 hrs x 3 doses/week for 8-12 weeks)  
C. Plasmapheresis (vascular rejection)  
D. Total lymphoid irradiation  
E. Photophoresis  
F. Re-transplantation

EXTENDED OUTLINE

A. Major Histocompatibility Complex (MHC)-prime physiologic role is to recognize “self” from “nonself”; in humans, this is known as the HLA system  
B. HLA: class I—HLA-A, B, C; expressed on all cells of an organism. Class I molecules present antigenic peptides to activated T lymphocytes expressing CD8 phenotype  
C. class II—DP, DQ, DR; expressed on antigen presenting cells, e.g., B cells, T cells, macrophages, dendritic cells, and endothelium. Present to T lymphocytes expressing the CD4 phenotype.
D. Pivotal cells moderating rejection are the T cells expressing the CD4 complex. These T cells recognize foreign Class II antigens on antigen presenting cells (APCs)—these cells not only present, but also provide signals (lymphokines/adhesion molecules) for T cell activation (second signal). There are two pathways for this to occur—direct and indirect routes of sensitization.

E. Activated CD4 cells are divided into Th1 and Th2 populations: Th1 subpopulation produces: IL-2 (CD8 differentiation), INF (MHC class II differentiation), TNF (NO radicals/O2/Prostaglandins) Th2: IL-4,5,10—augments B cell mediated responses

G. Effectors of Graft Rejection:
1) CD8 activation is thought to involve recognition of class I antigen (first signal) in a setting of increased levels of IL-2 (second signal) secreted by activated CD4 cells. Graft destruction ensues.
2) Hyperacute rejection is secondary to pre-existing blood group antibodies, anti-MHC antibodies, or natural antibodies which react with the endothelial antigens—complement, coagulation, and kallikrein/bradykinin cascades activated. Leads to graft edema, hemorrhage, and vascular thrombosis.
3) Accelerated rejection from IgM/IgG antibodies formed in response to the donor graft. Biopsy shows vascular destruction with a paucity of cellular infiltrate.

H. Hallmark of cellular rejection is graft infiltration:
1) leukocyte attachment to the endothelium
   a) mediated by cell adhesion molecules: selectins (rolling effect), integrins (bind the attached molecules), immunoglobulin superfamily-related molecules. This is followed by diapedesis—ICAM-1 and LFA-1 interaction
   2) transmigration through the vessel wall
   3) migration within the graft
   4) selective retention of activated cells in the graft
   5) local proliferation of cells

1. Rejection Prevention
   A. MHC matching
   B. Immunosuppression
   1) Cyclosporin (CyA) and FK506—inhibit lymphocyte proliferation and lymphokine production by binding to cytosolic intracellular receptors known as immunophilins (CyA-cyclophilins/FK506-FK506 proteins). These complexes inhibit calcineurin an intracellular protein phosphatase which plays a crucial role in the induction of lymphokine genes (IL-2). Side effects: renal dysfunction, GI, CNS, hypertension, and diabetes
2) Corticosteroids—negatively affecting the release of IL-1 and IL-6 from macrophages and thereby inhibiting IL-2 release. Side effects include hypertension, diabetes, cushingoid features, poor wound healing and asceptic bone necrosis.

3) Azathioprine works non specifically by virtue of its antimetabolite effects to inhibit lymphocyte proliferation.

4) OKT3—mouse monoclonal antibody against T cell receptor CD3 which nonspecifically suppresses all T cell functions. Use is generally in acute rejection episodes. Side effects: cytokine release causing fever, chills, and pulmonary edema; antibody production against the murine antibody which precludes future courses; dramatic increase in lymphoproliferative disorders.

5) Rapamycin—homolog of FK506, but does not inhibit calcineurin. Mode of action is unclear. Has prevented development of cardiac allograft vasculopathy in rat allografts.

6) 15-Deoxyspergualin (DSG)—binds cytoplasmic protein Hsc70 and interferes with antigen presentation and T and B cell development. Good for pancreatic islet cell survival. Causes myelosuppression.

7) Mycophenolate mofetil—inhibits inosine monophosphate dehydrogenase which blocks the de novo pathway for purine synthesis. This pathway is crucial for the proliferative response of T and B cell response. There is a low side effect profile.

8) Brequinar inhibits dihydroorotase dehydrogenase and blocks the de novo synthesis of pyrimidines. The proliferative response is attenuated.

C. Induction therapy

1) its use is associated with a greater cumulative rejection frequency

2) does not delay the onset of first rejection

3) does not reduce the cumulative number of episodes of rejection

D. Tolerance

1) refers to the elimination of the immune response to the antigens of the transplant while the immune response to all other antigens remains intact

2) Anergy—inactivation of cells reactive to the foreign antigen; thought to be the result of T cells binding specific antigen, but not receiving the appropriate second signal from APCs or CD4 cells. IL-2 experimentally has been shown to reverse this

3) Clonal deletion—elimination of cells reactive to the foreign antigen; occurs primarily in the thymus by a process known as negative selection

4) Suppression—suppression of cells responsive to the foreign antigens by another, regulatory immunologic process. Veto cell—inhibits the activity of T cells reactive with antigens on its surface thereby suppressing the activity of the attacking cells.
2. **Chronic Rejection**  

A. Cardiac allograft vasculopathy (CAV)  
1) is now the leading cause of death or graft failure after the first year. a) manifested by diffuse and accelerated form of coronary arteriosclerosis—often involves the full length of the artery.  
2) virtually all transplant recipients have these findings.  
3) rapidly progresses to vessel occlusion and MI  
a) pathologic finding is a diffuse intimal thickening and perivascular inflammation extending from large epicardial arteries into medium sized arteries and arterioles  
b) the endothelial response to injury theory likely forms the common bond; stimulated endothelial and smooth muscle cells produce cytokines and growth factors causing cell proliferation and smooth muscle and macrophage migration to the intima resulting in concentric lipid-laden calcium-poor plaque. There is evidence to document an inflammatory stage prior to the smooth muscle cell proliferation and also an impairment of endothelial-derived relaxation factor.  
c) immune mechanisms are probably at work because the vasculopathy is selective for the allograft which it effects diffusely; the cause of the presumed endothelial injury is unknown  
d) Risk factors??—lipid levels, hypertension, smoking, diabetes, and a history of previous atherosclerosis have not correlated with an increased risk of CAV. Only CMV infection has shown a strong association with either death or retransplantation from CAV.  
4) use of dobutamine stress echocardiography to follow vs. angiography  
a) best addressed by repeat transplantation although this is associated with a 30% or greater lower rate of survival  

B. Xenotransplantation  
1) widespread preformed antibodies in humans which are reactive for antigens of other species—e.g. pig to human transplant results in hyperacute rejection (discordant) [Concordant rejection is when closely related species reject transplants in a manner similar to allograft rejection]  
2) cells and organs from one species may not be able to function in a xenogenic environment  
3) cell mediated xenographic rejection may differ from allogeneic rejection and thus require different immunosuppression  
4) the future may lie in manipulating the donor organ endothelial system expression of complement inhibitory proteins and therefore mediate hyperacute rejection by preventing complement activation.
Chapter 37 - The Mediastinum

1. Anatomy
A. Compartments
1) Mediastinal borders: thoracic inlet (superior), diaphragm (inferior), sternum (anterior), spine (posterior), pleura (lateral)
2) Anterosuperior compartment is anterior to pericardium
3) Contents include thymus and great vessels
4) Middle, or visceral, compartment is between anterior and posterior pericardial reflections
5) Contents include heart, phrenic nerves, tracheal bifurcation, major bronchi, lymph nodes
6) Posterior, or paravertebral, compartment is posterior to posterior pericardial reflection
7) Contents include esophagus, vagus nerves, sympathetic chains, thoracic duct, descending aorta, and azygos/hemiazygos
2. Mediastinal Conditions
   A. Mediastinal Emphysema
      1) Introduction of air from esophagus, tracheobronchial tree, neck, or abdomen
      2) Causes include penetrating or blunt trauma, or spontaneous mediastinal emphysema
      3) Presents as substernal chest pain, crepitation, and pericardial crunching sound
      4) May result in tamponade
      5) Treat underlying cause; may require chest tube placement for pneumothorax
   B. Mediastinitis
      1) Occurs in about 1% of patients after median sternotomy
      2) Risk factors include prolonged surgery or CPB, re-exploration, wound dehiscence, shock, and use of bilateral internal mammary artery grafts in patients who are older or have diabetes
      3) Presents as fever, elevated WBC, and tachycardia
      4) Best treatment results with wound debridement and tissue flaps
   C. Mediastinal Hemorrhage
      1) Caused by trauma, aortic dissection, aneurysm rupture, or surgical procedures
      2) May result in mediastinal tamponade, which is more insidious than pericardial tamponade
      3) Meticulous hemostasis and adequate chest tube drainage will prevent this syndrome
      4) Spontaneous mediastinal hemorrhage can result from mediastinal masses, altered coagulation status, and severe hypertension
   D. Superior Vena Cava Obstruction
      1) Acute and chronic syndromes occur
      2) See SVC Syndrome

MEDIASTINAL TUMORS

1. Location
   1) Lesions are predictable to some degree predictable
   2) Most common tumors are neurogenic (20%), thymomas (20%), primary cysts (20%), lymphomas (13%), and germ-cell tumors (10%)
3) Most are located in anterosuperior compartment (54%), followed by posterior (26%) and middle (20%) tumors.

<table>
<thead>
<tr>
<th>Location</th>
<th>Tumors and Cysts by Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior</td>
<td>Thymoma, Thymic cyst</td>
</tr>
<tr>
<td>Middle</td>
<td>Enterogenous cyst, Lymphoma</td>
</tr>
<tr>
<td>Posterior</td>
<td>Germ cell tumor, Lymphoma</td>
</tr>
<tr>
<td></td>
<td>Neurogenic origin, Hamartoma</td>
</tr>
<tr>
<td></td>
<td>Hemangioma, Lipoma</td>
</tr>
<tr>
<td></td>
<td>Parathyroid adenoma, Granuloma</td>
</tr>
</tbody>
</table>

4) A significant portion (25-40%) of mediastinal tumors are malignant.

5) Anterosuperior tumors are more likely to be malignant, as are tumors of patients between the ages of 10 and 40.

6) Neurogenic tumors and non-Hodgkin’s lymphomas are the most common tumors in children.

2. Clinical Presentation

1) About two-thirds of patients will have symptoms at the time of diagnosis.
2) The absence of symptoms is a reasonably good indicator that a diagnosed tumor is benign.
3) Most common symptoms include chest pain, cough, and fever.
4) Signs of mechanical compression or invasion of mediastinal structures are more common with malignant tumors.
5) Paraneoplastic syndromes are not uncommon and include Cushing’s syndrome, thyrotoxicosis, hypertension, hypercalcemia, hypoglycemia, diarrhea, and gynecomastia.
3. Diagnosis
A. CXR will localize the tumor and give information on calcification and relative density of the tumor
B. CT scanning identifies chest wall invasion, multiple masses, and extension into spinal column
C. MRI is more accurate for vascular involvement and intracardiac pathology
D. Echocardiography is useful for patients with middle compartment tumors to localize between intracardiac and pericardial tumors
E. Guided needle biopsy can make a diagnosis of malignancy in 80-90% of patients
F. Mediastinoscopy/mediastinotomy may be necessary to make a diagnosis and establish resectability

4. Thymoma
A. Features
1) Represents 20% of all mediastinal masses in adults
2) Peak incidence is in 3rd to 5th decades of life; rare in children
3) About half are of mixed cell type, followed by epithelial (28%) and lymphocytic (20%) types
4) Between 15 and 65% of thymomas are benign
5) Frequently associated with paraneoplastic syndrome, most commonly myasthenia gravis
6) Myasthenia gravis is diagnosed in 30-50% of patients with a thymoma, and 15% of myasthenia patients will have a thymoma
7) Autoimmune reaction directed against the **postsynaptic nicotinic receptors** results in skeletal muscle fatigability and weakness, especially in axial muscles
B. Operative Technique

1) Remove all anterior mediastinal tissue and any invasive disease, including involved lung, pleura, pericardium, and SVC/innominate vein
2) **Thymic blood supply** arises from the internal mammary arteries

3) Patients with stage IIa or higher disease should receive postoperative radiation
4) Chemotherapy is indicated for stage III or IV disease
5) Debulking may be appropriate for stage IV disease, although there is no evidence for increased survival. At 5 years after resection, 25-30% of patients will have complete resolution of myasthenia symptoms and 30-50% will be improved
6) Prognosis is dependent on stage of tumor, not on presence of myasthenia gravis

5. Thymic Carcinoid

A. Most occur in males and about two-thirds are symptomatic
B. Originate from Kulchitsky cells in the thymus, but are not associated with myasthenia gravis or the carcinoid syndrome
C. May cause other paraneoplastic syndromes, however, most commonly Cushing’s syndrome (33%)
D. Presence of such syndromes is a very poor prognostic factor
E. Up to 75% will develop local recurrence or metastases
F. Low overall cure rate and mean survival is 3 years
6. Lymphoma
   A. Between 40 and 70% of lymphoma patients will have mediastinal involvement during their disease course
   B. Only 5-10% of lymphoma patients will have isolated mediastinal disease, and are usually symptomatic
   C. Characteristic Hodgkin’s lymphoma symptoms are chest pain after alcohol consumption and cyclic Pel-Ebstein fevers
   D. Nodular sclerosing and lymphocyte predominance forms of Hodgkin’s lymphoma are the most common to cause mediastinal involvement
   E. Up to 40% of patients with lymphoblastic non-Hodgkin’s lymphoma will have mediastinal disease
   F. Surgery is indicated if fine-needle aspiration is inconclusive or to evaluate residual mass after chemotherapy
   G. Surgical options include cervical mediastinoscopy, parasternal mediastinotomy, and thoracoscopy

7. Germ Cell Tumors
   A. Comprise 15-25% of anterior mediastinal masses
   B. Most common in children and young adults
   C. Includes teratomas, teratocarcinomas, seminomas, embryonal cell carcinomas, choriocarcinomas, and endodermal cell or yolk-sac tumors
   D. Identical to germ cell tumors originating in the gonads, but are not metastatic lesions from primary gonadal tumors
   E. About 60% are benign and 40% are malignant
   F. Predominantly Benign Tumors
      1) Teratomas are complex, multiple tissue element tumors
      2) Symptoms are related to mechanical effects
      3) Simplest form is the dermoid cyst, which consists of mostly dermal and epidermal tissue
      4) More complex teratomas may have well-differentiated bone, cartilage, nerve, or glandular tissue
      5) Malignant tumors are differentiated upon histologic identification of embryonic tissue
   G. Malignant Tumors
      1) Male predominance and most patients are symptomatic
2) 40% are seminomas and 60% are nonseminomas (embryonal cell, choriocarcinoma, yolk-sac, and teratocarcinoma)

<table>
<thead>
<tr>
<th></th>
<th>Seminomas</th>
<th>Non-seminomas</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AFP/B-HCG</strong></td>
<td>rare</td>
<td>90%</td>
</tr>
<tr>
<td><strong>Associated syndromes</strong></td>
<td>none</td>
<td>Klinefelter’s, trisomy 8, 5q deletion</td>
</tr>
<tr>
<td><strong>Radiosensitivity</strong></td>
<td>High</td>
<td>Insensitive</td>
</tr>
<tr>
<td><strong>Metastatic behavior</strong></td>
<td>Remain intrathoracic</td>
<td>Frequently disseminated</td>
</tr>
<tr>
<td><strong>Treatment</strong></td>
<td>Radiation</td>
<td>Cis-platinum chemotherapy</td>
</tr>
<tr>
<td><strong>Remission</strong></td>
<td>Over 80%</td>
<td>CR in 55-60%, PR in 30-35%</td>
</tr>
<tr>
<td><strong>5-year survival</strong></td>
<td>50-80%</td>
<td>50-60%</td>
</tr>
<tr>
<td><strong>Remission</strong></td>
<td>CR=complete</td>
<td>PR=partial</td>
</tr>
</tbody>
</table>

3) Initial surgical intervention typically only for diagnosis due to high radiosensitivity of seminomas and frequent metastatic disease in non-seminomas.

4) Surgical resection after induction of chemotherapy may have a role in non-seminomatous tumors.

8. Endocrine Tumors
A. Intrathoracic Thyroid
1) 80% are substernal extensions of a cervical goiter
2) True intrathoracic thyroid (derives blood supply from thoracic vessels) comprises only 1% of all mediastinal tumors
3) More common in women and in the 6th to 7th decades, most are adenomas
4) Usually presents with tracheal or esophageal compression; thyrotoxicosis is uncommon
5) I-131 scanning should be done to identify presence of functioning cervical thyroid tissue before resecting these tumors
6) Resect substernal extensions through a cervical incision and true intrathoracic lesions through the chest
B. Parathyroid
1) Most are adenomas and are found by the superior pole of the thymus due to common embryogenesis from the third branchial cleft
2) Symptoms are usually due to hyperparathyroid syndrome
3) Parathyroid cysts are not usually hormonally active
9. Primary Cysts
A. Bronchogenic Cysts
1) Most common primary cysts in the mediastinum (5%)
2) Arise from ventral foregut and are usually located in the subcarinal or right paratracheal region
3) Two-thirds are asymptomatic; symptoms include tracheobronchial or esophageal compression and infection from tracheobronchial communication
4) Complete excision is recommended, even if asymptomatic, to prevent late complications
B. Esophageal/Enteric Cysts
1) Comprise 3-5% of mediastinal tumors
2) More common in children and tend to occur in the lower third of the esophagus
3) Dysphagia is the most common symptom
4) CT scanning is essential in patients with vertebral anomalies to evaluate for possible spinal cord involvement (neuroenteric cyst)
5) Avoid endoscopic biopsy, as this may cause cyst perforation and infection
6) Complete excision is indicated; a thoracoscopic approach can be used for uninfected cysts
C. Pleuropericardial Cysts
1) Uncommon, classically occur at the pericardiophrenic angles, 70-80% on the right side
2) Usually asymptomatic and may communicate with the pericardium
3) Guided needle aspiration is the initial therapy of choice
4) Surgical excision is indicated if the cyst recurs or if the diagnosis is in doubt

10. Neurogenic Tumors
A. Etiology and Diagnosis · Most posterior mediastinal masses are of neurogenic origin
1) 95% of these tumors in adults are benign and are usually asymptomatic
2) In children, most neurogenic tumors are malignant
3) Classified according to cell origin; most arise from intercostal nerve or sympathetic chain

<table>
<thead>
<tr>
<th>Intercostal nerve</th>
<th>Sympathetic ganglia</th>
<th>Paraganglia cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neurofibroma</td>
<td>Ganglioma</td>
<td>Paraganglioma</td>
</tr>
<tr>
<td>Neurilemoma</td>
<td>Ganglioneuroblastoma</td>
<td>(pheochromocytoma)</td>
</tr>
<tr>
<td>Neurofibrosarcoma</td>
<td>Neuroblastoma</td>
<td></td>
</tr>
</tbody>
</table>
4) Neurilemomas are the most common and originate from Schwann’s cells
5) These are encapsulated tumors which stain with S-100 protein immunostain
6) Two primary types: Antoni A (organized pallisading pattern) and Antoni B (loose reticular pattern)
7) Neurofibromas originate from peripheral nerve
8) Form a pseudocapsule and have more variability with the S-100 stain
9) Both types of tumors are associated with von Recklinghausen’s disease, although more commonly neurofibromas
10) Chest CT is sufficient for diagnosis of most of these tumors, and MRI should be used when an intraspinal component is present

B. Operative Indications
1) Benign tumors (neurofibroma, neurilemoma, ganglioneuroma) can be effectively treated with local excision
2) Combined thoracic and neurosurgical approach is indicated for tumors with intraspinal extension
3) Recurrence is rare for benign tumors
4) Local recurrence is common for malignant tumors and overall prognosis is poor
Chapter 38- Diseases of the Diaphragm

Diseases Of The Diaphragm

1. Anatomy
   A. Composed of a central tendinous portion and a peripheral muscular portion
   B. Muscular portion consists of sternal, costal, and lumbar components
   C. Three major openings: aortic (aorta, azygos vein, thoracic duct), esophageal (esophagus, vagus nerves), caval (IVC)
   D. Right and left phrenic arteries arise from the abdominal aorta
   F. Additional arterial supply from pericardiophrenic and musculophrenic arteries
   G. Venous drainage is via right and left phrenic veins to the IVC; some drainage to the left renal vein as well
   H. Right and left phrenic nerves supply both sensory and motor innervations

2. Congenital Diaphragmatic Hernias
   A. Bochdalek’s Hernia
      1) Occurs posterolateral in the area of the 10th and 11th ribs
      2) 90% occur on the left
      3) 2:1 male to female incidence
      4) Usually isolated and not associated with other congenital defects
      5) Typically manifests as acute respiratory distress
6) CXR demonstrates intestine in the thorax and shift of mediastinal contents to the right
7) Initial treatment includes NG decompression, positive-pressure ventilatory support, and surgical correction
8) Approach left-sided defect through the abdomen in order to explore for malrotation and obstruction
9) Right-sided defects are repaired through a thoracotomy
10) Postoperative mortality can be as high as 50%, mostly attributed to increased pulmonary vascular resistance
11) ECMO is useful to reduce pulmonary vascular resistance and help resolve persistent fetal circulation

B. Morgagni’s Hernia
1) Defect occurs in a subcostosternal location
2) Uncommon (less than 3% of diaphragmatic hernias) and usually asymptomatic
3) Well defined hernia sac becomes symptomatic typically after age 40, when obesity, pregnancy, or trauma increases intraabdominal pressure
4) The transverse colon is the most common organ to herniate, and can present as an acute colonic obstruction
5) Repair is usually performed through a upper midline incision

C. Esophageal Hiatal Hernia
1) Congenital defects causing these hernias are uncommon in adults, but some neonates and infants may have reflux associated with an esophageal hiatal hernia
2) Typical symptoms are vomiting, respiratory complications, anemia, and failure to thrive
3) Diagnosis rests on esophagography, fluoroscopy, and pH monitoring
4) Treatment is primarily medical; surgery is indicated for medical failure

3. Tumors of the Diaphragm
A. Primary
1) Rare tumors; cysts are more common than inflammatory masses, which are more common than neoplasms
2) Equal male:female incidence; left-sided tumors are slightly more common than right-sided tumors
3) Symptoms include pain, cough, dyspnea, and GI symptoms
4) CXR and CT scan will localize the tumor
5) The majority of neoplasms are benign (60%), which are usually cysts
6) Up to 40% are malignant, usually sarcomas
7) Treatment includes excision and closure of the diaphragmatic defect
B. Metastatic
1) Most neoplastic involvement of the diaphragm occurs from contiguous extension of nearby tumors
2) The most common lesions arise from lung, esophagus, stomach, liver, and the retroperitoneum
3) Treatment is based on the primary tumor

4. Traumatic Perforation
A. Penetrating perforation should be suspected with any thoracic injury below the level of the nipples (5th ICS)
B. Most blunt hernias are caused by automobile accidents, and about 90% occur in the left hemidiaphragm
C. Blunt trauma defects are large, usually about 10-15 cm, and typically located in the posterior left hemidiaphragm
D. Stomach is the most commonly herniated organ, followed by spleen, colon, small bowel, and liver
E. Respiratory insufficiency is common early, while intestinal obstruction predominates later
F. CXR and CT scan will diagnose most; barium contrast is contraindicated, as it can produce a total obstruction in this setting
G. Missed injury and delayed diagnosis commonly leads to bowel incarceration and obstruction
H. Mortality is relatively high (15-40%) due to high incidence of associated injuries
I. Repair should be undertaken promptly with full exploration for other injuries
J. Left-sided perforation should be repaired through the abdomen to allow correction of associated injuries
K. Right-sided perforations may require thoracotomy

5. Pacing
A. Indications
1) Sarnoff (1940's) and Glenn (1950's) were the primary developers of diaphragmatic pacers
2) Pacing is indicated in patients who have chronic ventilatory insufficiency with normal nerves, lungs and diaphragm
3) This includes some quadriplegic patients and central alveolar hypoventilation
4) Contraindications to pacing are lower motor neuron dysfunction, muscular dystrophy, and extensive lung disease
B. Mechanism
1) There are four components to a diaphragmatic pacemaker:
   a) Transmitter: sets respiratory rate and length of inspiration
   b) Antennae: transfers signal across intact skin to the receiver
   c) Receiver: obtains signal and energy from external portion by inductive coupling
   d) Electrode: stimulates the phrenic nerve

2) The electrode portion is usually implanted on the phrenic nerve through the 2nd ICS anteriorly
3) The receiver is placed in a subcutaneous pocket

C. Central Alveolar Hypoventilation
   1) Features of CAH include: hypoxemia and hypercapnia increasing with sleep, hypoventilation or apnea during sleep, and clinical findings of cyanosis, polycythemia, and cor pulmonale
   2) These patients have near-normal ventilatory capacity tests, but have a reduced response to induced hypoxemia and hypercapnia
   3) Absence of upper airway obstruction or persistence after relief must also be demonstrated
   4) These patients should begin pacing within 3 weeks of operation

D. Quadriplegia
   1) Patients with high cervical lesions (C1 or C2) are suitable candidates; injury to C3-C5 may injure the motor component of the phrenic nerves, preventing adequate pacing
   2) Delay surgery for several months to allow for potential recovery after spinal cord injury
   3) Pacing should be gradually introduced to avoid diaphragmatic fatigue and permanent damage
   4) Patients should be selected who are good candidates for long-term rehabilitation
Chapter 39 - Chest Wall Anomalies and Tumors

1. Pectus Excavatum
   A. Most common *congenital sternal deformity*, occurring in 1 in 400 children

B. Excessive growth of lower costal cartilage results in *sternal depression*
C. Usually causes a deeper depression on the right, pushing heart to the left
D. Congenital with progressive worsening over time
E. Rarely familial

2. Physiologic Manifestations
A. Usually asymptomatic
B. Subjective decrease in respiratory reserve with exercise
C. Scoliosis and mitral valve prolapse have been associated with pectus excavatum
D. Decreased maximal voluntary ventilation and a mild restrictive pattern on PFTs has been documented in some studies
E. Decreased SV and CO during upright exercise has also been demonstrated

3. Operative Indications
A. Cosmetic correction is the most common reason
B. Psycho-social factors, however, may be quite limiting, particularly in older children
C. Respiratory insufficiency and recurrent pulmonary infections
D. Best results are obtained in patients between the ages of 3 and 5

4. Operative Technique
A. Ravitch repair
1) Midline or transverse inframammary incision
2) Pectoralis reflected bilaterally to expose costal cartilages
3) Subperichondrial resection of all deformed costal segments
4) **Elevate sternum** from underlying structures and **separate from cartilage**

5) Transverse sternal osteotomy and **fixation** with pin or cartilage support
B. Sternal eversion

1) En bloc excision of sternum and associated deformed cartilages
2) Free graft *everted and fixated*

3) Alternatively, the graft can be mobilized on an *internal mammary artery pedicle*
4) New anterior surface of the sternum shaped to form proper contour
   C. Prosthetic implants
   1) Silastic or other prosthetic molds generally give poor results

5. Results
   A. Cosmetic results are good in 80-90%
   B. Recurrence occurs in about 10-20% of patients
   C. Return of normal respiratory function and improvement in exercise capacity is possible

6. Other Deformities
   A. Pectus Carinatum
      1) More common in males and is associated with scoliosis
      2) Usually presents as anterior sternal displacement with symmetric costal cartilage concavity
      3) Costal cartilage resection gives excellent results
   B. Poland’s syndrome
      1) Unilateral absence of pectoralis major with hypoplasia or aplasia of ipsilateral breast and ribs, and bradysyndactyly
      2) More common in males, usually occurs on the right side, and is most often sporadic
      3) Operative repair involves rib grafts and prosthetic patching of the chest wall
   C. Sternal fissure
      1) Complete, upper, or distal varieties occur
      2) Narrow clefts can be closed primarily after mobilization by oblique chondrotomies
      3) Broader clefts may require a prosthesis to avoid compressing the heart
   D. Cantrell’s Pentalogy
      1) Characterized by a distal cleft, omphalocele, diaphragmatic cleft, pericardial defect, and congenital heart defect (usually VSD or TOF)
      2) One-stage repair is usually possible

CHEST WALL TUMORS

1. Incidence
   A. Comprise 7-8% of all bony tumors
   B. Most primary chest wall tumors are malignant
C. 85-90% occur in the ribs (50% malignant)
D. 10-15% occur in the sternum (95% malignant)
E. Male:female = 2:1

2. Clinical Presentation
A. Slowly enlarging mass eventually causes pain and presence of mass
B. Pain is more common in malignant tumors, but 20-25% are asymptomatic
C. Tumors occur at any age and are more likely to be malignant in older patients
D. CXR with rib detail films and CT scan are usually adequate and can evaluate associated pulmonary nodules
E. MRI distinguishes nerve and vascular invasion

3. Etiology

<table>
<thead>
<tr>
<th>Malignant</th>
<th>Benign</th>
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<tbody>
<tr>
<td>Chondrosarcoma</td>
<td>Fibrous dysplasia (40%)</td>
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<tr>
<td>Myeloma</td>
<td>Chondroma (30%)</td>
</tr>
<tr>
<td>Osteogenic sarcoma</td>
<td>Osteochondroma</td>
</tr>
<tr>
<td>Ewing’s sarcoma</td>
<td>Desmoid</td>
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4. Principles of Treatment
A. Excisional rather than incisional biopsy should be performed if a primary chest wall tumor is suspected
B. Full thickness excision of the tumor with 1 rib margin is necessary; do not compromise resection to avoid large chest wall defect
C. Large tumors may warrant incisional biopsy
D. Needle biopsy is best for suspicious mets or myeloma
E. Sternal tumors should be treated by sternectomy

5. Principles of reconstruction
A. A defect less than 5 cm does not require reconstruction
B. Posterior defects do not require reconstruction due to scapula
C. Defects larger than 5 cm will require reconstruction
D. Skeletal stabilization can be accomplished with a mesh patch or methyl methacrylate
E. Soft tissue reconstruction can be done in a variety of ways, including myocutaneous flaps (latissimus dorsi, pectoralis major, rectus abdominus) and omental transposition
6. Results
   A. Low operative mortality and good postoperative pulmonary function
   B. Overall long term survival is about 50-70%, with best rates for chondrosarcoma and rhabdomyosarcoma, and worst rates for malignant fibrous histiocytoma
   C. Survival is better with wide excision
   D. Adjunctive therapy may improve survival
Chapter 40 - Thoracic Trauma

1. Definition Trauma to the chest is usually divided into blunt and penetrating injury. Proper emergency care and resuscitation are integral parts of the management of these patients, who may have airway obstruction, life-threatening hemorrhage, and severe associated injuries.

BLUNT THORACIC TRAUMA

1. Chest Wall Injuries
   A. Rib fracture is the most common thoracic injury
   B. Significant intrathoracic injury may be present without rib fracture in children due to rib cage elasticity
   C. Narcotics and intercostal nerve blocks are sufficient for simple rib fractures
   D. Patients with flail chest should be supported with mechanical ventilation for several days to regain chest wall stability
   E. Consider tracheostomy for prolonged intubation to minimize laryngeal injury and facilitate pulmonary care
   F. First rib fracture indicates significant force, and aortography is indicated if the patient also has brachial plexus deficit, absent radial pulse, pulsating supraclavicular mass, or widened mediastinum
2. Pulmonary Injuries
A. Pulmonary contusion probably occurs to a varying degree in all thoracic injuries and is a major component of flail chest
B. Significant hypoventilation and shunting from contusion requires judicious fluid management and ventilatory support, if indicated
C. Partial, complete, and tension pneumothorax should all be managed promptly with chest tube insertion
D. Subcutaneous emphysema should prompt investigation for pneumothorax but is not in itself an indication for chest tube placement
E. Hemothorax should be managed with early chest tube drainage to prevent clot formation and incomplete evacuation
F. Surgical exploration is recommended if initial output is more than 1000 ml or chest tube drainage is more than 100 ml/hr for 4 hours
G. A clotted hemothorax should be evacuated early by thoracotomy to improve pulmonary function and prevent late fibrothorax

3. Tracheal/Bronchial Injuries
   A. Most tracheal injuries are cervical and range from crush injuries to complete tracheal separation
   B. If endotracheal intubation is not possible, a surgical airway should be obtained
   C. Primary repair of tracheal lacerations or separation should be performed, if possible
   D. Blunt trauma typically causes a circumferential laceration of either main bronchus with complete separation
E. Only 50% of patients will have a pneumothorax with this injury, and hemothorax is uncommon
F. Only 1/3 of patients are diagnosed in the first 24 hours, and only 1/2 within the first month
G. Early repair is the preferred treatment if the diagnosis is made, and requires thoracotomy with intubation of the uninjured bronchus
H. Late strictures from incomplete tears or parenchymal isolation from complete tears can be repaired with bronchoplastic procedures, but may require pulmonary resection

4. Cardiac/Great Vessel Injuries
A. Myocardial contusion is the most common injury and is suspected with EKG changes and serial enzyme elevations
B. Coronary artery injury can result in thrombosis and myocardial infarction
C. Atrial or ventricular rupture is usually fatal, although the pericardium may restrict bleeding enough to allow survival to the ER
D. The patient should be monitored in the ICU and may require heparinization for coronary thrombosis and anti-arrhythmic therapy
E. Echocardiography and angiography are indicated for tamponade and post-injury murmurs, which suggest valvular insufficiency or septal defect
F. Aortic rupture is also usually fatal, but can result in formation of a false aneurysm, typically at the aortic isthmus
G. Patients with a widened mediastinum on CXR should have prompt aortography, which will demonstrate an intimal tear

H. Surgical repair should be done promptly, as fatal hemorrhage can occur at any time
I. Techniques include LA-FA bypass, proximal aorta-distal aorta shunting, and cross-clamping without cardiopulmonary bypass

5. Diaphragm Rupture
A. Most lacerations occur on the left hemidiaphragm and result from automobile accidents
B. Usually, the stomach herniates and undergoes volvulus, massively dilates, and causes left lung collapse and mediastinal shift to the right

C. Gastric distension can also result in perforation and should be prevented by NG tube placement
D. Splenic and liver injury is also common in this setting
E. The diaphragm can be repaired either through the chest or abdomen, and all tears should be closed in double-layer fashion

**PENETRATING THORACIC TRAUMA**

*Comment:* Knowledge of the type of weapon in gunshot wounds is useful, as unbalanced or hollow-point ammunition can cause extensive internal destruction despite small entrance wounds. In addition, such missiles can fragment and embolize. It is important to remember that any penetrating injury to the fourth interspace or below may well have passed through the diaphragm, and attention given to possible intraabdominal injury.

1. Chest Wall Injuries
A. Laceration of intercostal or internal mammary arteries can be life-threatening and operative intervention based on chest tube output
2. Pulmonary Injuries
   A. Most penetrating wounds only require chest tube insertion and lung expansion
   B. Parenchymal injuries requiring operation can usually be oversewn without difficulty
   C. Bronchial or pulmonary artery injury can require resection
   D. A large vascular clamp placed across the lung hilum facilitates exploration and vessel repair

3. Base of Neck Injuries
   A. The close proximity of major structures make injury highly probable
   B. This can be assessed by angiography, contrast swallow, endoscopy, or surgical exploration
   C. The surgical approach will vary, but median sternotomy with lateral or superior extension provides the widest exposure
   D. Avoid prosthetic grafts for vascular repair if the trachea or esophagus are also injured
   E. Cardiopulmonary bypass may be required if the aorta must be cross-clamped

4. Cardiac/Great Vessel Injuries
   A. The right ventricle is most commonly injured, followed by the left ventricle
   B. Ventricular septal defect is the most commonly intracardiac injury
   C. Most patients do not reach the hospital, as the injury to the pericardium leads to exsanguination instead of tamponade
   D. Hypotension that does not respond to rapid volume replacement suggests significant injury
   E. CXR, EKG, and echocardiography have little diagnostic value in these patients

F. Subxiphoid pericardiocentesis is useful for diagnosis; negative deflection of the QRS complex indicates contact with the epicardium and a drain should be left in place
G. Subxiphoid pericardial window is preferred for tamponade, however, and should be performed in the operating room, as the patient may rapidly exsanguinate.
H. Emergency room thoracotomy is seldom indicated, being reserved for moribund patients or rapid deterioration without time to transfer to the OR
I. Median sternotomy is the preferred approach
J. Repair ventricular lacerations with pledgetted nonabsorbable horizontal mattress sutures
K. Oversew atrial or aortic injuries
L. Coronary artery division should be managed by ligation and bypass grafting on cardiopulmonary bypass
M. Obvious septal defects or gross valvular insufficiency should be repaired; otherwise, the injury should be more adequately studied with postoperative catheterization

5. Tracheal/Bronchial Injuries
A. Tracheal injury is suggested by pneumothorax, pneumomediastinum, subcutaneous emphysema, hemoptysis, and airway obstruction
B. Following intubation or a surgical airway, an anterior collar incision is the best approach
C. Median sternotomy may be required for associated vascular injury or intrathoracic tracheal laceration
D. Avoid tracheostomy if possible when a vascular repair is in proximity

ESOPHAGEAL INJURIES
A. Blunt injury is rare; the most common cause is endoscopic perforation, followed by penetrating injuries
B. Mediastinitis is a lethal complication and early surgical intervention is recommended
C. Cervical esophageal injury should be approached through a lateral neck incision and thoracic injuries via thoracotomy
D. If the tissue is not extensively damaged, primary repair with drainage is appropriate; otherwise, the wound is left open
E. Postemptic rupture (Boerhaave’s syndrome) presents with pain, fever, and shock; death can occur within 24-48 hours
F. The diagnosis is suggested by cervical and mediastinal air, widened mediastinum, and pleural effusion
G. The esophagus should be closed in two layers, the mediastinum widely opened, and the area drained into the pleural space via thoracotomy
COMPLICATIONS OF THORACIC TRAUMA
A. ARDS follows many types of injuries, but is particularly common in thoracic trauma
B. It typically begins a few hours after injury and progresses rapidly
C. Ventilatory support with PEEP and high FIO2 is the standard of care
D. Failure of ARDS to improve after 4-6 days is associated with a high incidence of death
E. Arrhythmias are common in this patient population, particularly atrial fibrillation, which can be treated with standard measures
F. Ventricular arrhythmias suggest myocardial injury or infarction and should be investigated
G. Many patients require tracheostomy and attention should be given to proper care
H. Other complications include atelectasis, thromboembolism, infection, and air embolism
Chapter 41 - Thoracic Outlet Compression Syndrome

1. Definition
Compression of the subclavian vessels and brachial plexus at the superior aperture of the chest, most commonly against the first rib. Other terms for this syndrome include scalenus anticus syndrome, costoclavicular syndrome, hyperabduction syndrome, cervical rib syndrome, and first thoracic rib syndrome.

2. Anatomy
A. Surgical Anatomy
1) The first rib divides the cervicoaxillary canal into a proximal space and a distal space (the axilla)

2) Most neurovascular compression occurs in the proximal section, which consists of the costoclavicular space and the scalene triangle
3) Costoclavicular space boundaries: clavicle (superior), first rib (inferior), costoclavicular ligament (anteromedial), and scalenus medius/long thoracic nerve (posterolateral)
4) Scalene triangle boundaries: scalenus anticus (anterior), scalenus medius (posterior), and first rib (inferior)
5) The subclavian vein lies anteromedial to the scalenus anticus; the subclavian artery and brachial plexus run posterolateral to this muscle
B. Functional Anatomy
1) Certain movements and position of the arm and shoulder girdle, as well as anatomic variations, can narrow the costoclavicular space or scalene triangle
2) Arm abduction rotates the clavicle toward the first rib
3) Arm hyperabduction pulls the neurovascular bundle around the coracoid process and head of the humerus
4) Poor shoulder posture lessens the angle of the sternoclavicular joint as the distal end of the clavicle "droops"
5) Severe emphysema or excessive muscular development causes abnormal lifting of the first rib
6) Anatomic variations narrow either the superior angle or the base of the scalene triangle, producing upper and lower types of compression syndromes, respectively

3. Etiology
There are many factors which can cause neurovascular compression at the thoracic outlet. Bony abnormalities are present in about 30% of patients, and some of these may be visualized on plain chest x-ray.

<table>
<thead>
<tr>
<th>1. Anatomic Factors</th>
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<tbody>
<tr>
<td>Interscalene compression</td>
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<td>Costoclavicular compression</td>
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<td>Subcoracoid compression</td>
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<tr>
<th>2. Congenital Factors</th>
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<tbody>
<tr>
<td>Cervical rib</td>
</tr>
<tr>
<td>Rudimentary first rib</td>
</tr>
<tr>
<td>Scalen muscle abnormalities</td>
</tr>
<tr>
<td>Fibrous bands</td>
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<tr>
<td>Bifid clavicle</td>
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<tr>
<td>First rib exostosis</td>
</tr>
<tr>
<td>Enlarged C7 transverse process</td>
</tr>
<tr>
<td>Omohyoid muscle abnormalities</td>
</tr>
<tr>
<td>Anomalous transverse cervical artery</td>
</tr>
<tr>
<td>Postfixed brachial plexus</td>
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<tr>
<td>Flat clavice</td>
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<th>3. Traumatic Factors</th>
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Fractured clavice
Humeral head dislocation
Upper thorax crush injury
Sudden effort of shoulder girdle muscles
C-spine injuries/cervical spondylosis

4. Clinical Presentation
The character and pattern of symptoms will vary depending on the degree to which nerves, blood vessels, or both are compressed

A. Neurogenic
1) More frequent than vascular compression
2) Pain and paresthesias present in 95% of patients
3) True motor weakness with atrophy of hypothenar/interosseus muscles found in 10%
4) Sensory fibers lie on the outside of the nerve bundles and are the first to be affected by compression
5) Symptoms usually have ulnar nerve distribution (medial arm and hand, 4th and 5th fingers)
6) Pain is insidious and involves neck, shoulder, arm and hand
7) Strenuous physical exercise precipitates the symptoms, with arm in abduction and neck hyperextended

B. Vascular
1) Pain is usually diffuse and associated with coldness, weakness, and easy fatiguability of the hand and arm
2) Unilateral Raynaud’s phenomenon in about 7.5% of patients, which can be precipitated by hyperabduction or carrying heavy objects
3) There may be signs of distal embolization, poststenotic dilation or aneurysm of the subclavian artery, or true arterial occlusion
4) Venous obstruction is much less common and is known as "effort thrombosis" or "Paget-Schroetter syndrome"
5) The affected arm is edematous, discolored, and aches

5. Diagnosis
A. Clinical maneuvers
1) Positive findings for all tests include a decrease or loss of the radial pulse, or reproduction of symptoms
2) Adson/scalene test: patient holds a deep inspiration, fully extends neck, and turns head to the side
3) Costoclavicular test: shoulders drawn inferiorly and posteriorly
4) Hyperabduction test: arm is hyperabducted to 180 degrees

B. Radiologic tests
1) CXR and C-spine films can detect cervical ribs and degenerative changes
2) Cervical CT should be performed if osteophytic changes and intervertebral space narrowing are present
3) Angiography is indicated for a pulsating paraclavicular mass, absent radial pulse, or paraclavicular bruit

C. Ulnar nerve conduction velocity
1) Points of stimulation include the supraclavicular fossa, middle upper arm, below elbow, and wrist
2) Normal value across the thoracic outlet is 72 m/sec; any value less than 70 m/sec indicates compression

<table>
<thead>
<tr>
<th>Grading of Compression</th>
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<tbody>
<tr>
<td>Velocity</td>
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<tr>
<td>66-69 m/sec</td>
</tr>
<tr>
<td>60-65 m/sec</td>
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<tr>
<td>55-59 m/sec</td>
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<tr>
<td>less than 54 m/sec</td>
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6. Differential Diagnosis
A. The differential diagnosis for thoracic outlet syndrome is quite broad and includes neurologic, vascular, pulmonary, cardiac, and esophageal disorders.
B. Some of the more common conditions include herniated cervical disk, cervical spondylosis, and peripheral neuropathies

7. Treatment
A. Physical therapy should be initiated in all patients
B. Most patients with an UNCV above 60 m/sec will improve with conservative therapy
C. Surgical intervention should be considered if symptoms persist after physical therapy and the UNCV shows minimal or no improvement

8. Operative Technique
A. Always document preoperative neurologic findings
B. Transaxillary first rib resection avoids division of major muscle groups, ensures complete removal of the first rib, and has the best cosmetic result
C. Position the patient in the lateral position with the affected arm abducted 90 degrees and loosely suspended (straight up to the ceiling)
D. **Transverse incision** in the axilla between pectoralis major and latissimus dorsi

![Diagram of thoracic outlet structures]

E. Dissect along the external thoracic fascia to the first rib
F. Divide the scalenus anticus at its insertion on the rib
G. Remove middle and anterior portion of first rib after periosteal elevation
H. Divide costoclavicular ligament and remove posterior portion of first rib
I. Always protect the brachial plexus and vessels
J. Remove the entire first rib, as any residual portion may cause recurrence

9. Results
A. Almost all patients will have relief with conservative therapy, with about 5% requiring surgery
B. Symptoms recur in about 10% of patients
C. Less than 2% will require reoperation
D. A recent **study** from the Annals of Thoracic Surgery of over 2200 patients showed excellent or good results after operation in over 90% of cases

10. **Recurrent Thoracic Outlet Syndrome**
A. About 1-2% of patients will have persistent or progressively more severe symptoms after their operation
B. Most have recurrence within 3 months of operation
C. Symptoms, physical examination, and UNCV findings should be diagnostic before reoperation
D. Pseudorecurrence occurs in patients in whom a cervical rib or the second rib was resected instead of the first rib, or the first rib was resected instead of the causative cervical rib
E. True recurrence occurs in patients in whom the first rib was incompletely resected or there was excessive scar development around the brachial plexus
F. The posterior thoracoplasty approach provides the best exposure
G. Persistent or recurrent bony remnants should be excised
H. Careful neurolysis of the nerve root and brachial plexus is performed along with dorsal sympathectomy
I. One series of over 400 patients had improvement in symptoms in about 80% of patients; 7% required a second reoperation
Chapter 42 - Superior Vena Cava Syndrome

1. SVC Obstruction and Collateral
A. Obstruction below azygous vein
   1) Azygous - hemiazygous, lumbar veins to IVC
B. Obstruction above azygous vein
   1) Venous collateral in neck to azygous to SVC

C. Obstruction includes azygous vein
   1) Internal mammary, paraspinal, esophageal and subcutaneous vein to IVC
D. Cerebral decompression through a single jugular vein via midline intracranial venous sinuses

2. Pathogenesis
A. Extrinsic compression of SVC
   1) Gradual SVC obstruction
B. Invasion of SVC
1) Obstruction develops rapidly
C. Thrombosis of SVC
1) Acute obstruction
D. Venous hypertension and lymphatic obstruction - all empty into the subclavian veins

3. Causes
A. Benign 10%
   1) Inflammatory - histoplasmosis, idiopathic fibrosing mediastinitis
   2) Iatrogenic - pacemaker electrode, hyperalimentation or other CV line
B. Malignant 90%
   1) Bronchogenic, epidermoid 65-80%
   2) Small cell 12-30%
   3) Lymphoma 12-20%

4. Symptoms and Signs
A. Swelling face, neck, arms
B. Shortness of breath, orthopnea, cough and chest pain suggest upper airway obstruction
C. Hoarseness, stridor, tongue swelling, nasal congestion
D. Headaches, syncope and lethargy are caused by cerebral edema from venous hypertension
E. Symptoms worse lying down, bending forward
F. Symptoms of cerebral or laryngeal edema is associated with a reduced life expectancy of about 6 weeks, demanding urgent intervention
G. Caval obstruction may be the life-limiting problem of patients with underlying malignancy
5. Diagnosis
A. Chest x-ray
1) **Right hilar mass** - bronchogenic carcinoma

![Diagram of a lung with a right hilar mass highlighted.]

2) Anterior mediastinal mass - lymphoma
3) Calcification - histoplasmosis

B. Simultaneous bilateral arm venogram
1) Defines obstruction and collateral circulation
2) Identifies **thrombus**
C. **Computerized axial tomography**
1) Assessment of mediastinum
2) Determine patency of jugular veins
3) Directed needle biopsy

6. **Radiation Therapy**
A. Since most cases due to malignancy, nearly all patients receive radiation
B. 80-90% relieved of SVC Syndrome
C. 50% of patients relapse
D. Relapse occurs in benign disease as well; although collaterals develop, thrombosis will continue to propagate and occlude these collaterals over time

7. Medical Therapy
A. Chemotherapy for lymphomas and small cell carcinoma
B. Diuretics and corticosteroids reduce cerebral edema
C. Anticoagulants in selected cases to prevent clot propagation
D. Thrombolytic therapy for selected acute thrombosis

8. Surgery
A. Severe SVC Syndrome associated with thrombosis of caval tributaries and inadequate collateral circulation
B. SVC bypass with composite autogenous vein grafts or PTFE 6-12 months after onset in benign causes or for palliation in malignant causes with severe or acute onset SVC syndrome
Notes: