History of Heart Sounds and the Search for Patterns for Disease Diagnosis

- With a Special focus on Cardiac Auscultation
- Presented by Dan Mathers

Heartland Workshop on Heart Sounds and AI

The Future of Heart Sounds for Diagnosing Heart Diseases in the Age of AI

A BRIEF HISTORY OF PHYSICAL ASCULTATION FOR THE DETECTION OF DISEASES

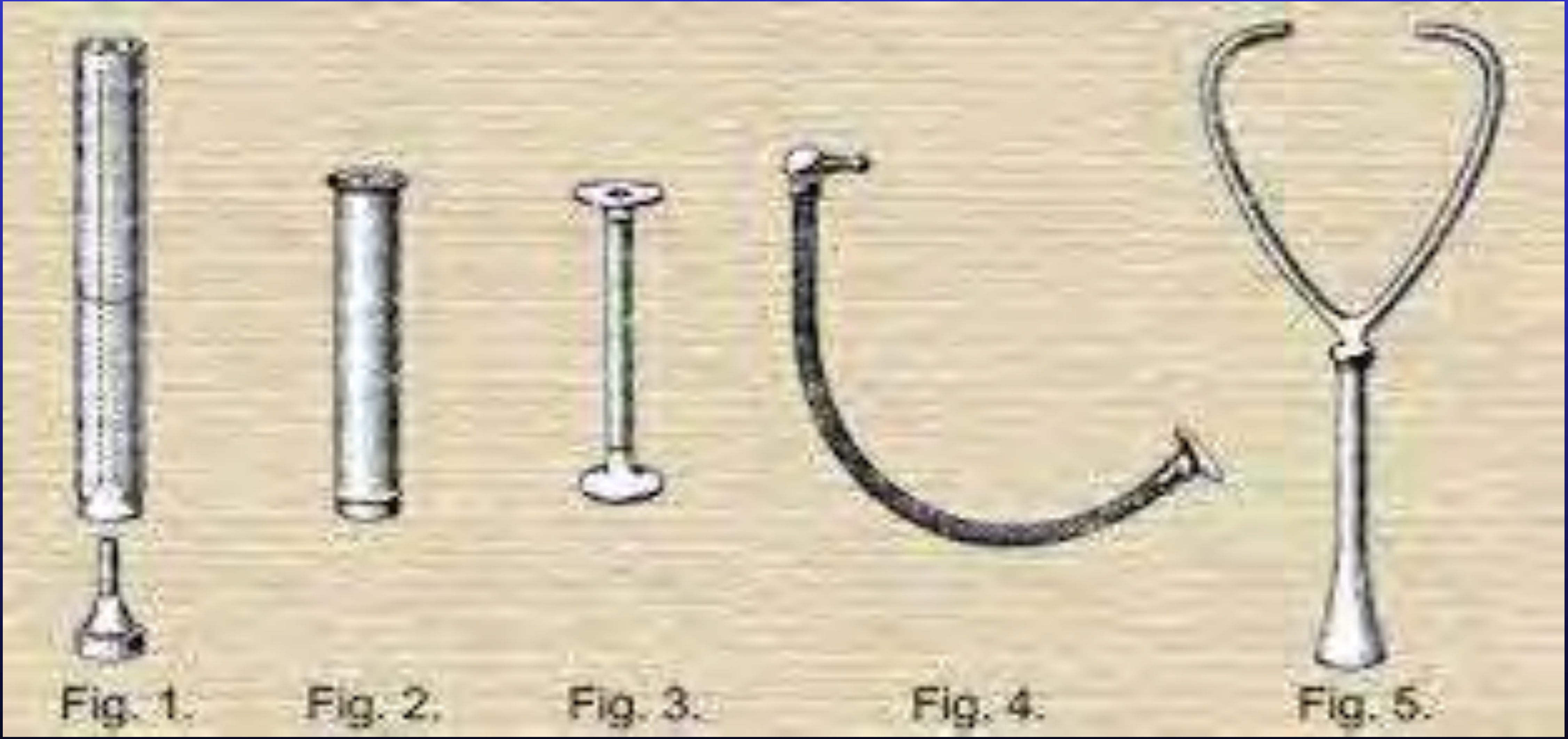
- Imhotep- Circa 2700 B.C., Egypt (Smith papyrus)
- China- 2700 B.C. Reign of Emperor Shen Nung
- Greece-circa 400 B.C. Hippocrates II, Praxagoras both of Kos, Aristotle, Herophilus
- Rufus of Ephesus-70-110 A.D. Connected the pulse to the heart.
- Galen- 129-214 A.D. Discovered the heart pumped blood
- Hooke- 1635-1703 A.D.- “Who knows, I say, but that it may be possible to discover the motions of the internal parts of bodies by the sound they make.”
- Laennec- 1781-1826 - invents the stethescope, publishes in 1819. Goes from ‘direct’ to mediated auscultation.

Disclosure of Potential Conflicts of Interest

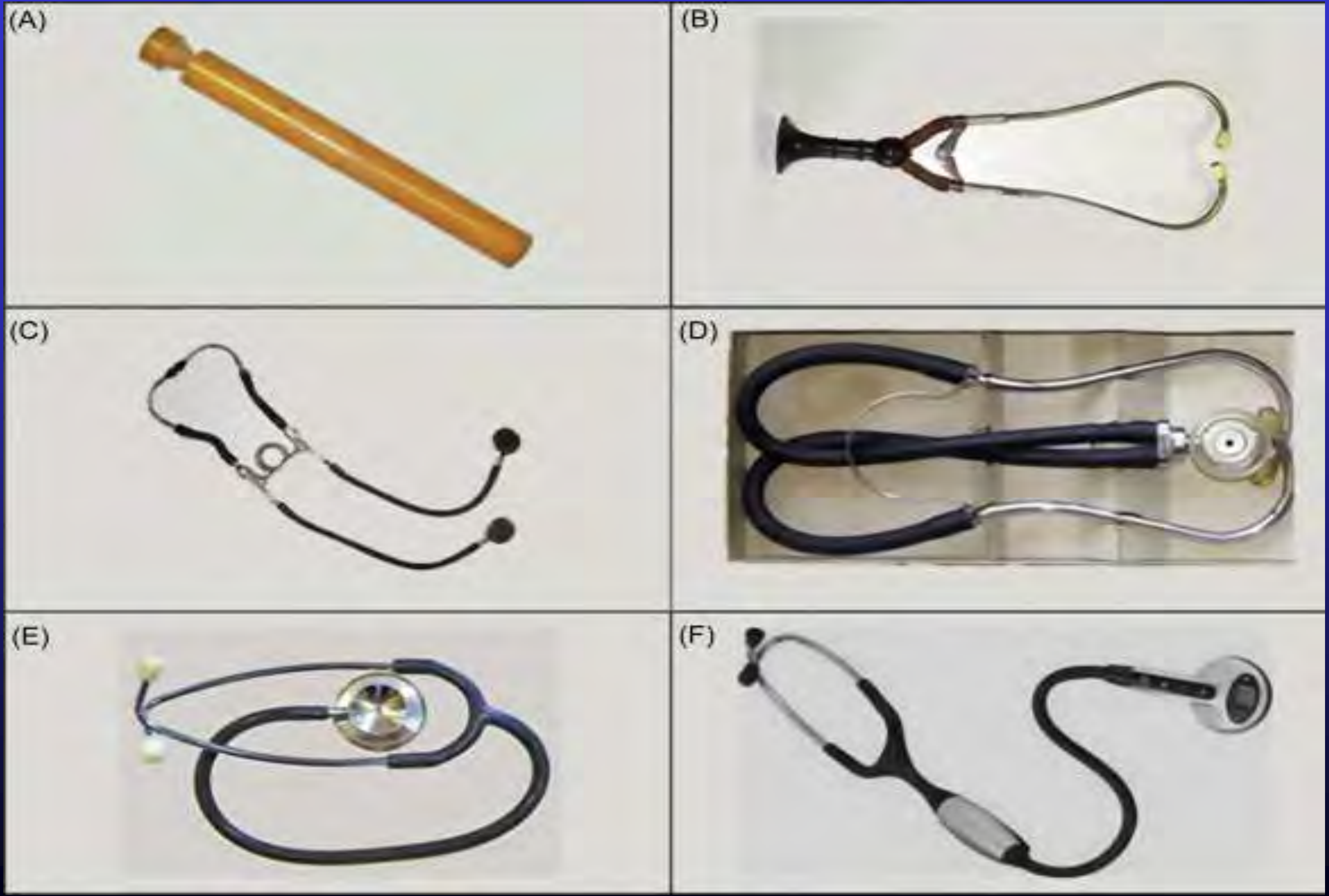
- None

Laennec with His Invention, Mediated Auscultation

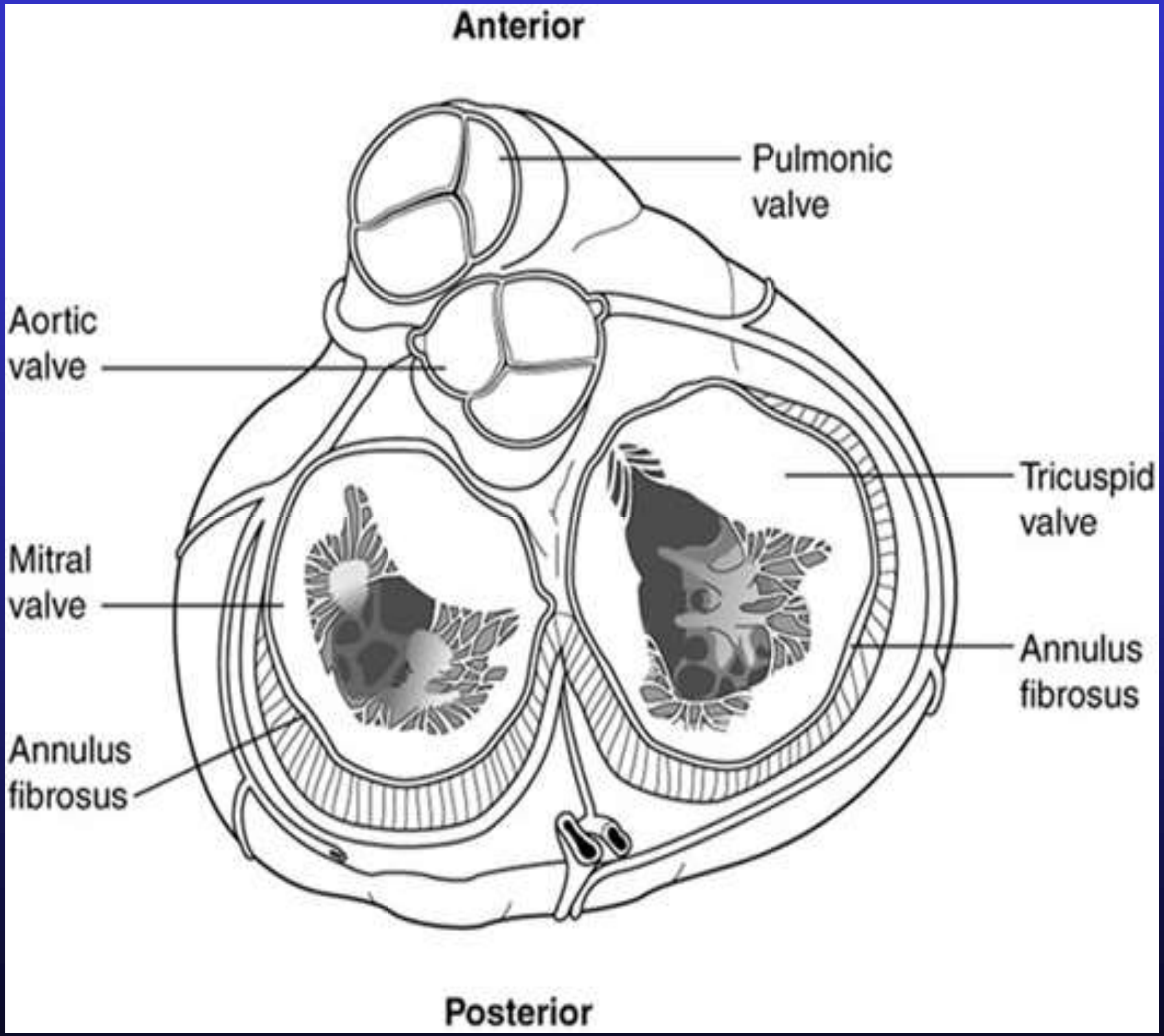
EARLY STETHESCOPES



MODERN STETHESCOPES



Valve Areas



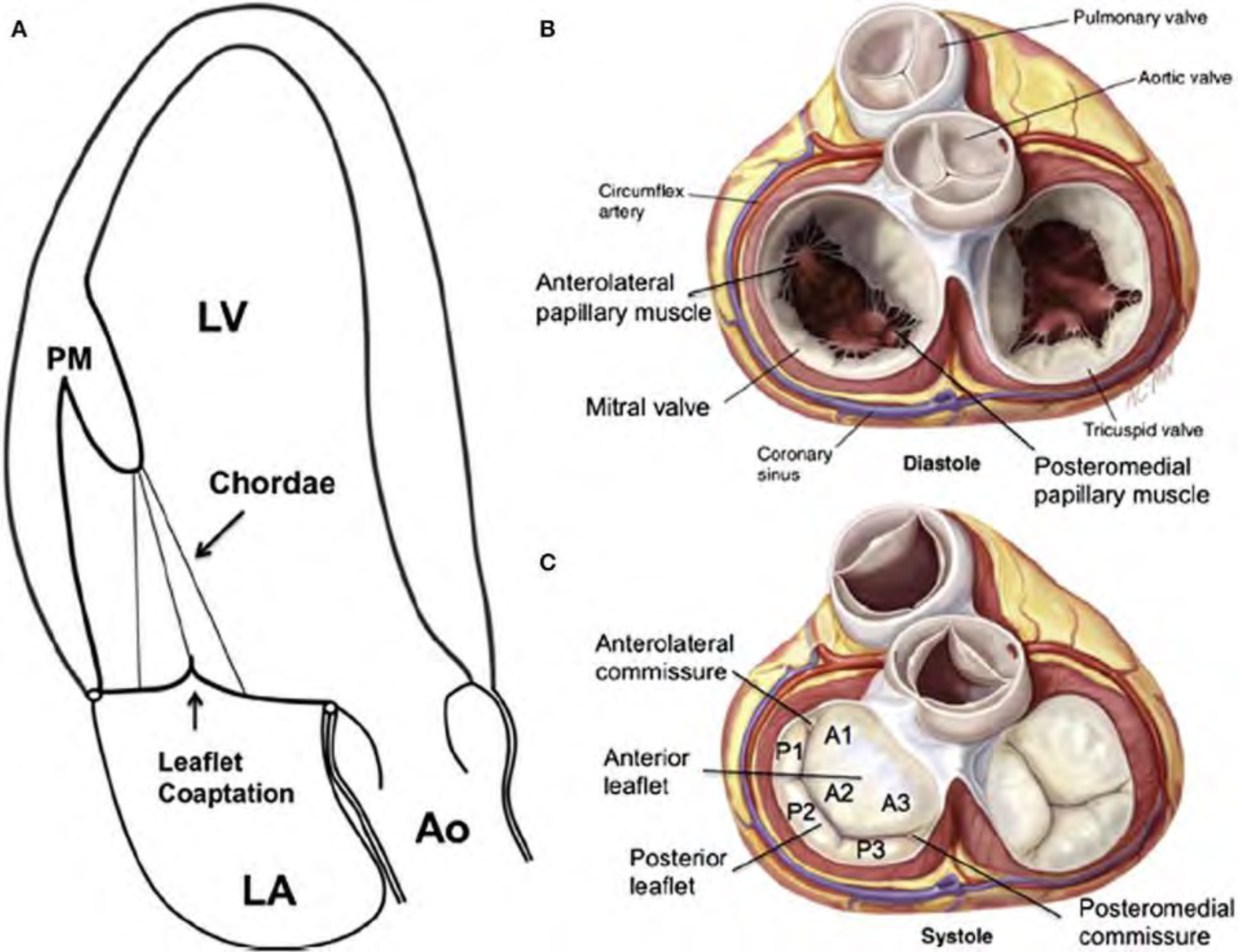
Normal Valve Areas:

Aortic & pulmonic 3-4 cm^2

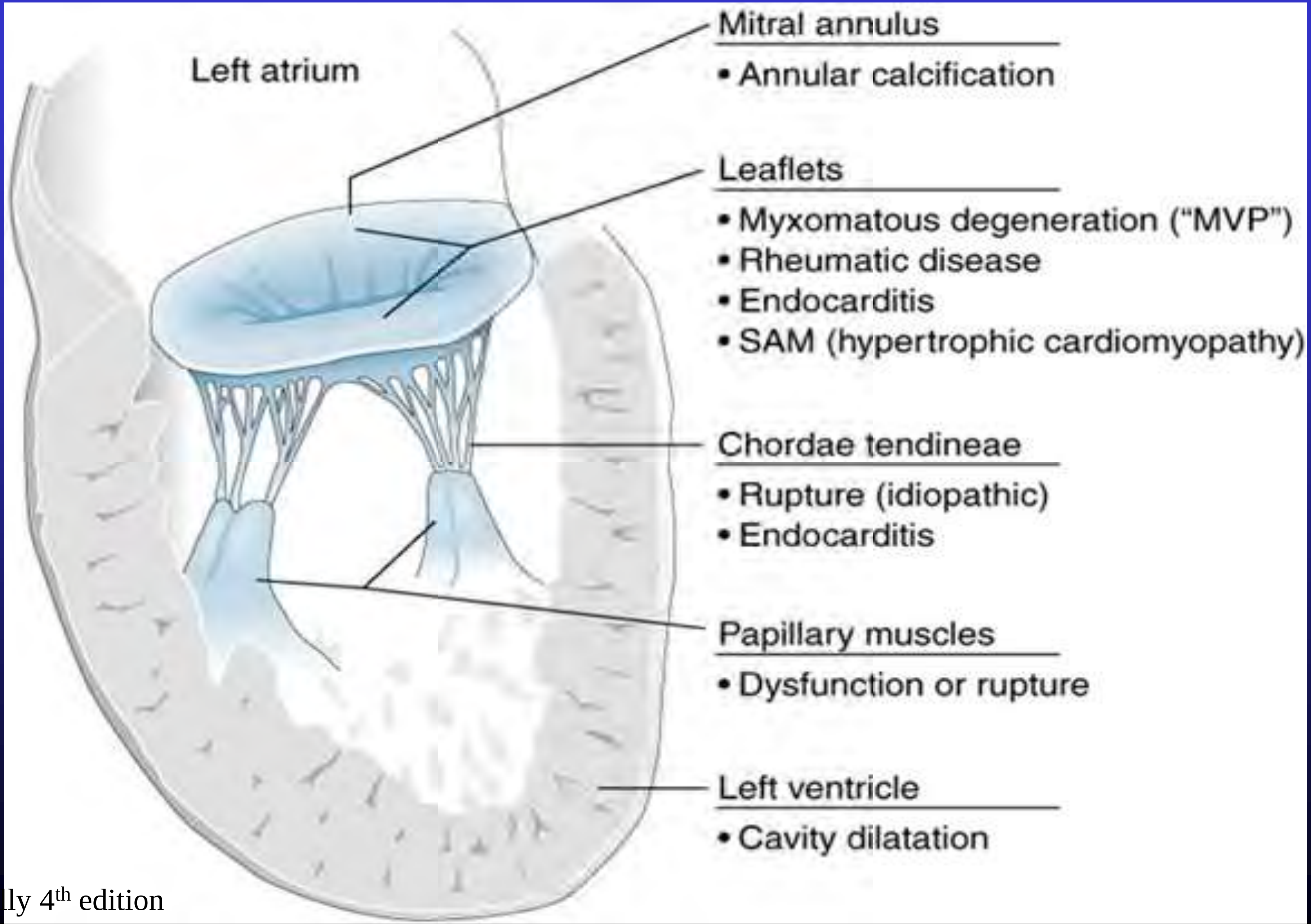
Mitral and tricuspid 4-6 cm^2

index 2.4 – 3.5 cm^2/m^2

Lilly 4th edition


A
LV
PM
Chordae
Leaflet
Coaptation
Ao
LA
B
Pulmonary valve
Aortic valve
Circumflex
artery
Anterolateral
papillary muscle
Mitral valve
Coronary
sinus
Diastole
Posteromedial
papillary muscle
Tricuspid valve
C
Anterolateral
commissure
Anterior
leaflet
Posterior
leaflet
A1
A2
A3
P1
P2
P3
Systole
Posteromedial
commissure

Mitral Valve – Vulnerable Structures



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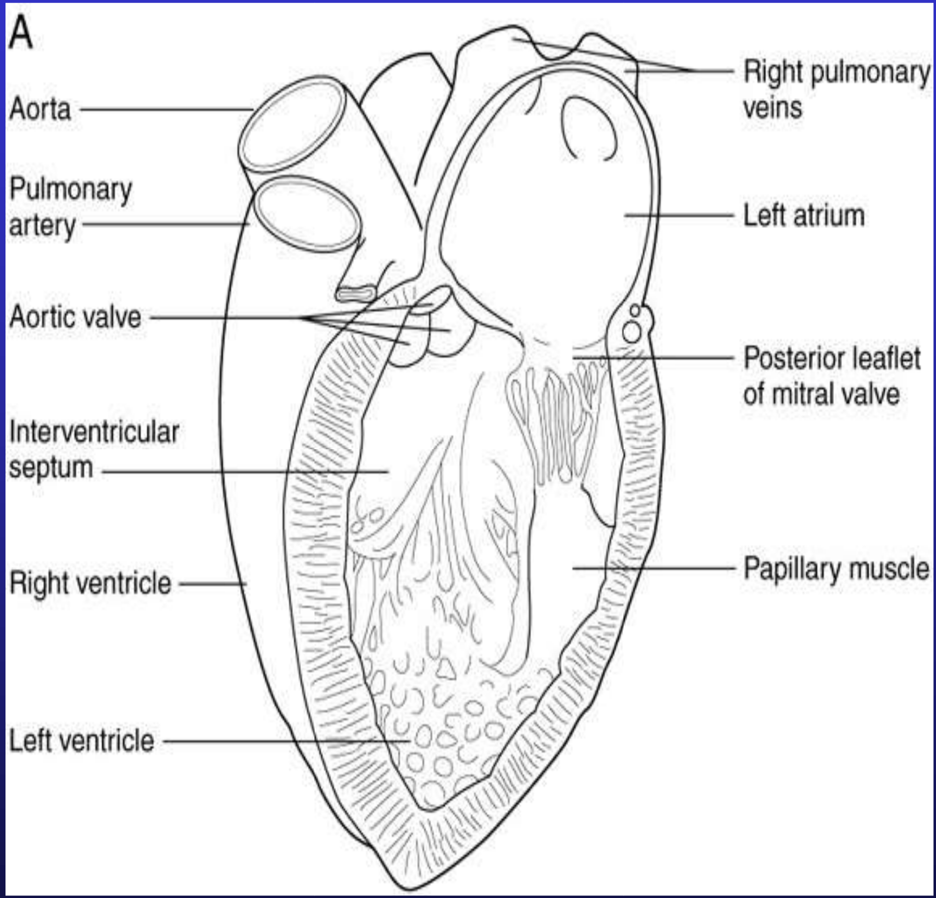
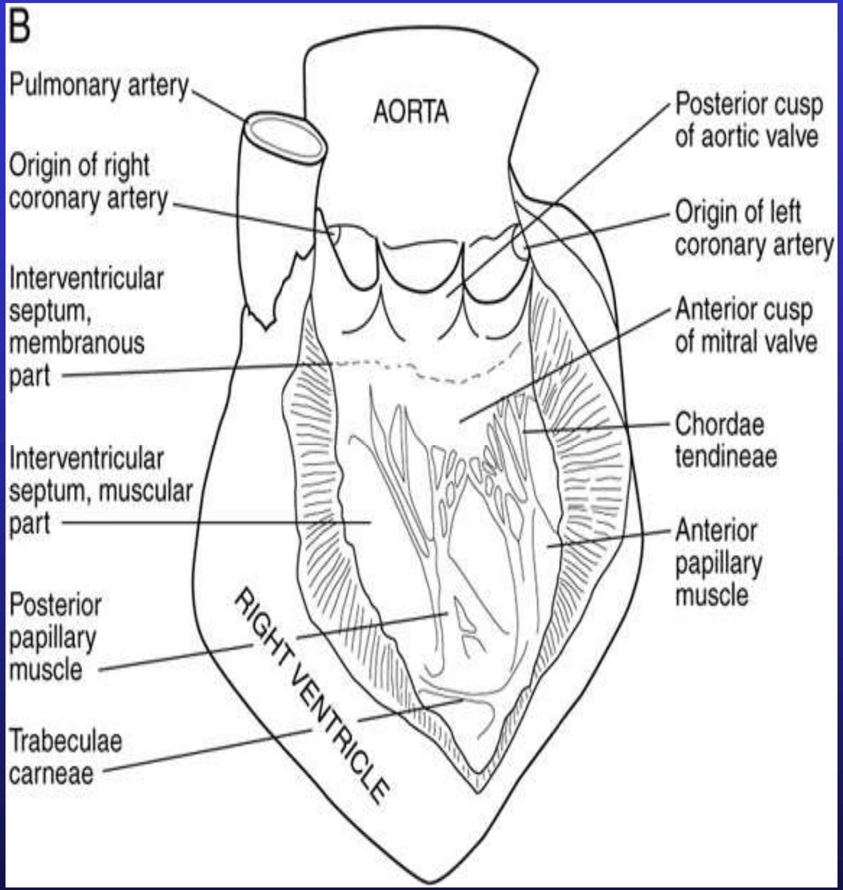
Additional Valve Views





Lateral Wall Removed

Anteroseptal Wall Removed

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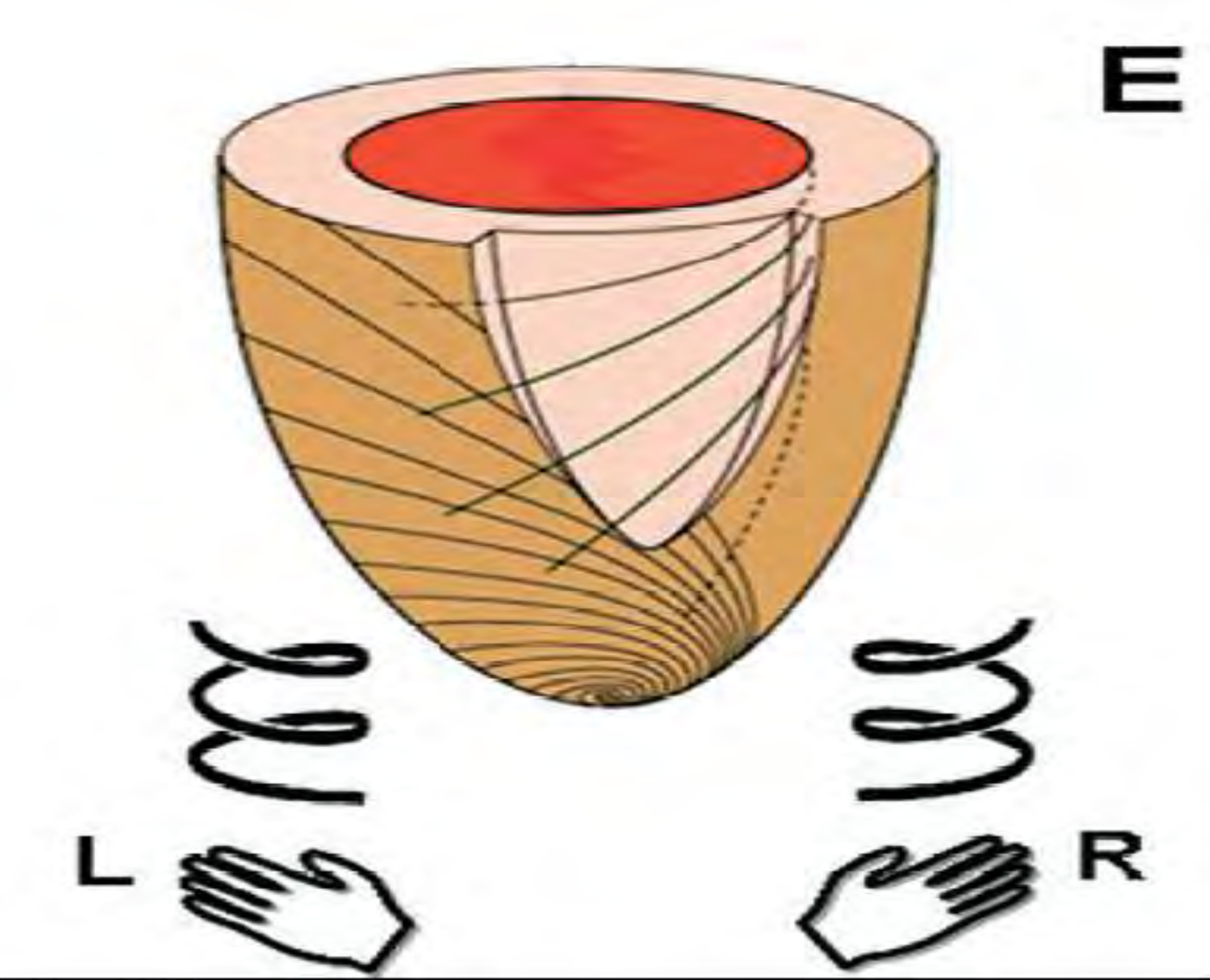
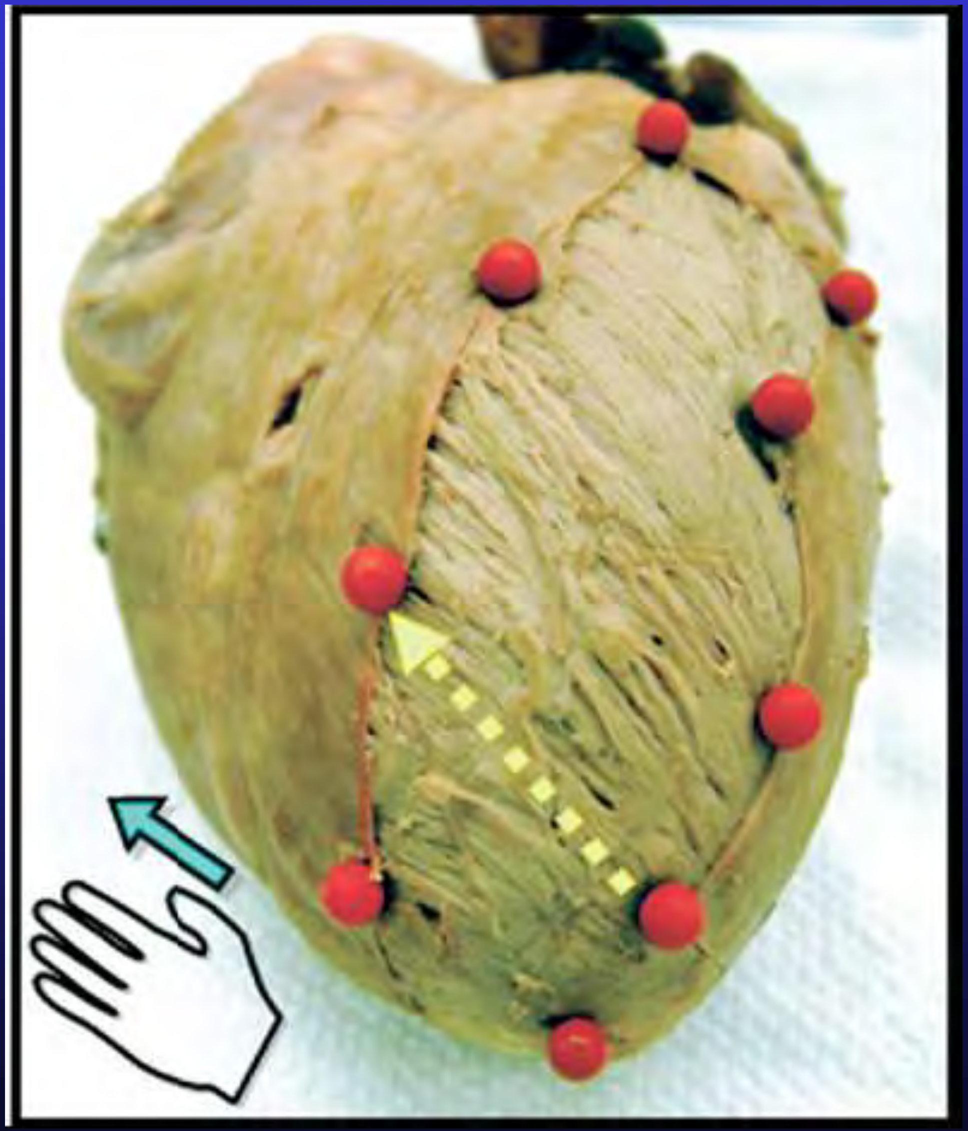
Endo- & Epicardial Contraction



JASE 20:539; May 2007

Endocardium [R]

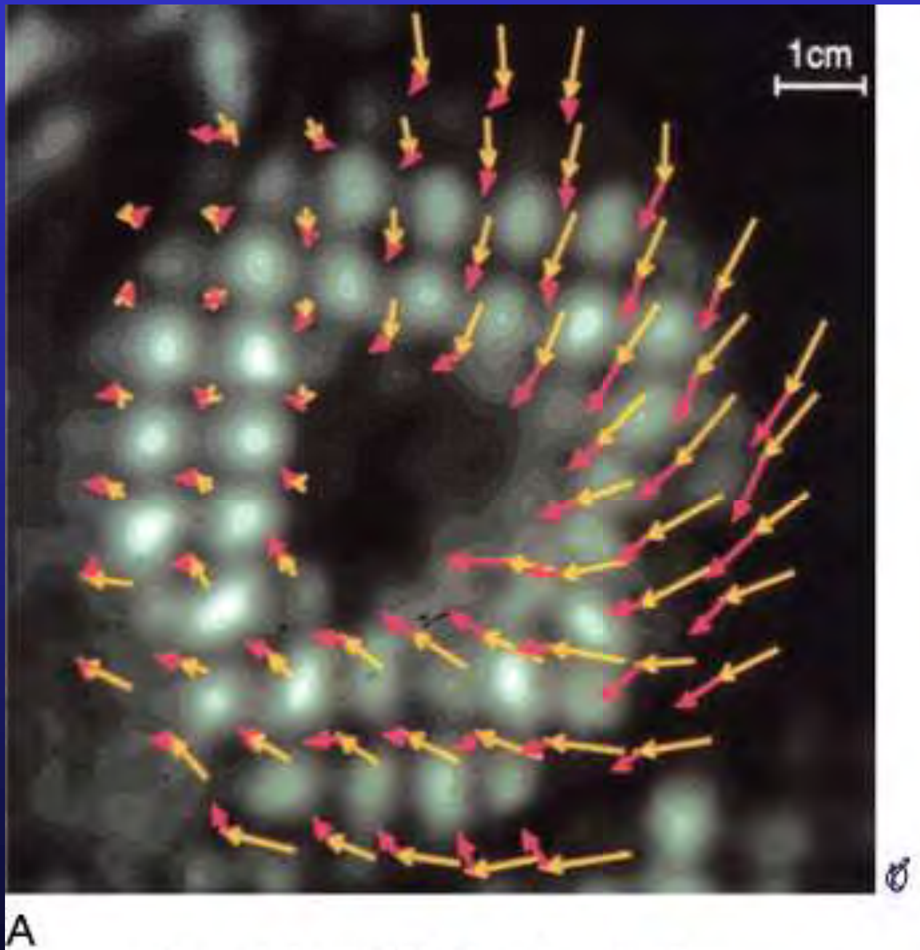
Epicardium [L]



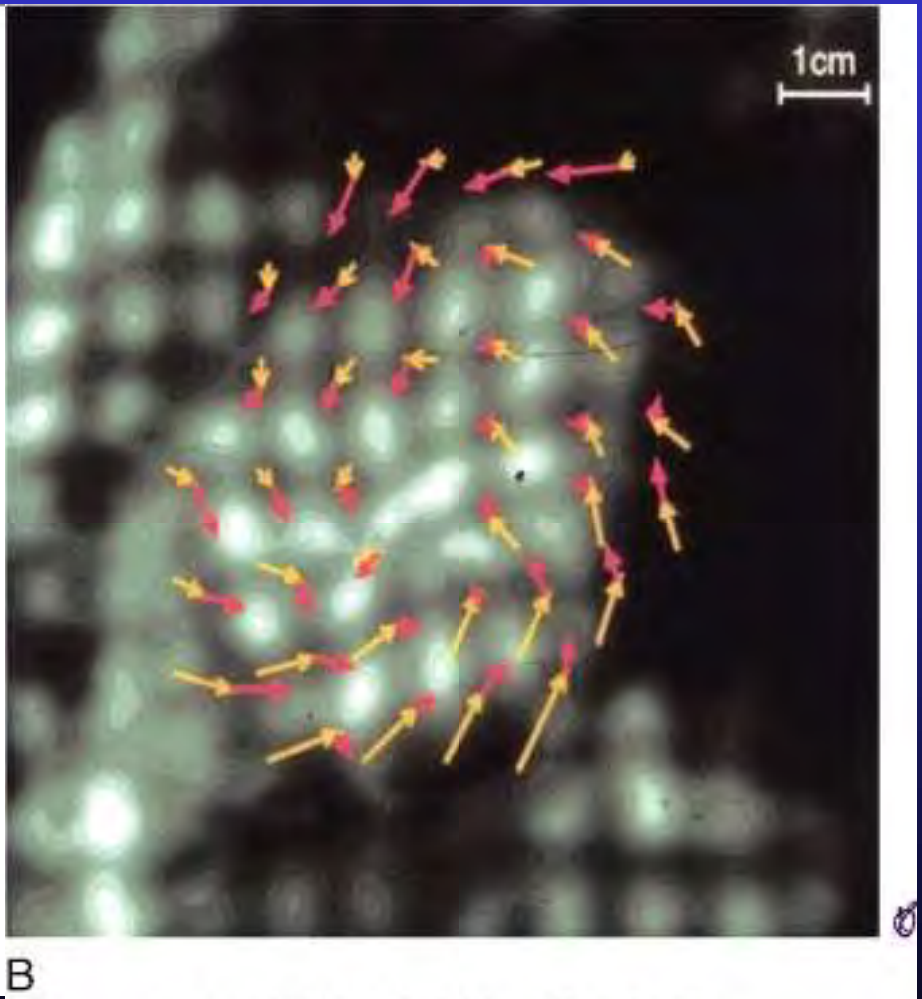
JASE 20:539, May 2007

Ventricular Base and Apex Torque in Opposite Directions

Base



Apex

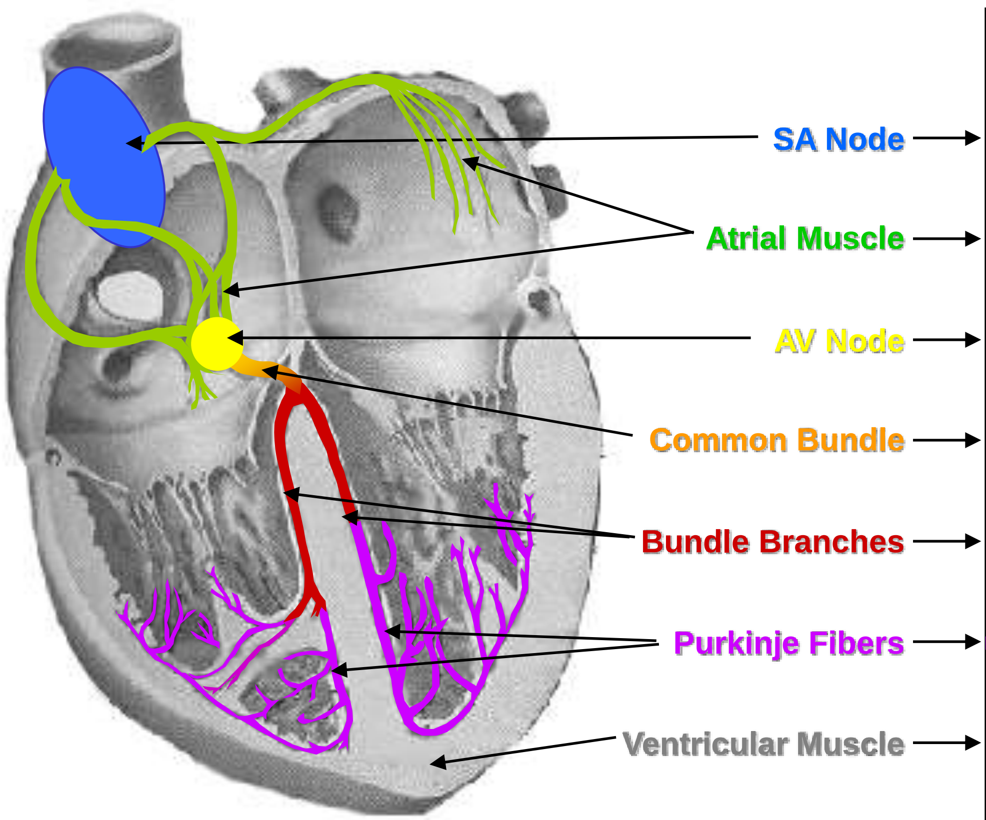


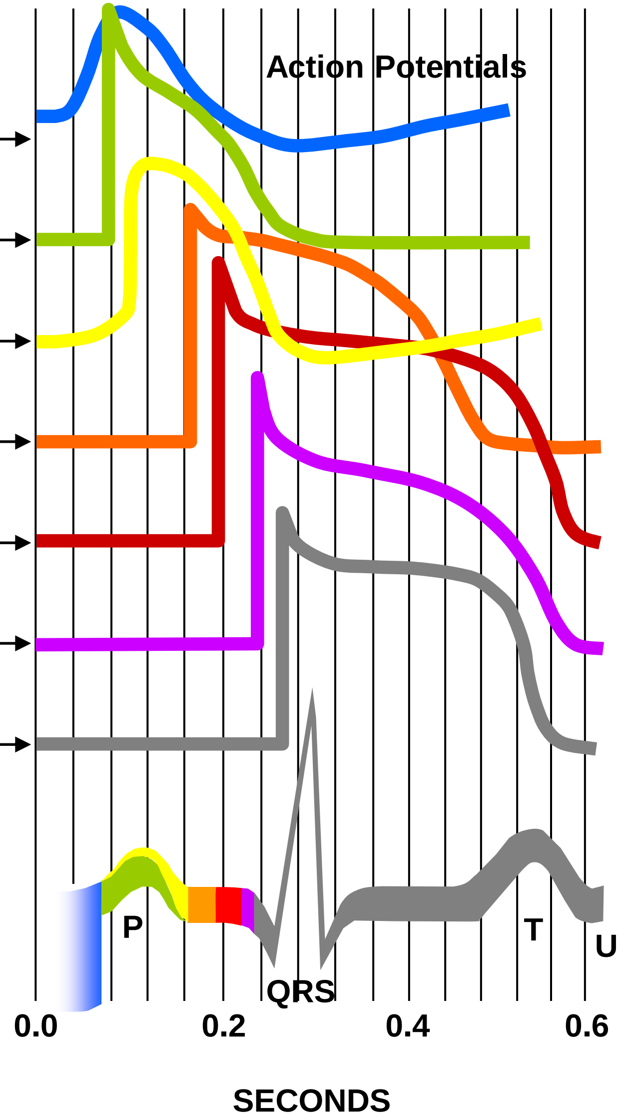
Braunwald 8th edition

Cardiac Electricity

- Volta- invents the battery 1774
- Galvani- demonstrates electricity causes muscle contraction, late 1700s
- Kollicker & Muller- discover electric stimulus causes heart beat
- Waller- discovers electrical activity caused by heart beat in mammals late 1800s
- Bell- invents telephone 1876
- Einthoven- discovers string galvanometer, coins the term electrocardiograph, EKG. Studies human EKGs 1891-1915
- Huerthle- first recording of heart sounds 1895
- Phonocardiography- multiple investigators 1930-1960s

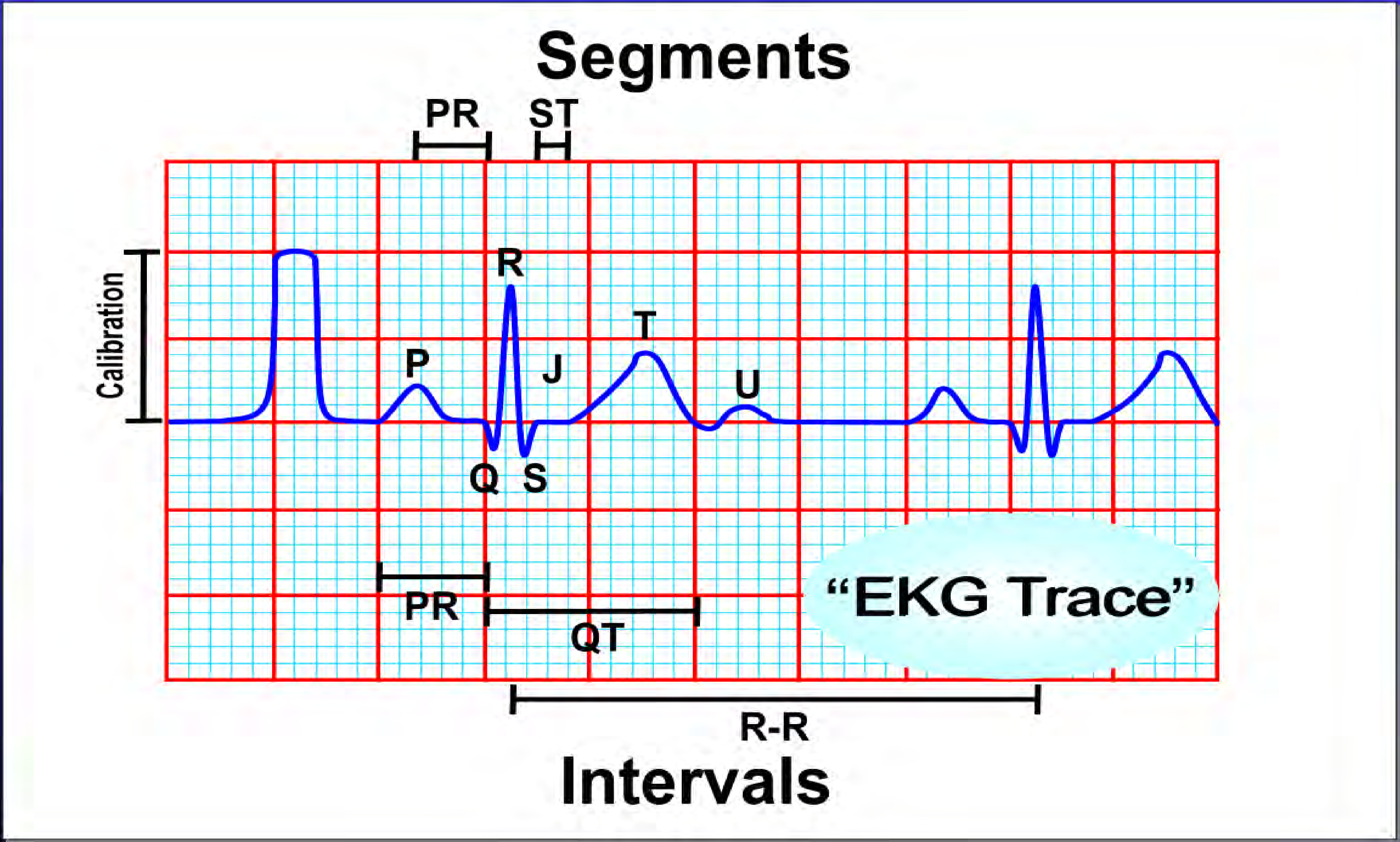
Cardiac Conduction

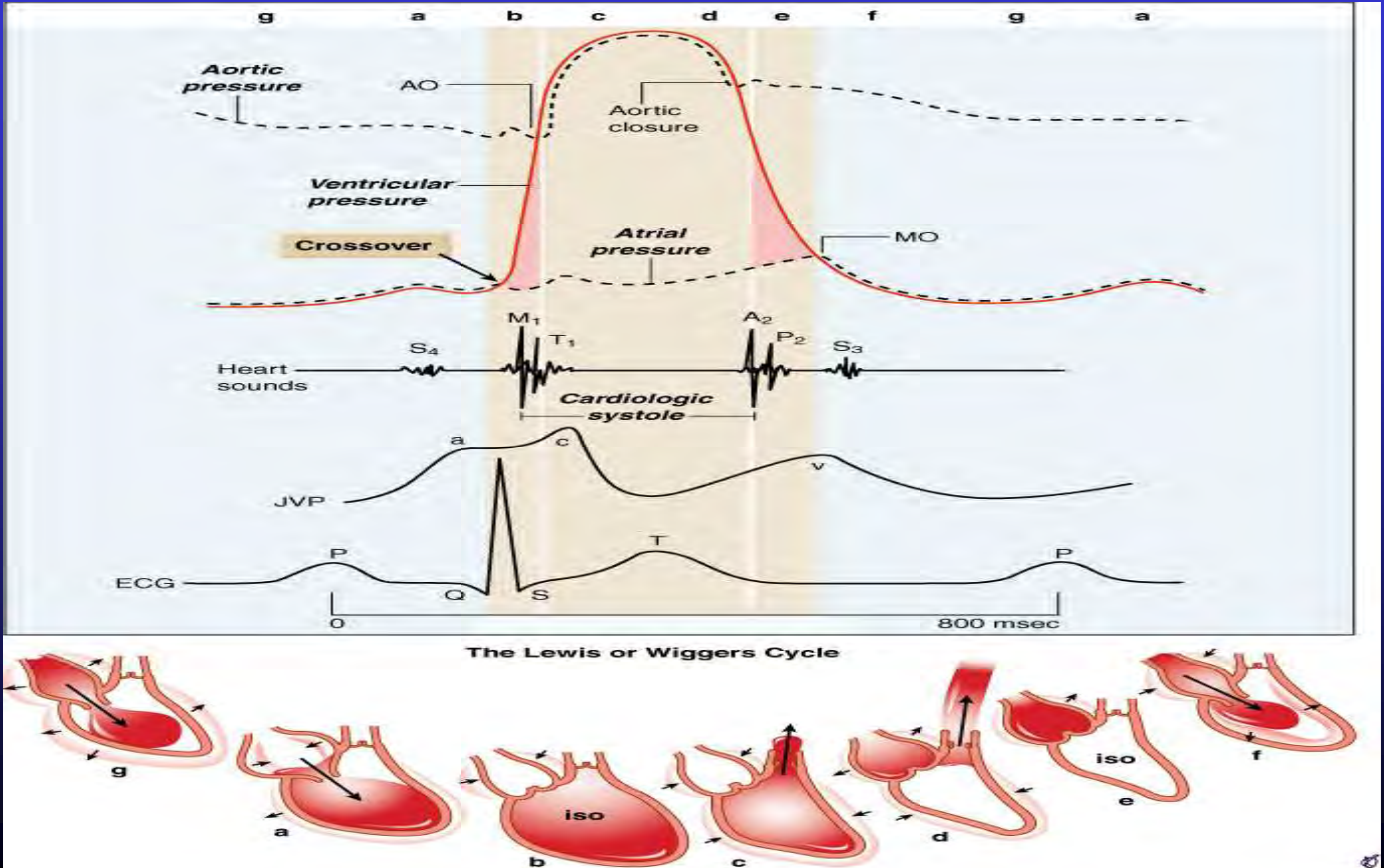




	meters/sec	APD in ms
SA Node	<0.05	100-300
Atrial Muscle	0.3-0.4	100-300
AV Node	0.1	100-300
Purkinje Fibers	2-3	300-500
Ventricle Muscle	0.3-0.4	200-300

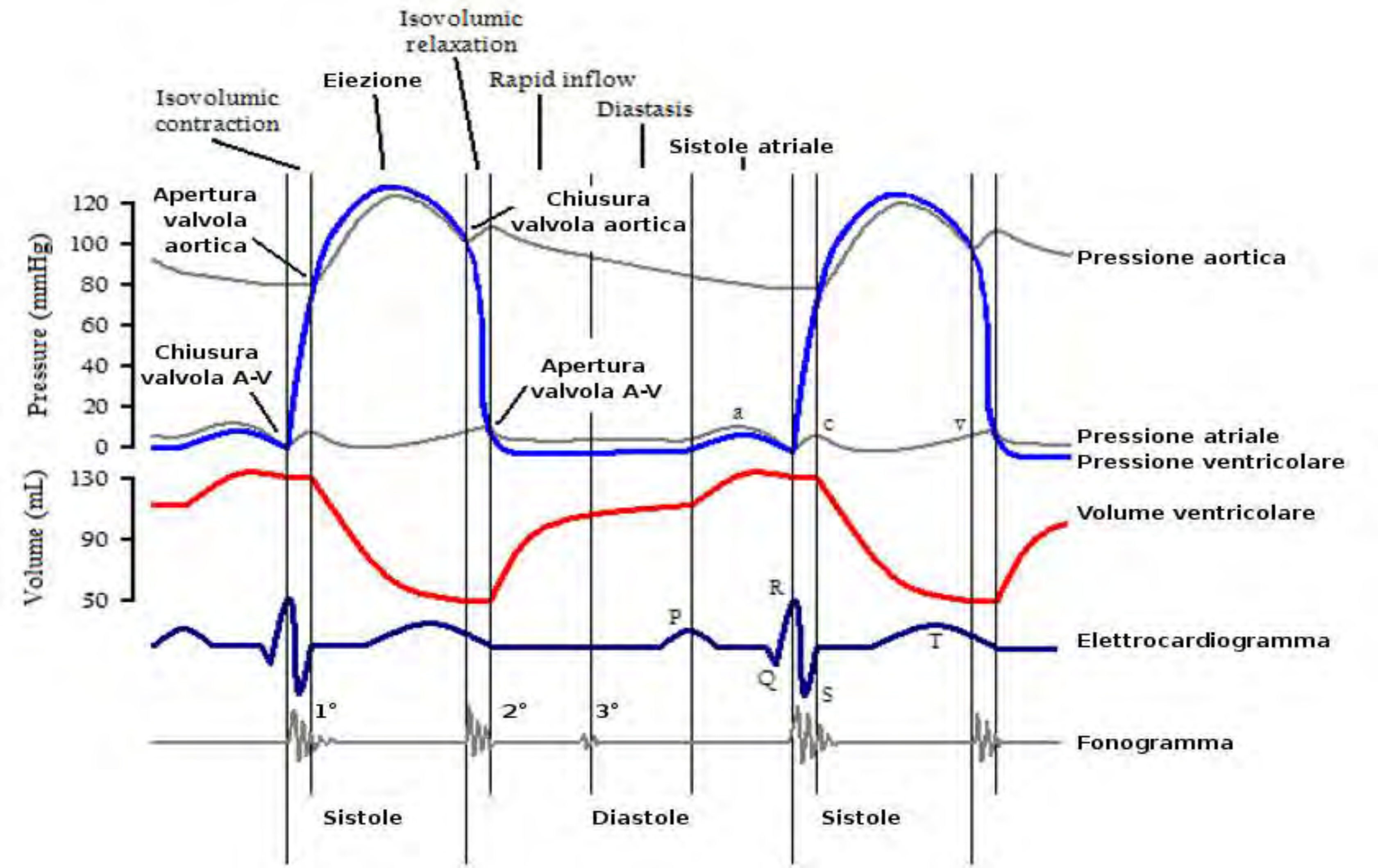
After Netter


Segments
PR
ST
Calibration
R
P
J
T
U
Q
S
PR
QT
"EKG Trace"
R-R
Intervals



The Lewis or Wiggers Cycle

Wigger or Lewis Diagram



Murmurs are caused by turbulent flow thru an orifice

Murmur Intensity

I – faint, barely audible

II – soft, heard in all auscultation points

III- loud but no thrill

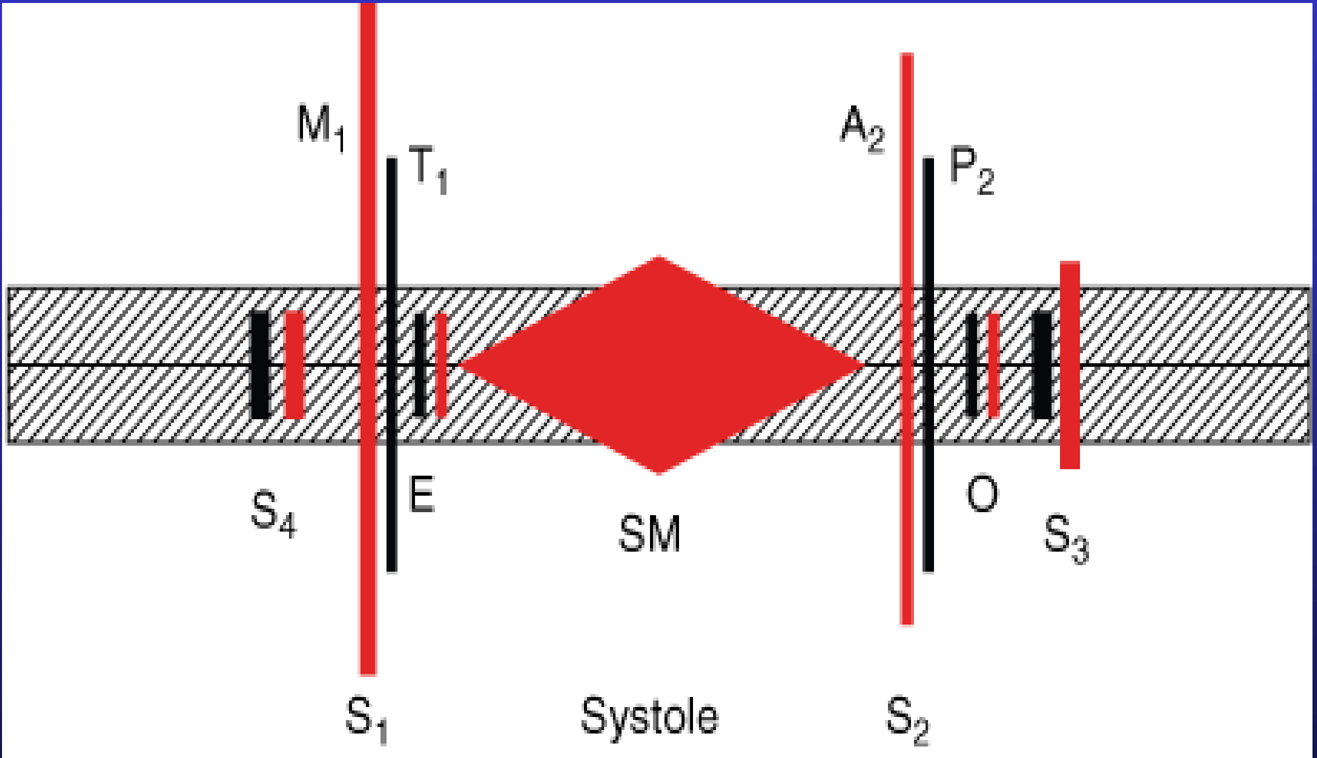
IV- louder with thrill

V- very loud with stethescope partially off the chest

VI- audible without a stethescope

Greater intensity implies greater pressure difference

Location in Time of Various Heart Sounds



Source: Pahlm O, Wagner GS: *Multimodal Cardiovascular Imaging: Principles and Clinical Applications*: www.accessmedicine.com

Relation of QRS to Various Heart Sounds

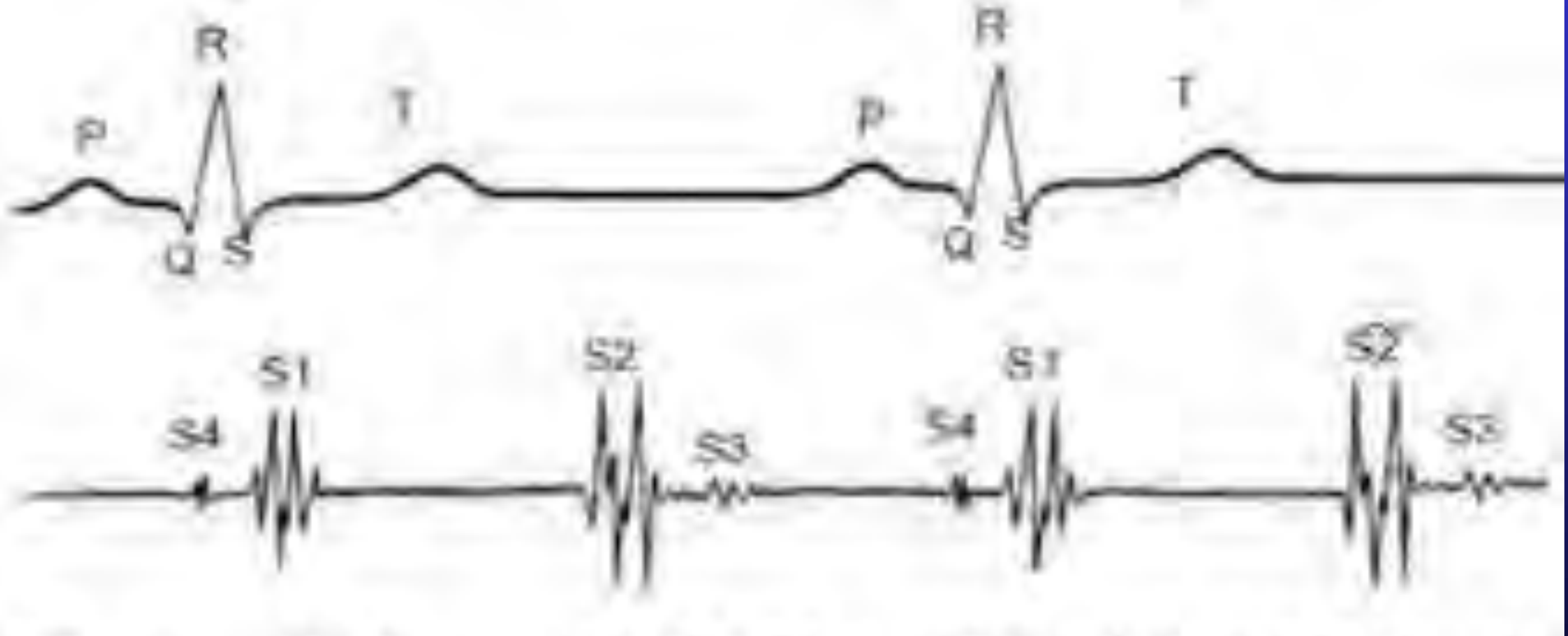


Fig. 1. All Classes (S1, S2, S3, and S4) of the PCG Signal.

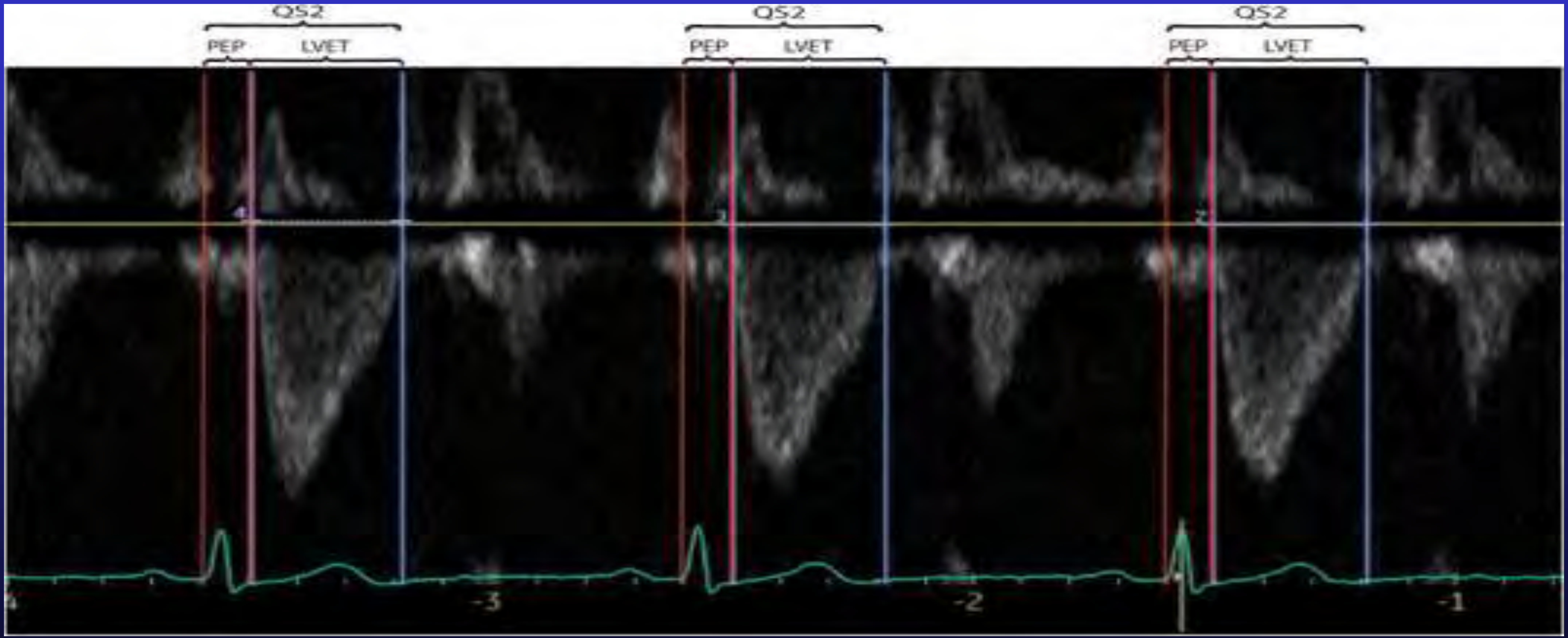
Heart Sounds

- Heart sound intensity and pitch reflect degree and rate of:
  - pressure rise in the ventricles [S_1, M_1 and T_1]
  - pressure drop in the great vessels [S_2, A_2 and P_2] at end systole
  - early [S_3] and late filling [S_4] pressures in the ventricles during diastole
- Murmurs reflect turbulent flow in systole or diastole. Pitch and intensity are determined by pressure gradient and flow volume
- S_3 occurs 100-200 msec following S_2
- Clicks [valve sounds], open snap [mitral valve] and rubs [pericardial sounds]

Electromechanical Intervals

- $Q\text{-}S_1$ pre ejection period [PEP]
- $S_1\text{-}S_2$ ejection time [ET] or period
- As heart dysfunction increases PEP prolongs and ET shortens. The $Q\text{-}S_2$ interval remains constant

Pre ejection Period & LV ejection time



Systolic Time Intervals

Sex dev	Equation	Normal Index	Std
M	$QS_2 I = 2.1(HR) + QS_2$	546 msec	14
F	$QS_2\ I = 2.0(HR) + QS_2$	549 msec	14
M	LVETI = 1.7(HR) + LVET	413 msec	10
F	LVETI = 1.6(HR) + LVET	418 msec	11
M	PEP I = 0.4(HR) + PEP	131 msec	10
F	PEP I = 0.4(HR) + PEP	133 msec	10

Circulation 56,2 :146-158 1977

PEP/LVET Ratio

- Prolonged PEP indicates decreased dP/dt , shortened LVET due to decreased stroke volume
- Normal dP/dt 1100 mmHg/sec, servere 6-700 mmHg/sec
- PEP/LVET normal 0.345 +/- 0.036, not effected by heart rate 50-110 bpm
- LVEF = 1.125 – 1.25(PEP/LVET), r = 0.90
- More reliable at heart rate 50-110 bpm

Circulation 42:455-462, 1970

PEP/LVET Ratio (cont’d)

- Less reliable with acute coronary artery disease
- Confounded by left bundle branch block
- QS_2 varies little with various myocardial diseases
- QS_2 decrease with heart rate
- Normal left ventricular ejection time [LVET] determined by heart rate. 50 bpm - 320 msec, 110 bpm- 230 msec

Electronic Analysis of Heart Sounds

-Timing of heart sounds relative to QRS onset

-Intensity relative to other heart sounds, especially S_2

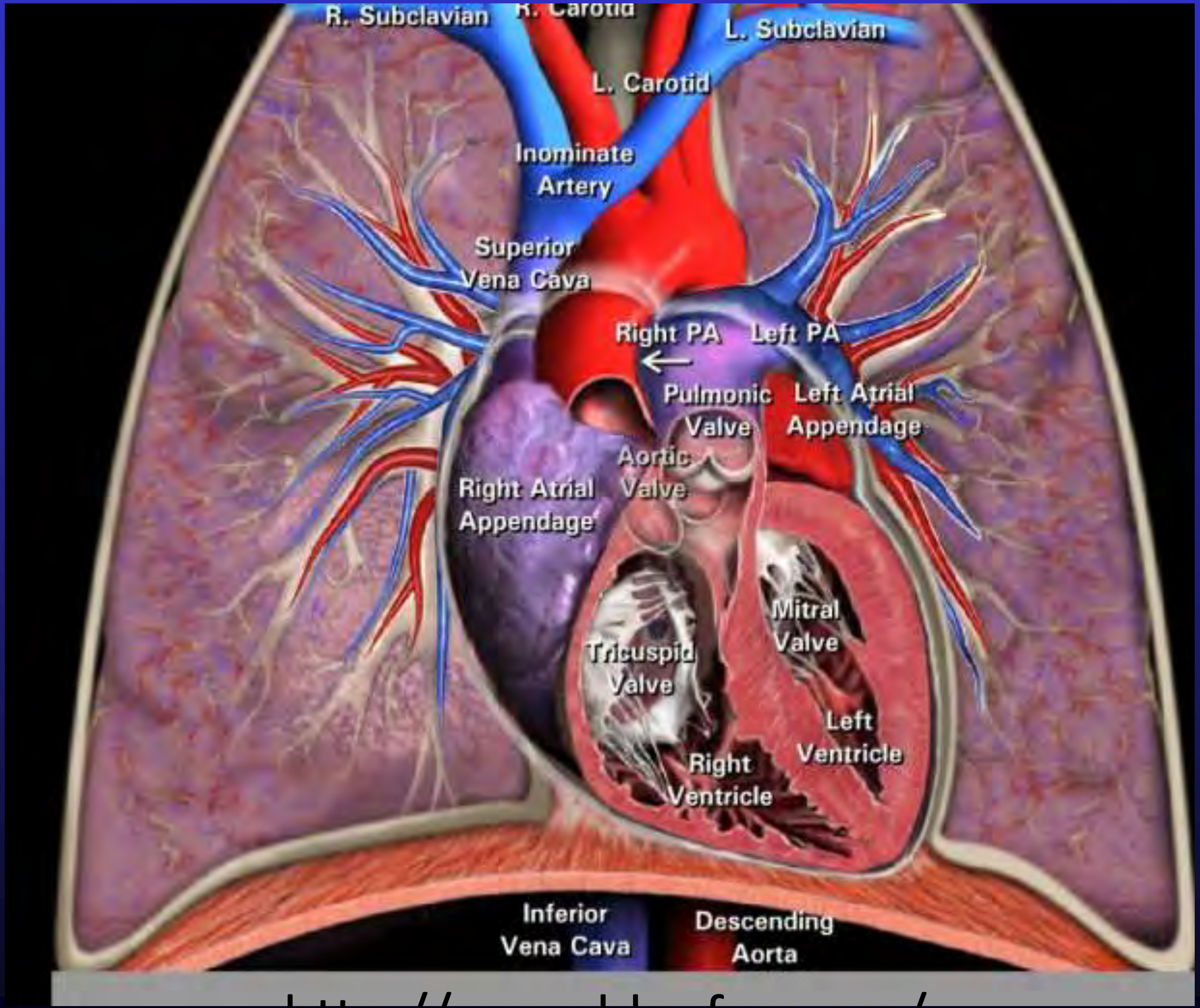
-Frequency, frequency range vs intensity of heart sounds

-Store for future comparison

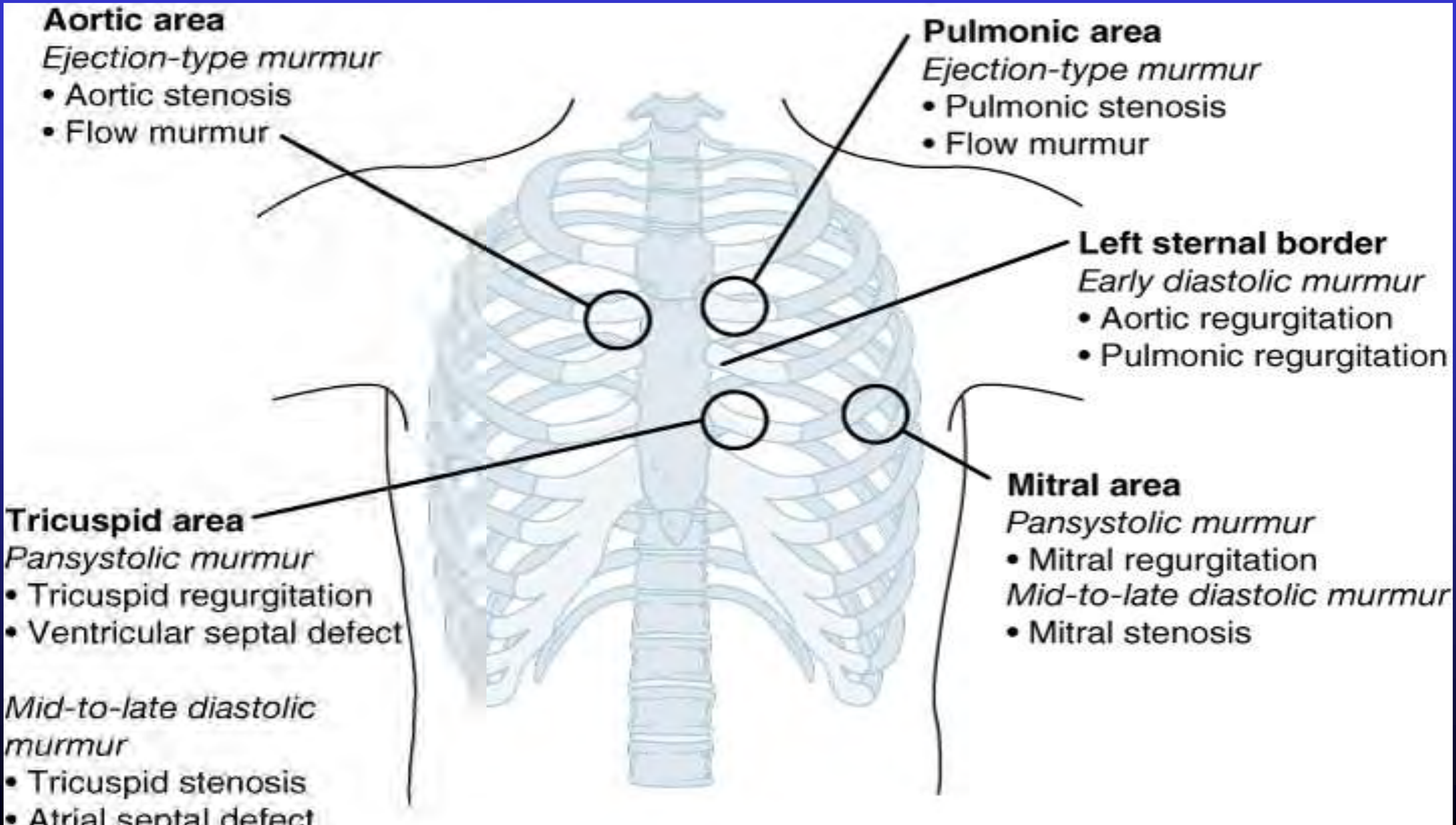
Ausculatory Technique

- The ‘bell’ of the stethescope is for low frequency sounds such as S_3 and S_4
- The diaphragm is for high frequency sounds such as aortic or pulmonic regurgitation
- Sounds closer in time than 30-40 msec are heard as a single sound
- Have the patient hold their breath for soft murmurs and exhale
- Examination should include the apex in the left lateral decubitus position

Location of Heart and Valves in the Chest

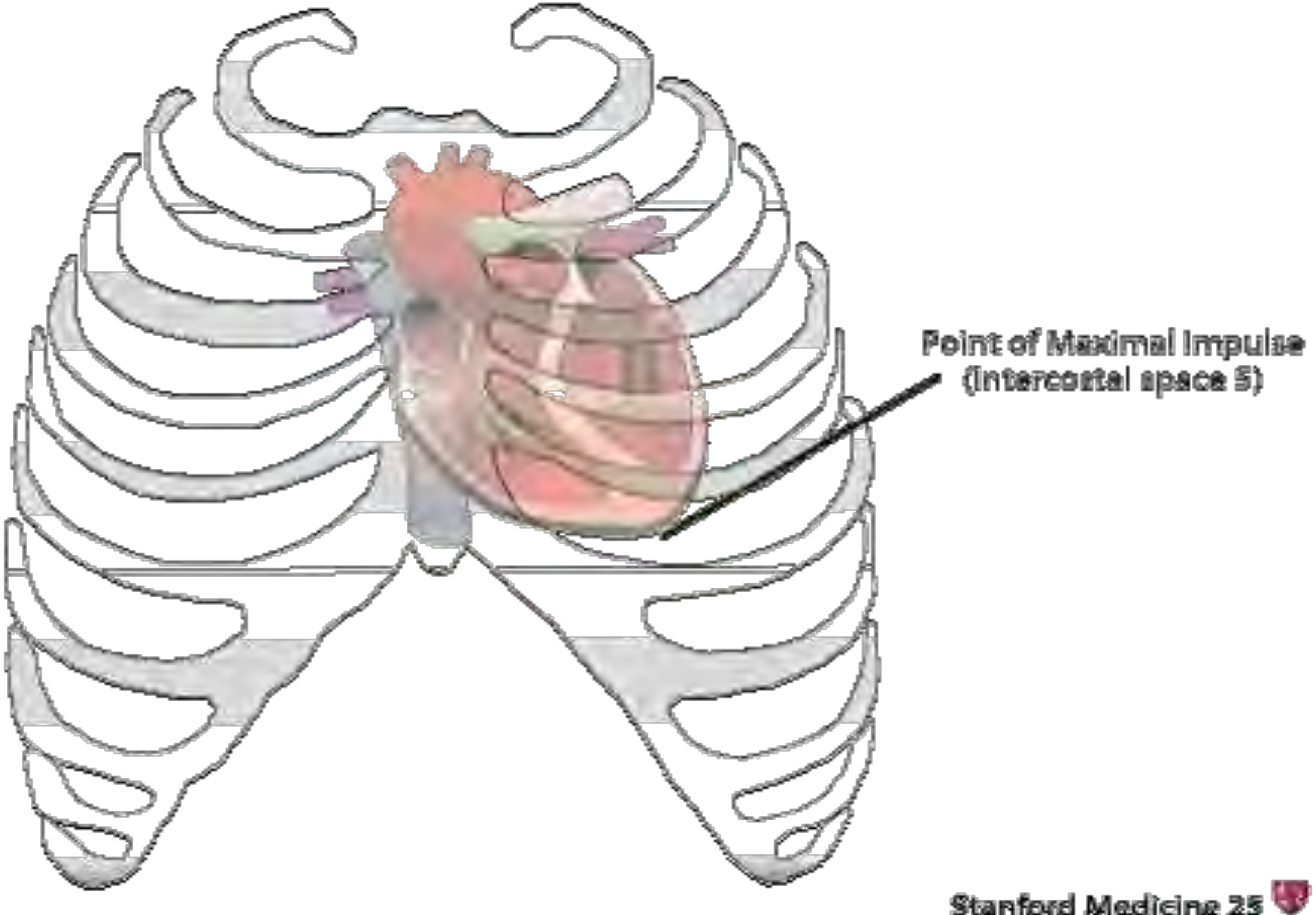


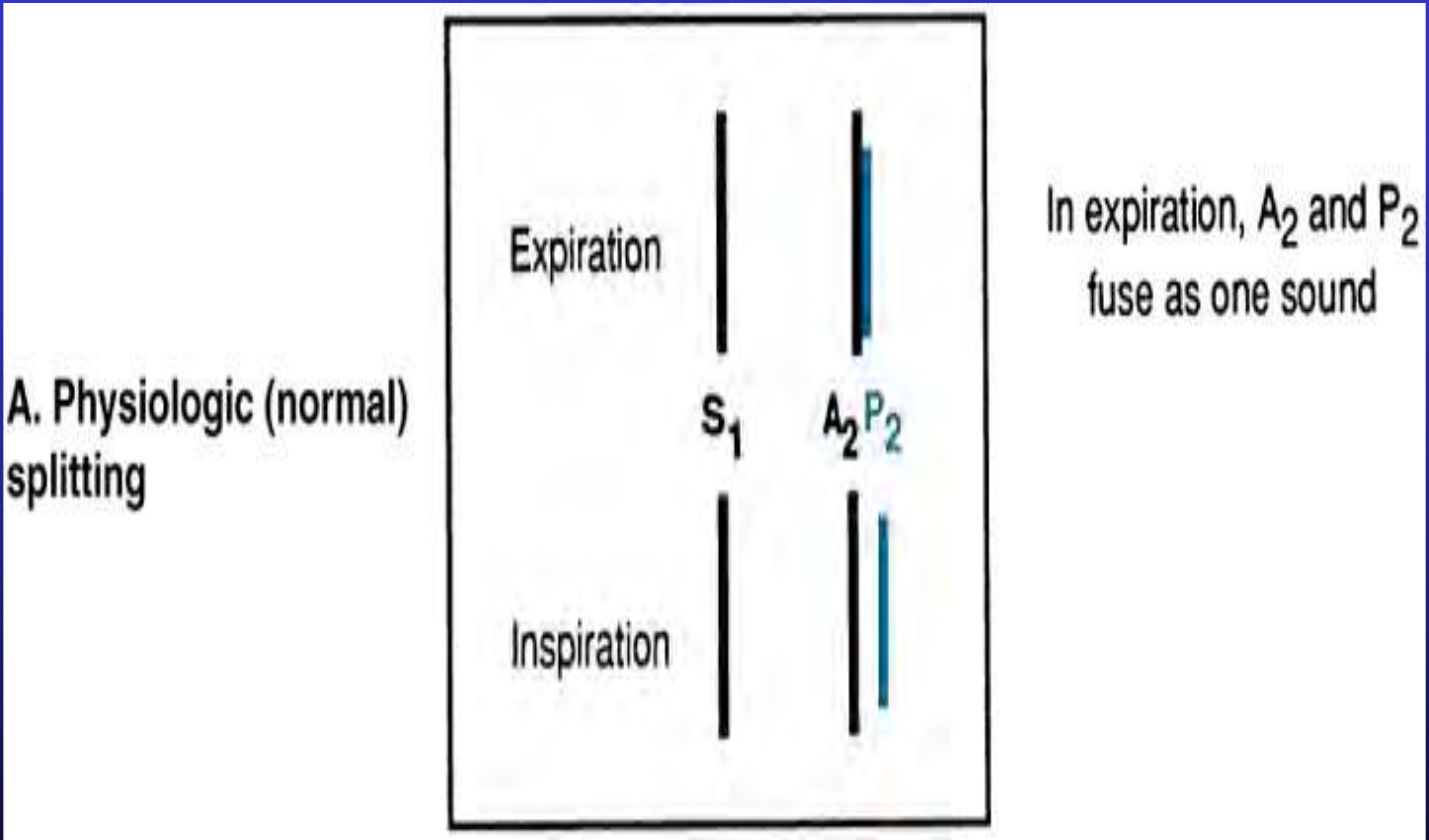
http://www.blaufuss.org/



Aortic area
Ejection-type murmur
• Aortic stenosis
• Flow murmur
Pulmonic area
Ejection-type murmur
• Pulmonic stenosis
• Flow murmur
Left sternal border
Early diastolic murmur
• Aortic regurgitation
• Pulmonic regurgitation
Tricuspid area
Pansystolic murmur
• Tricuspid regurgitation
• Ventricular septal defect
Mid-to-late diastolic murmur
• Tricuspid stenosis
• Atrial septal defect
Mitral area
Pansystolic murmur
• Mitral regurgitation
Mid-to-late diastolic murmur
• Mitral stenosis

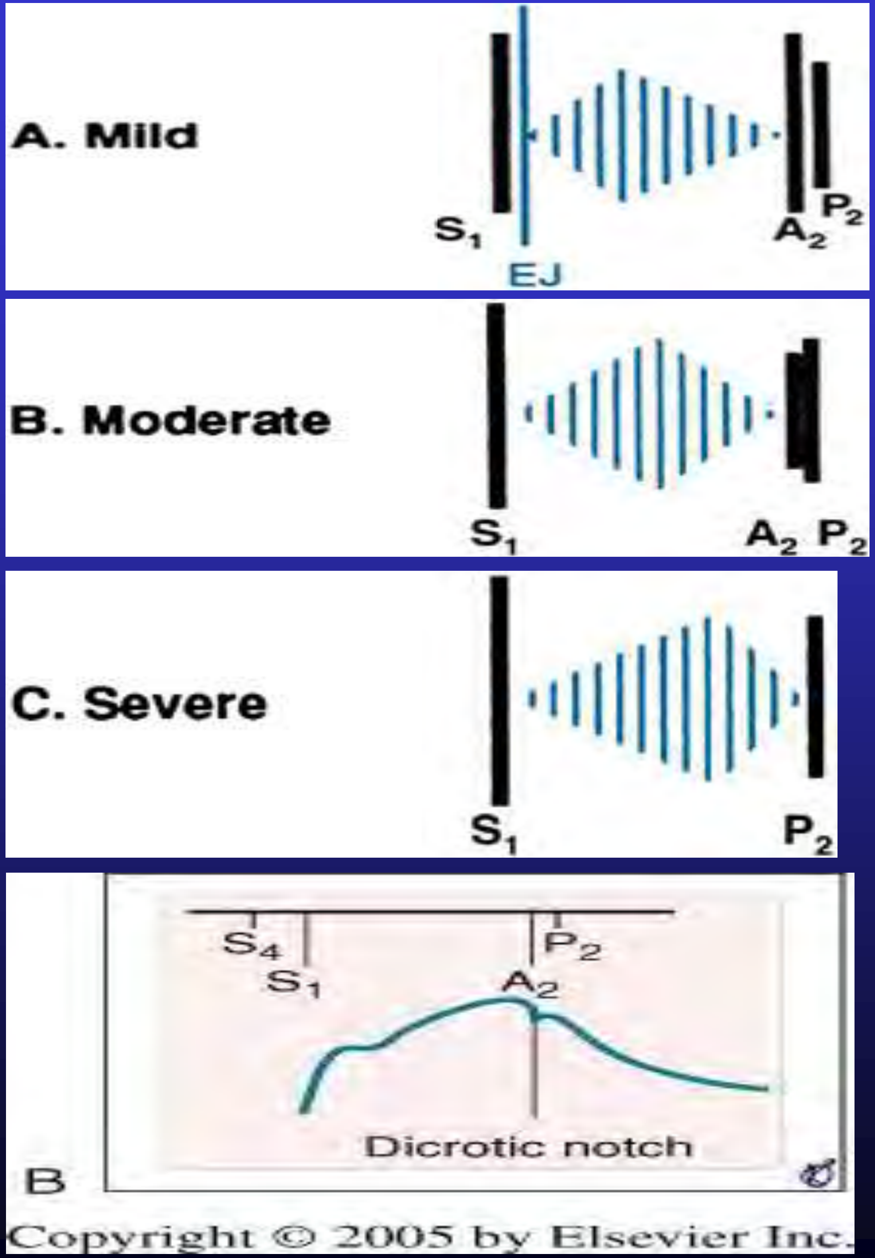
5^{th} Left Intercostal Space, Mid Clavicular Line





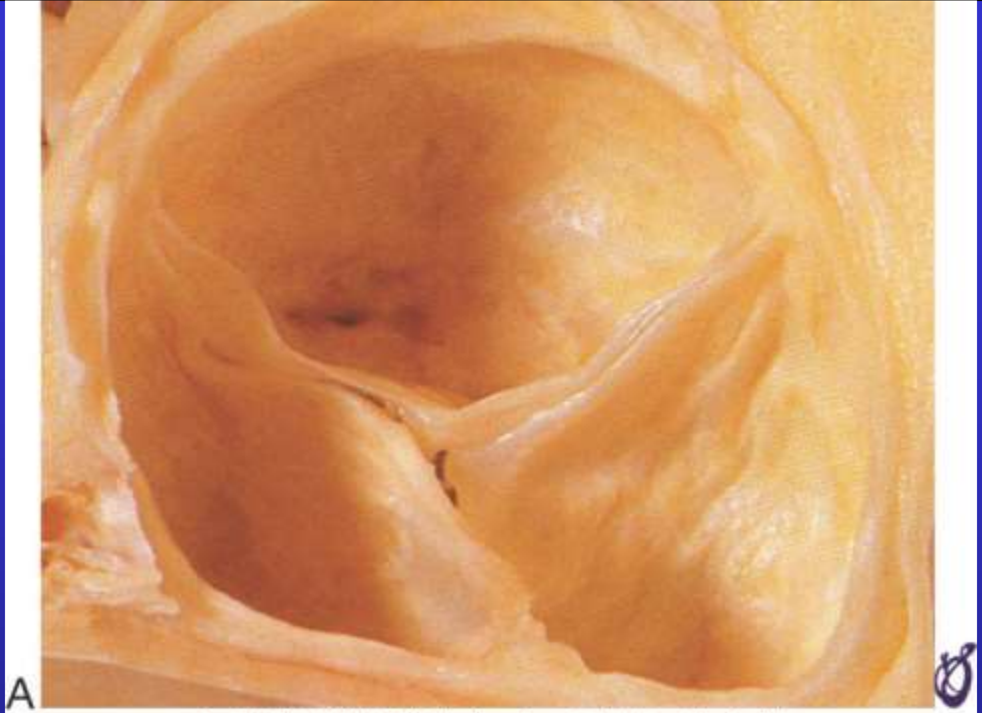
Lilly figure 2-3a

Aortic Stenosis: Auscultation



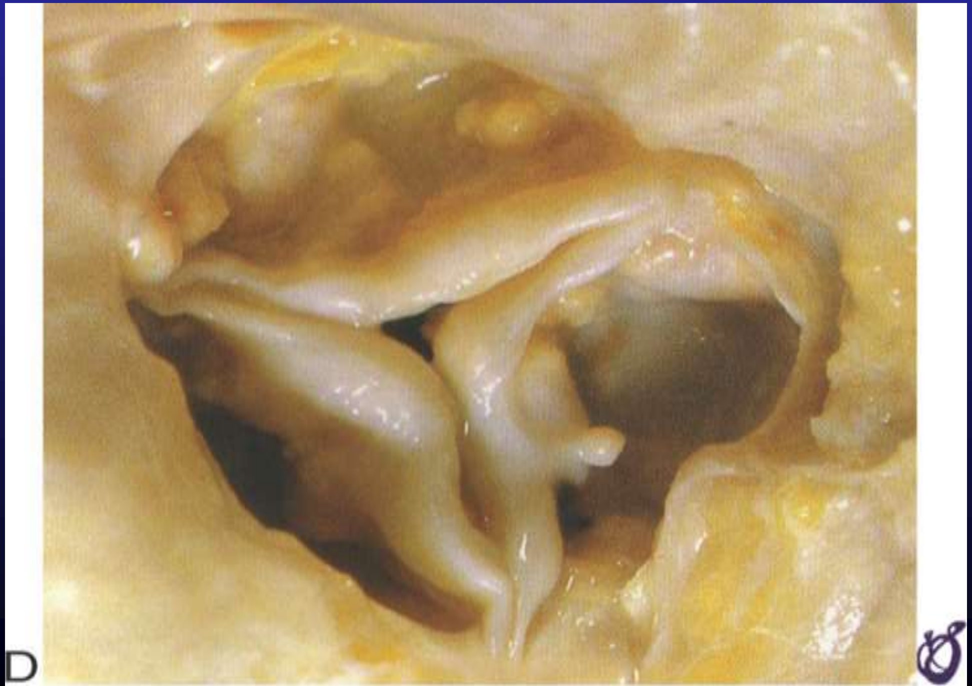
- Loud, harsh, **crescendo /descrescendo systolic murmur radiating to carotid arteries** at the 2nd RICS, sometimes loud over apex
- Frequently ejection click until valve becomes immobile
- Loud S4, sometimes palpable
- Sustained PMI over apex (due to LVH)
- "Slow and late" (parvus et tardus) rise to carotid pulsus with anacrotic notch

Lilly 4th edition, Braunwald 7th edition



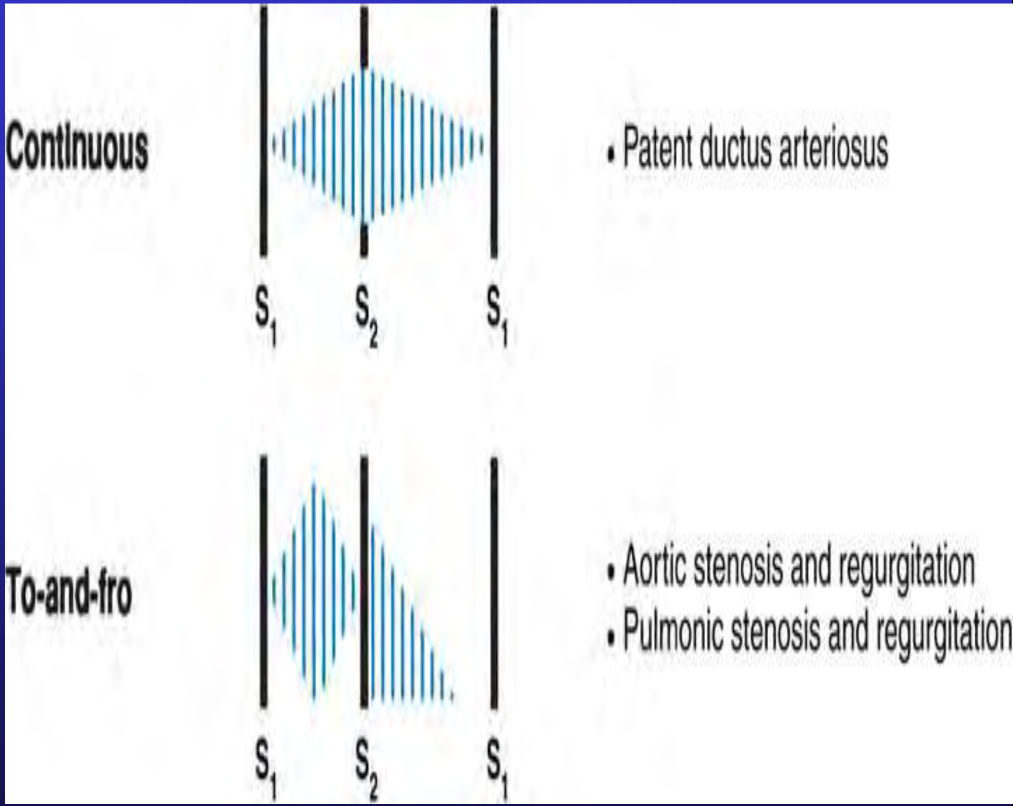
(From Manabe H, Yutani C [eds]: Atlas of Valvular Heart Disease. Singapore, Churchill Livingstone, 1998, pp 6 and 131.)

(Courtesy of William C. Roberts, MD.)



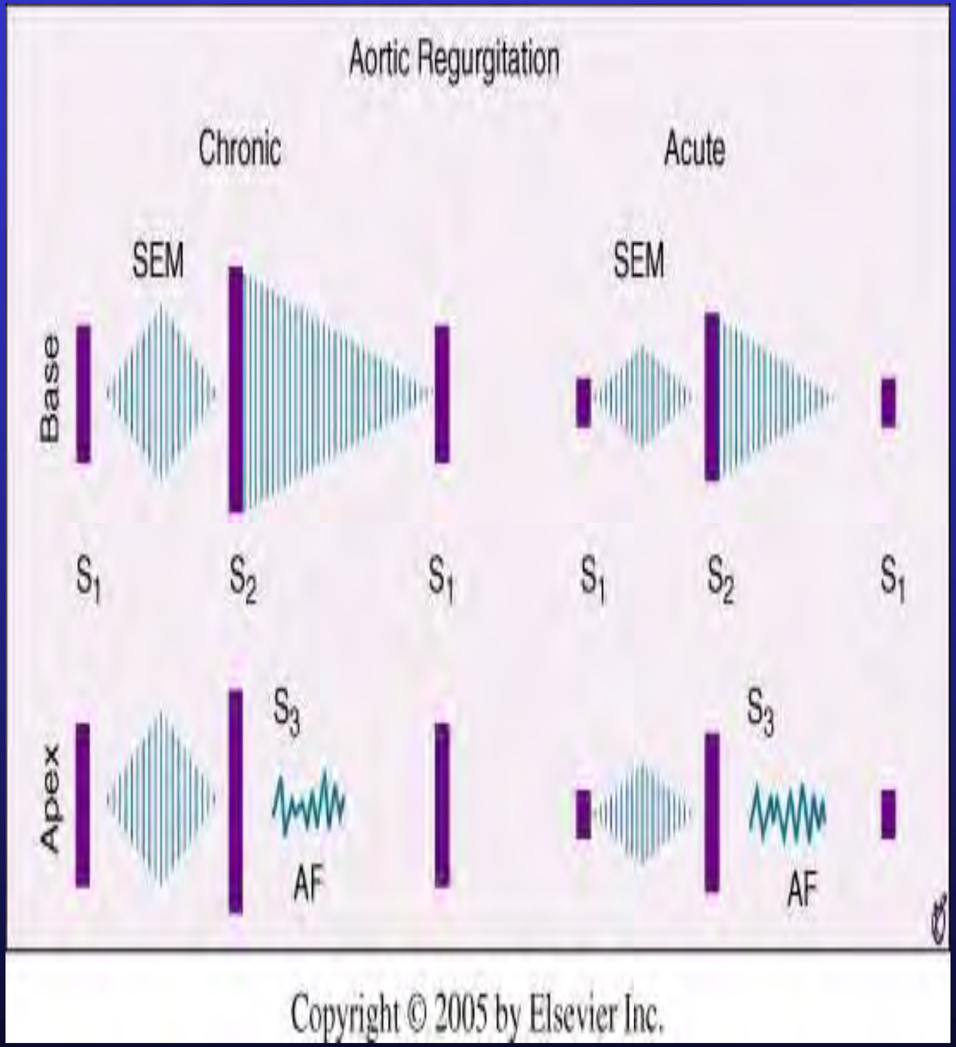
Systolic-Diastolic Murmurs

- Continuous murmurs- patent ductus arteriosus, ruptured sinus of Valsalva aneurysm
- To-and fro murmurs- aortic stenosis/regurgitation, pulmonic stenosis/ regurgition, 2 or 3 component pericardial friction rubs



Lilly figure 2-10

Aortic Regurgitation: Auscultation



Braunwald 7th edition

- Soft S1 and S2
- **Decrescendo diastolic murmur**, usually II-III/VI systolic ejection murmur
- Loud S3, variable S4
- **Austin Flint murmur**- diastolic rumble caused by AR jet “blowing the mitral valve closed”, may have presystolic accentuation
- Large palpable PMI

Mitral Valve

Classification of Systolic Murmurs

Examples

A. Ejection type

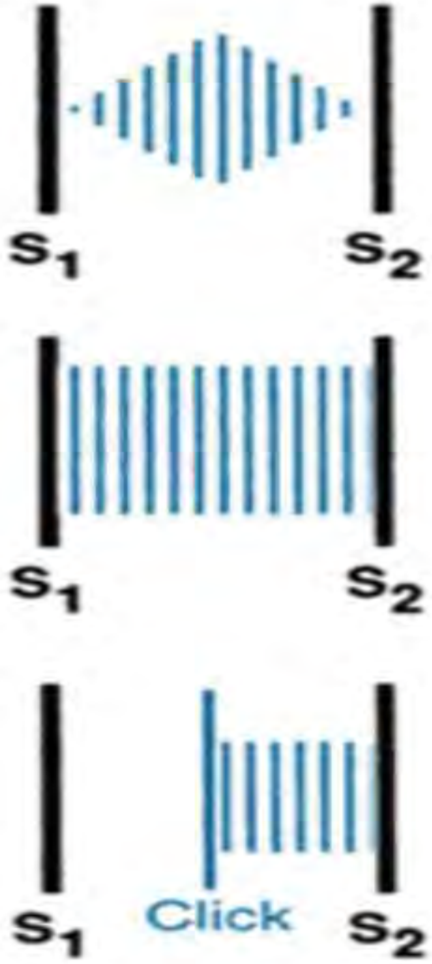
- Aortic stenosis
- Pulmonic stenosis

B. Pansystolic (holosystolic)

- Mitral regurgitation
- Tricuspid regurgitation
- Ventricular septal defect

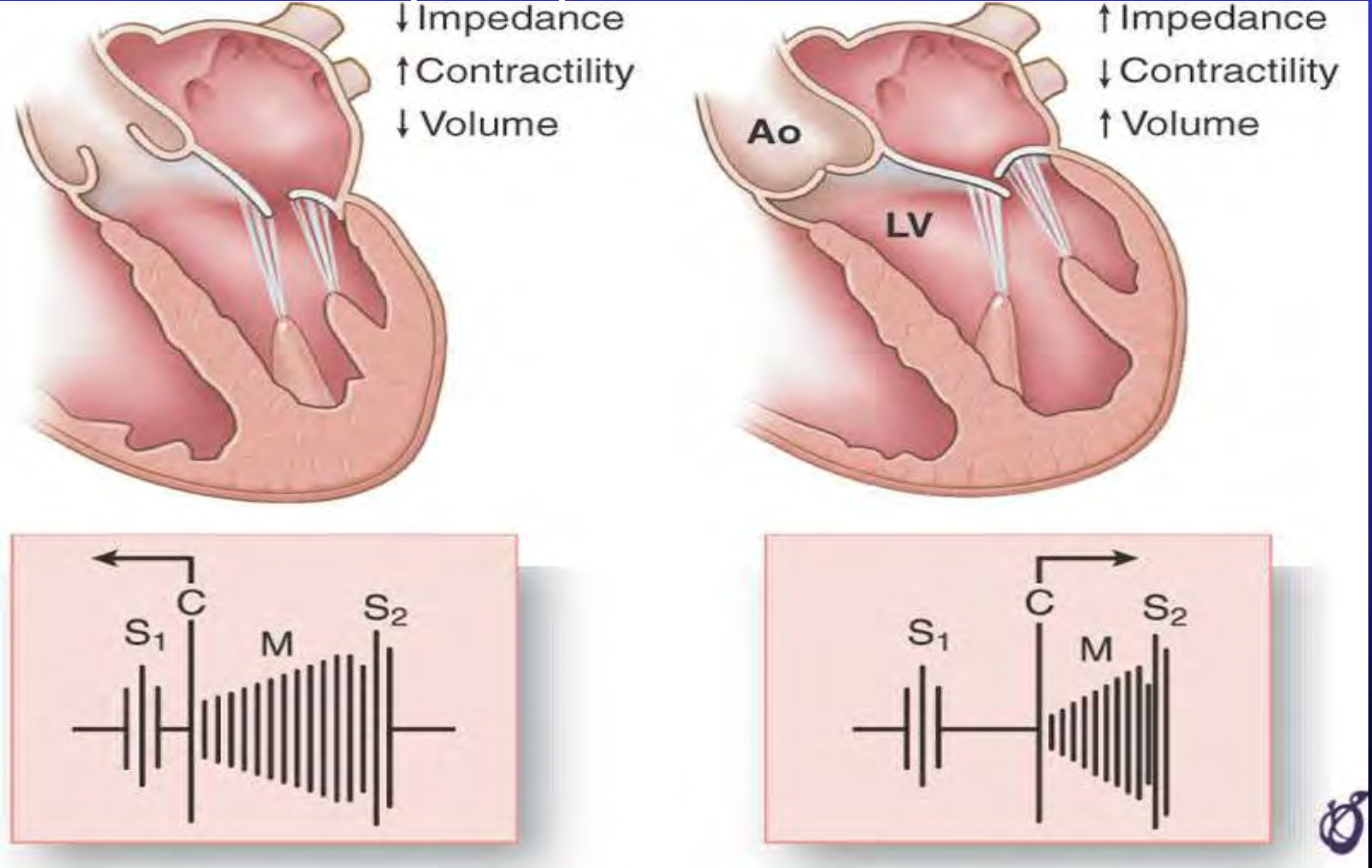
C. Late systolic

- Mitral valve prolapse

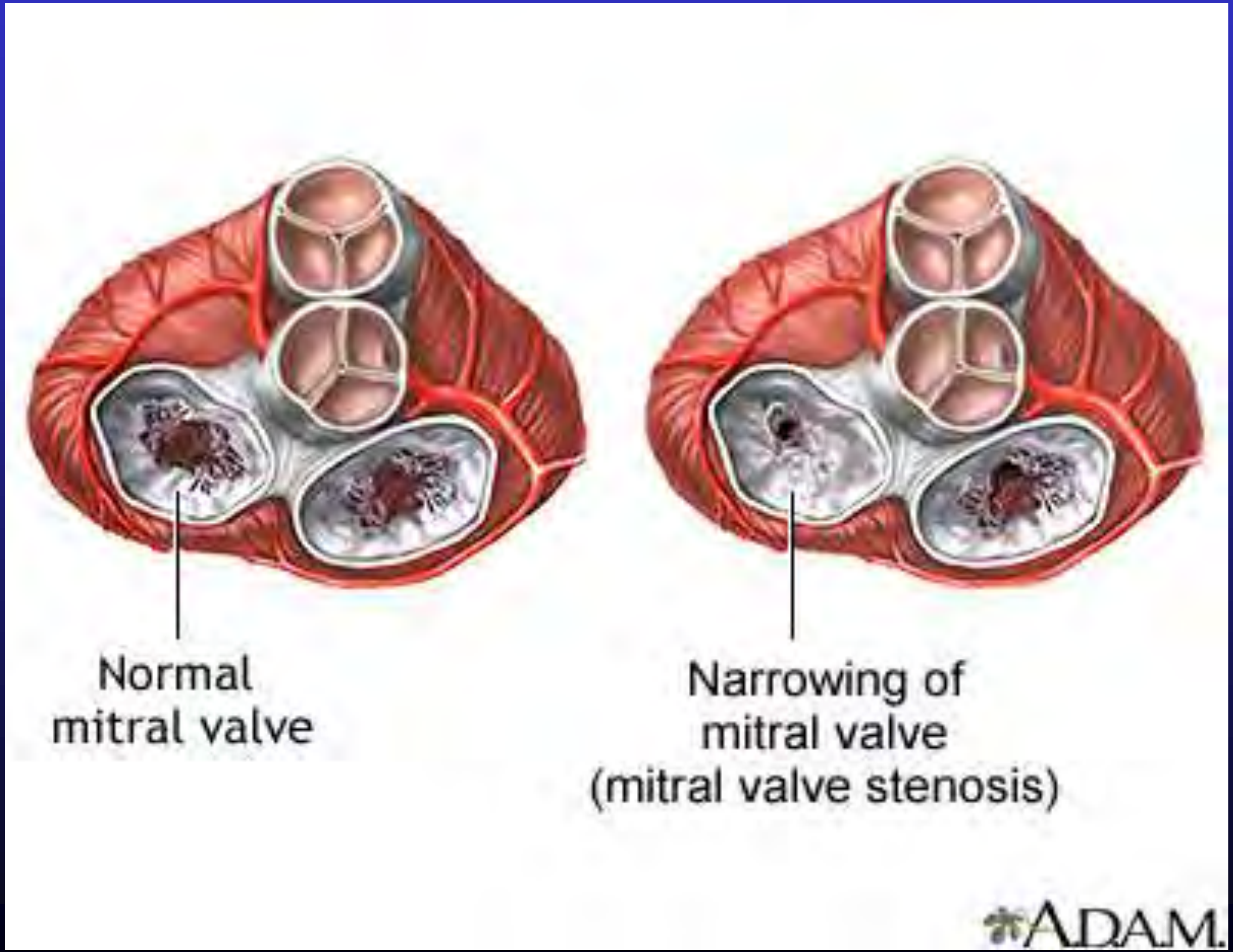


Lilly figure 2-6

Variation in Timing of Click/Murmur for Mitral Valve prolapse



Mitral Stenosis



Opening Snap [Mitral Stenosis]

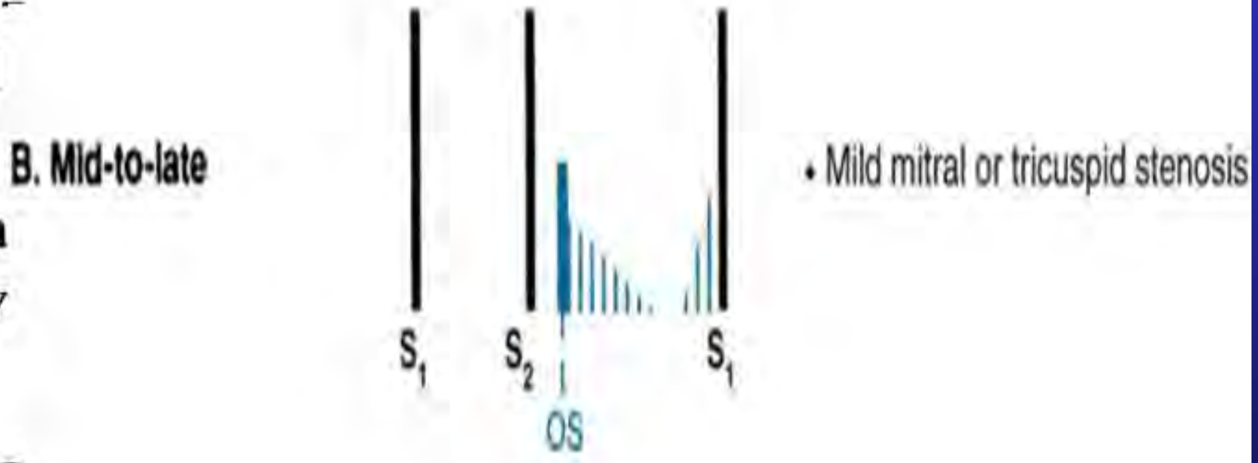
Opening Snap is patho-pneumonic of mitral stenosis

The timing of OS from S2 indicates severity

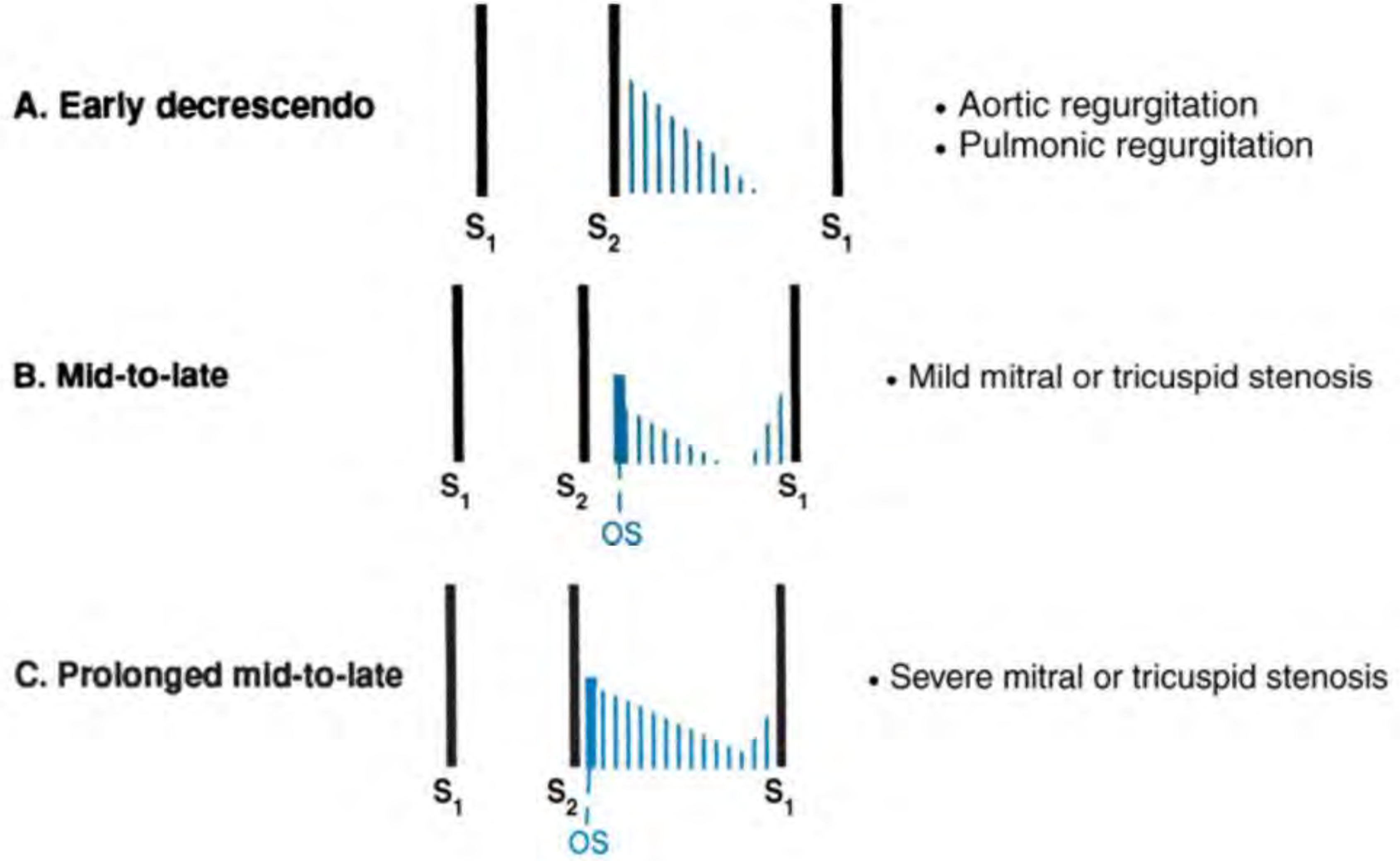
90-120 msec = mild

60- 90msec = moderate

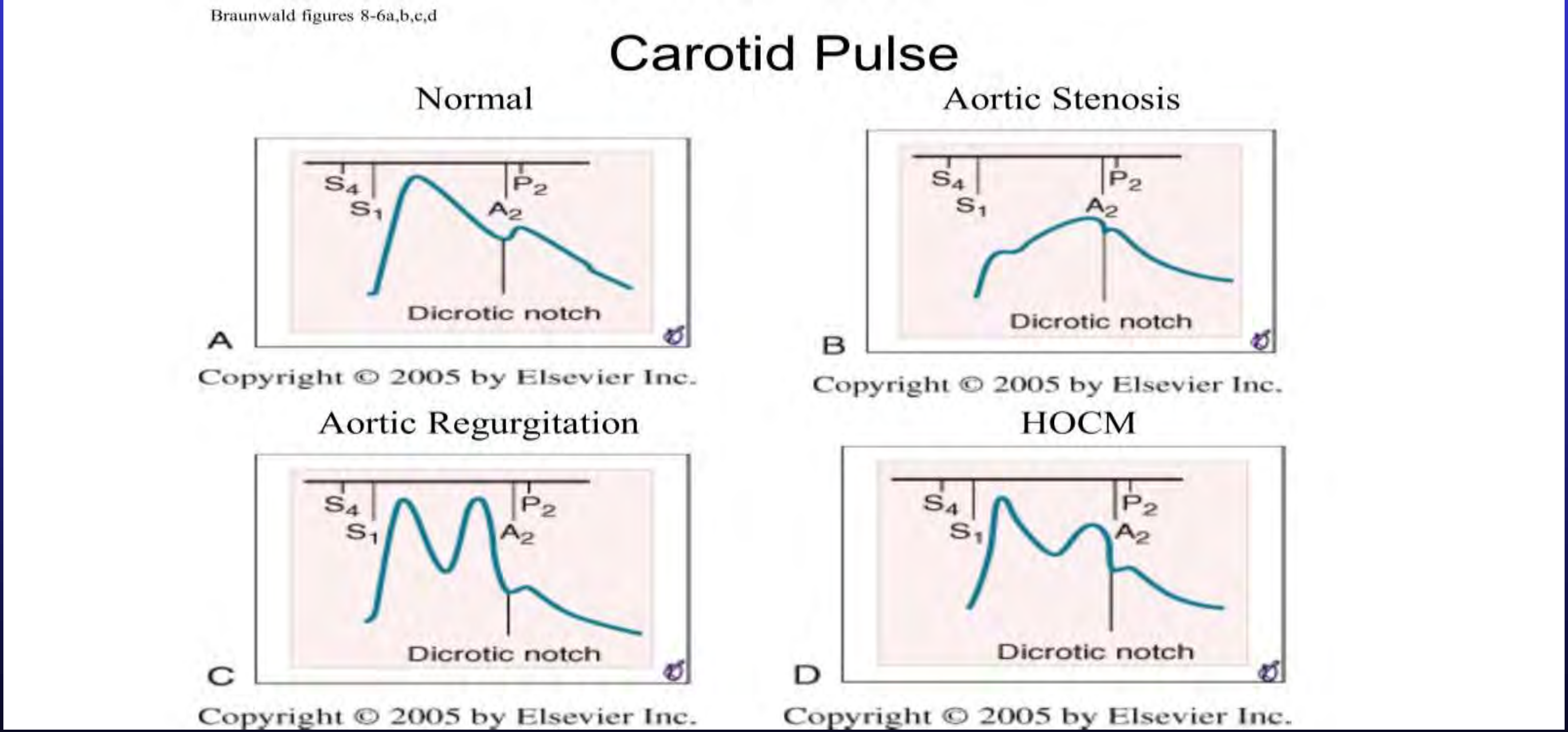
<60 msec = severe

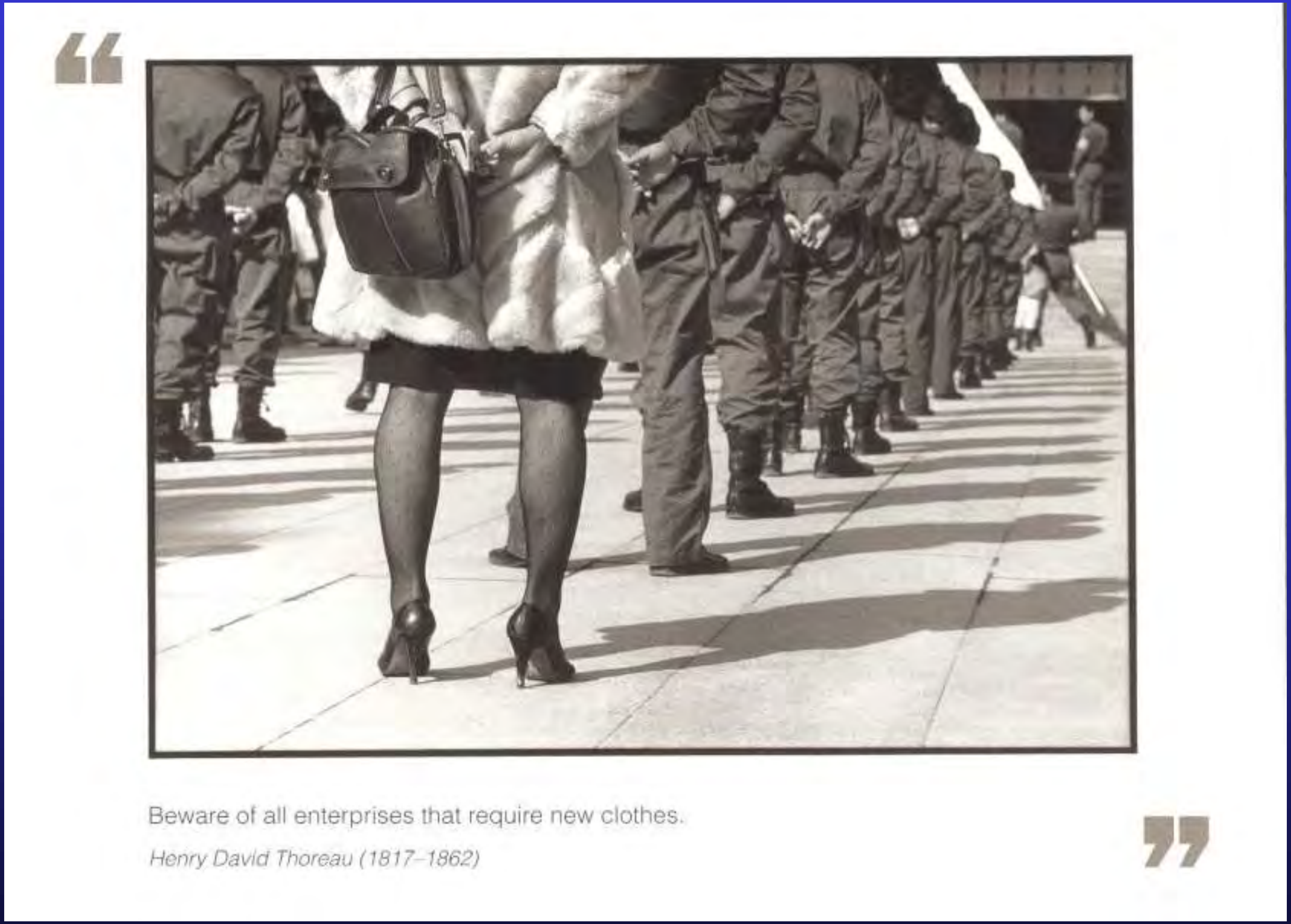


Diastolic Murmurs



USUALLY PALPATED FROM THE CAROTID OR RADIAL PULSE





Beware of all enterprises that requires new clothes

- *Henry David Thoreau*

How would cardiologists feel about AI

Advantages of Phonocardiography Compared to Alternative Technologies

Results immediately available

Cheaper and more time saving than alternative technologies, e.g. CT, MRI, Echocardiography

Training much less rigorous

Maintenance of skill less involved

Ease of application

Patients are their own control

Multiple variables lend themselves to AI

Observations Acquire on Daily Rounds

- As patients respond to treatment of congestive heart failure S_3 would become less audible and resolve.
- S_1 increase in intensity and evolves from a ‘muffled’ sound to be more crisp.
- Murmurs would increase in intensity as ventricular stroke volumes improved.
- These observations aid in adjusting heart failure medication, especially diuretics.

Success is the ability to go from failure to failure without losing your enthusiasm.

- *Winston Churchill*