Basic Hemodynamics

January 19, 2011

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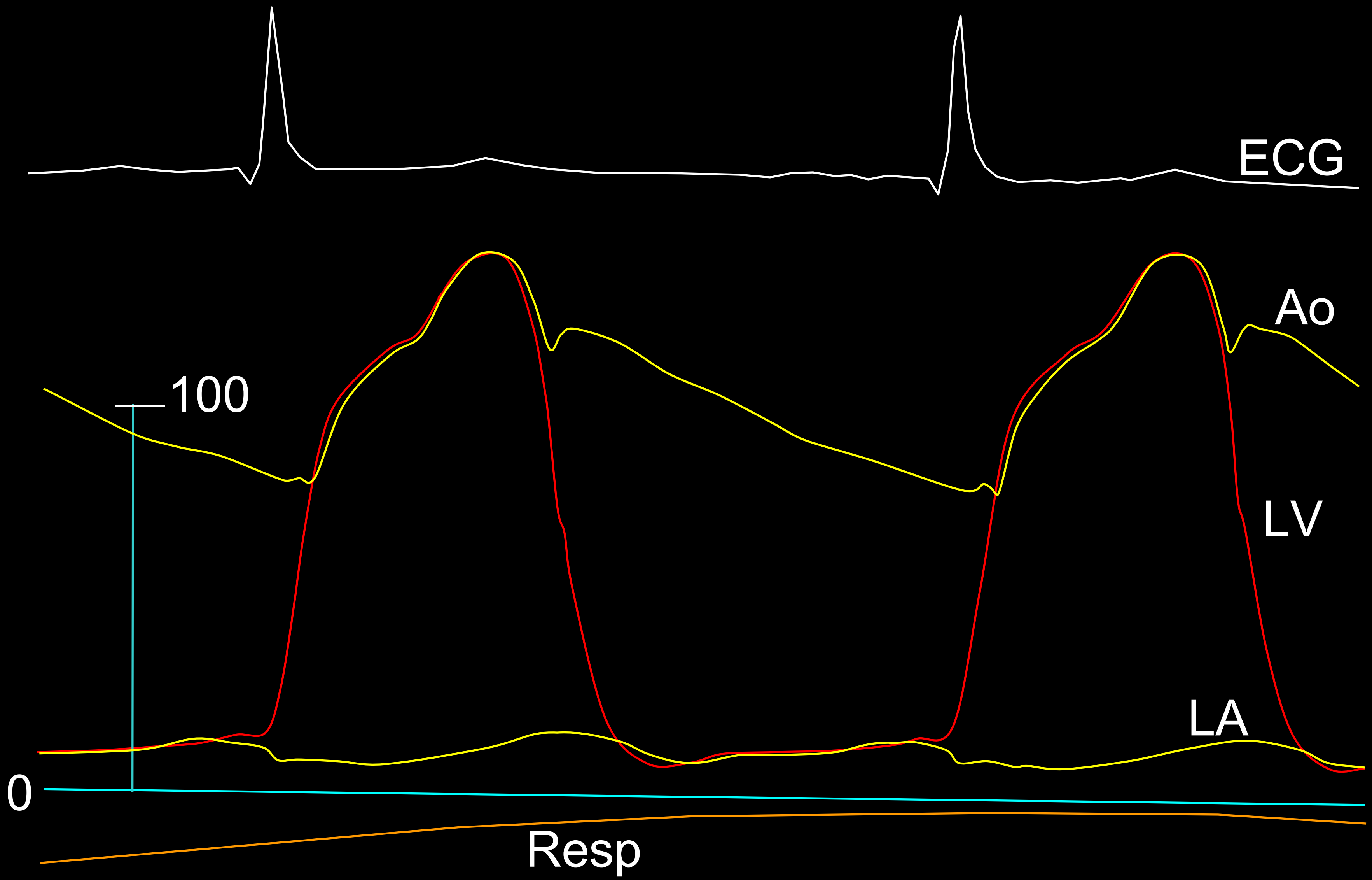
UTHSCSA and STVHCS

Outline

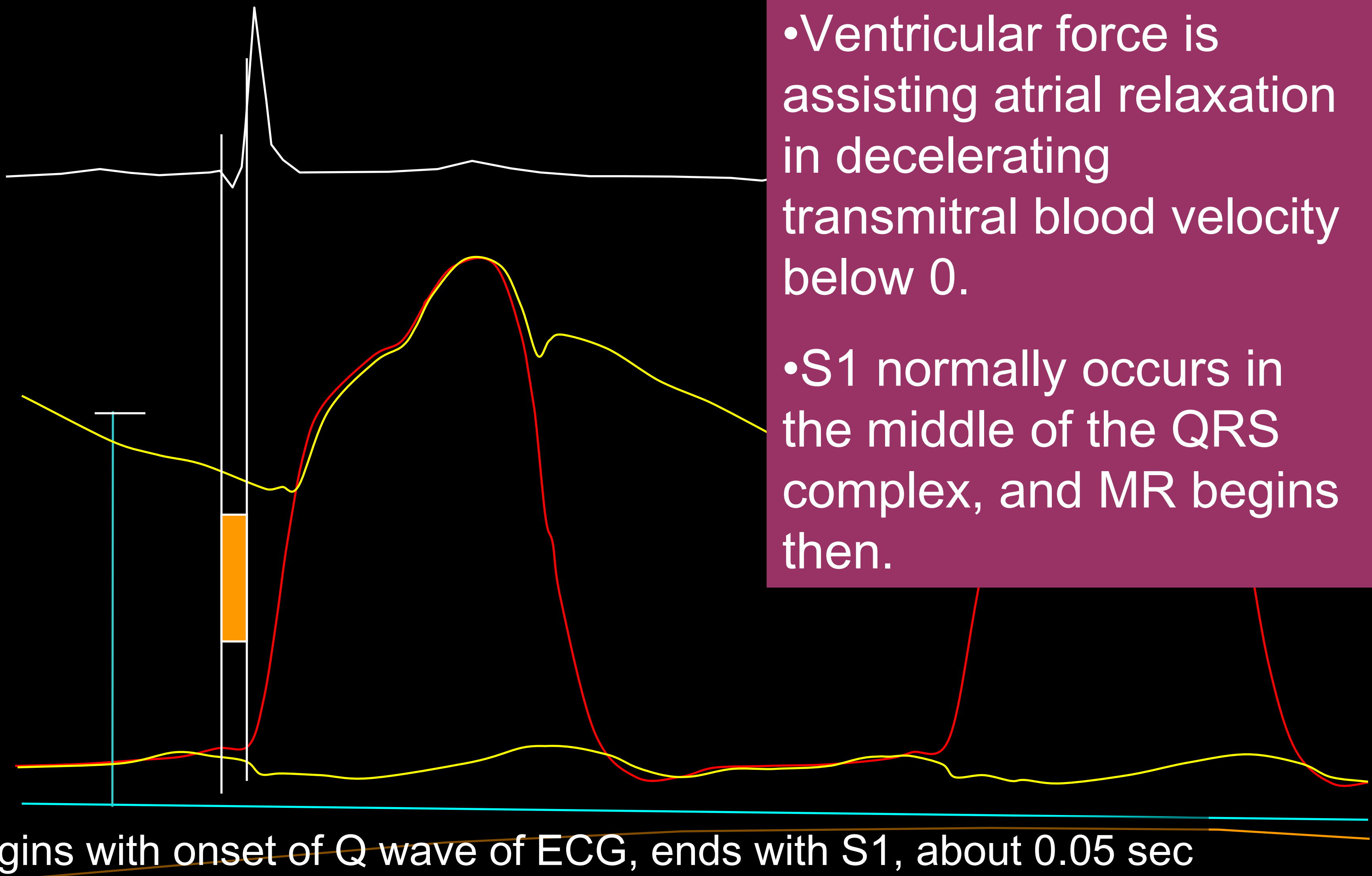
- The Cardiac Cycle
- Types of Measures
  - Pressure
  - Flow (Calculated from Temperature, O_2 Saturation, Indicator Concentration, Electromagnetic Flow Velocity or Image Measures)
  - Calculated Measures
  - Image Measures
    - Volume, Distance, Area
    - Flow (volume change by cine frame)
- Normal values

The Cardiac Cycle



The Cardiac Cycle

1. Electromechanical delay, Q-M1

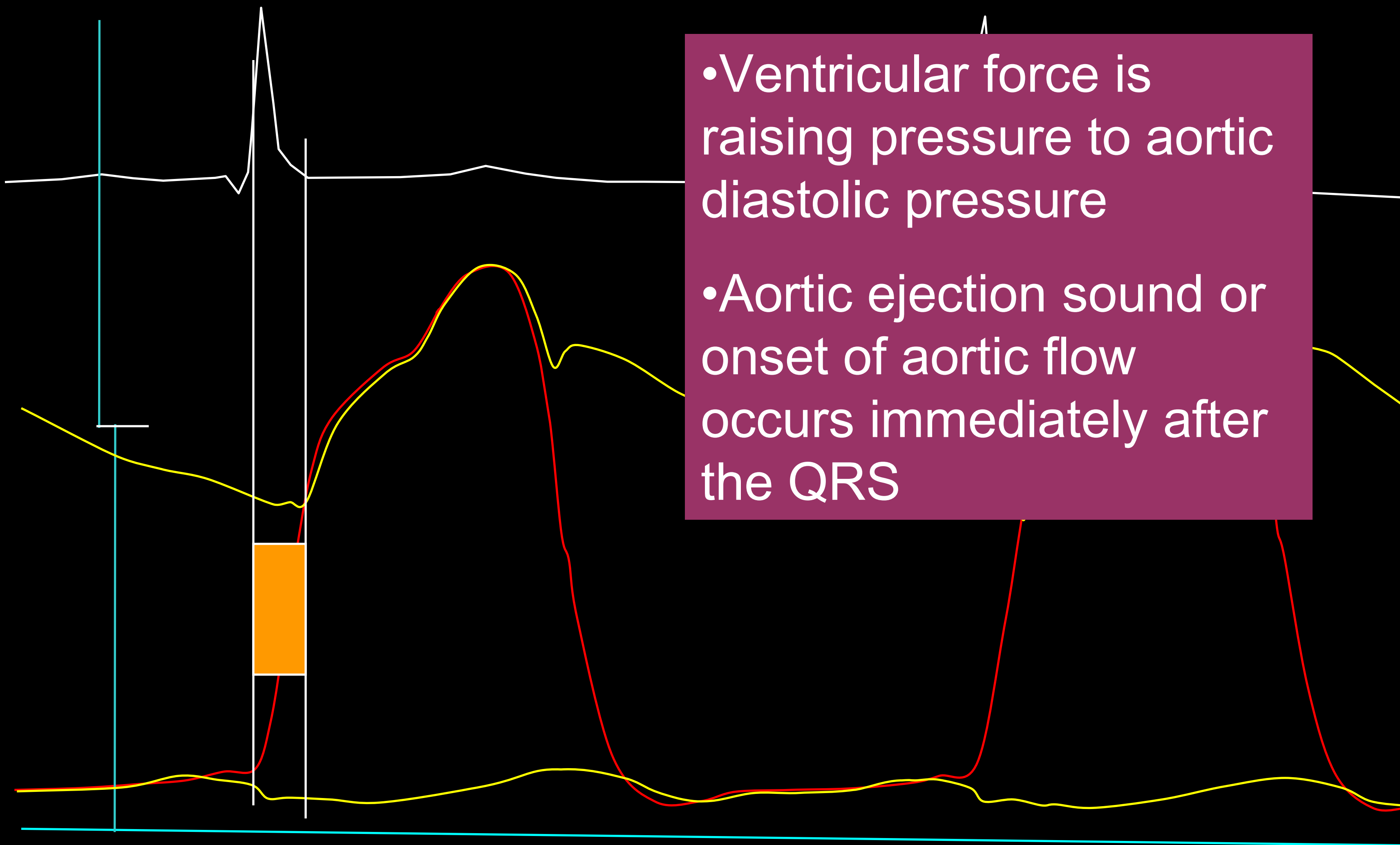


- Ventricular force is assisting atrial relaxation in decelerating transmitral blood velocity below 0.
- S1 normally occurs in the middle of the QRS complex, and MR begins then.

Begins with onset of Q wave of ECG, ends with S1, about 0.05 sec
Prolonged in mitral stenosis, reported prolongation in systemic hypertension, WPW, MR, VSD, PDA, Ebstein's

The Cardiac Cycle

1. Electromechanical delay, Q-M1
2. **Isovolumic contraction time**

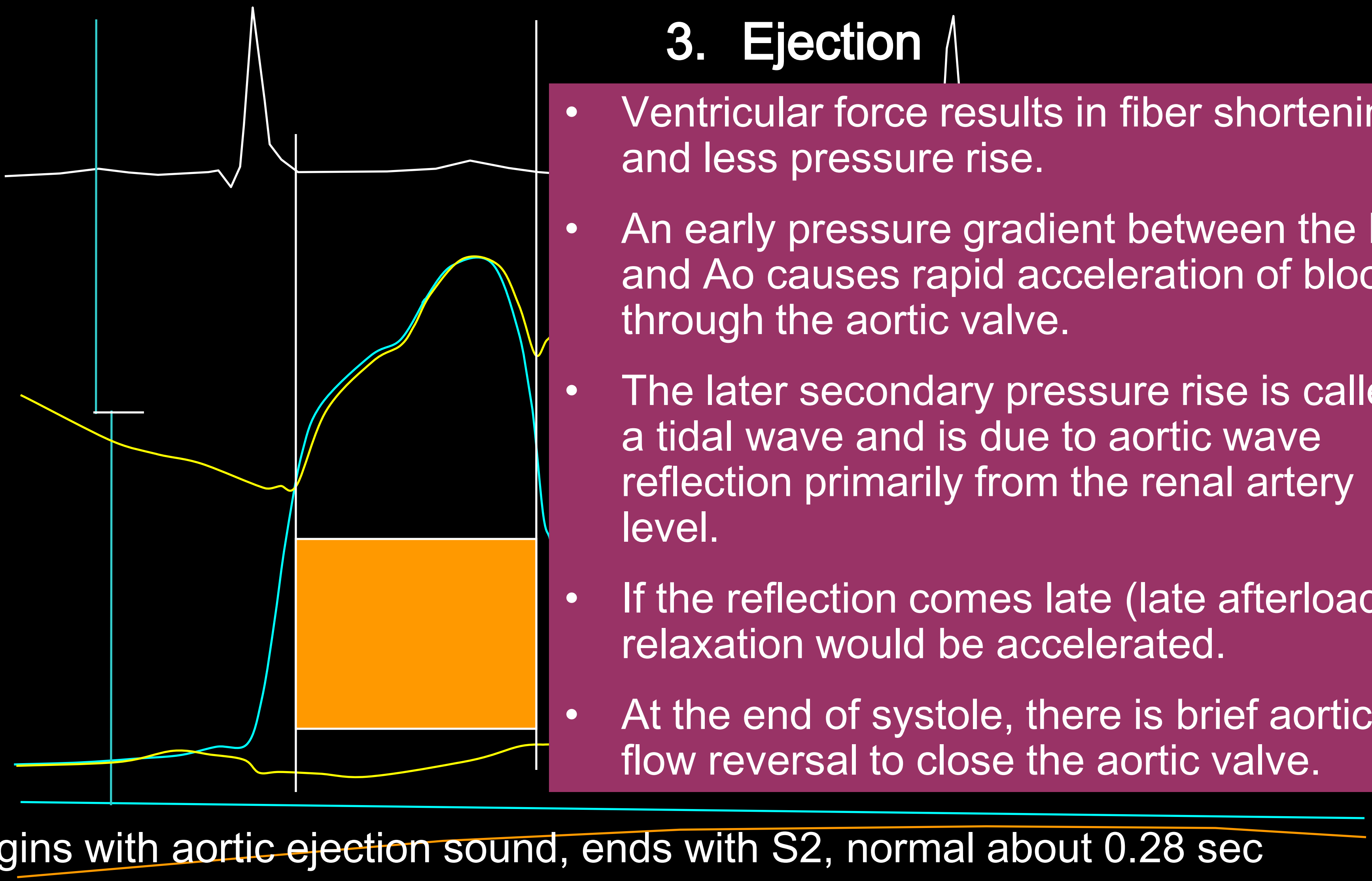


- Ventricular force is raising pressure to aortic diastolic pressure
- Aortic ejection sound or onset of aortic flow occurs immediately after the QRS

Begins with S1, ends with aortic ejection sound, about 0.05 sec
Shortened in increased contractility, increased EDV or SV (AR)
Prolonged in decreased contractility or CO, acute HTN, LBBB

The Cardiac Cycle

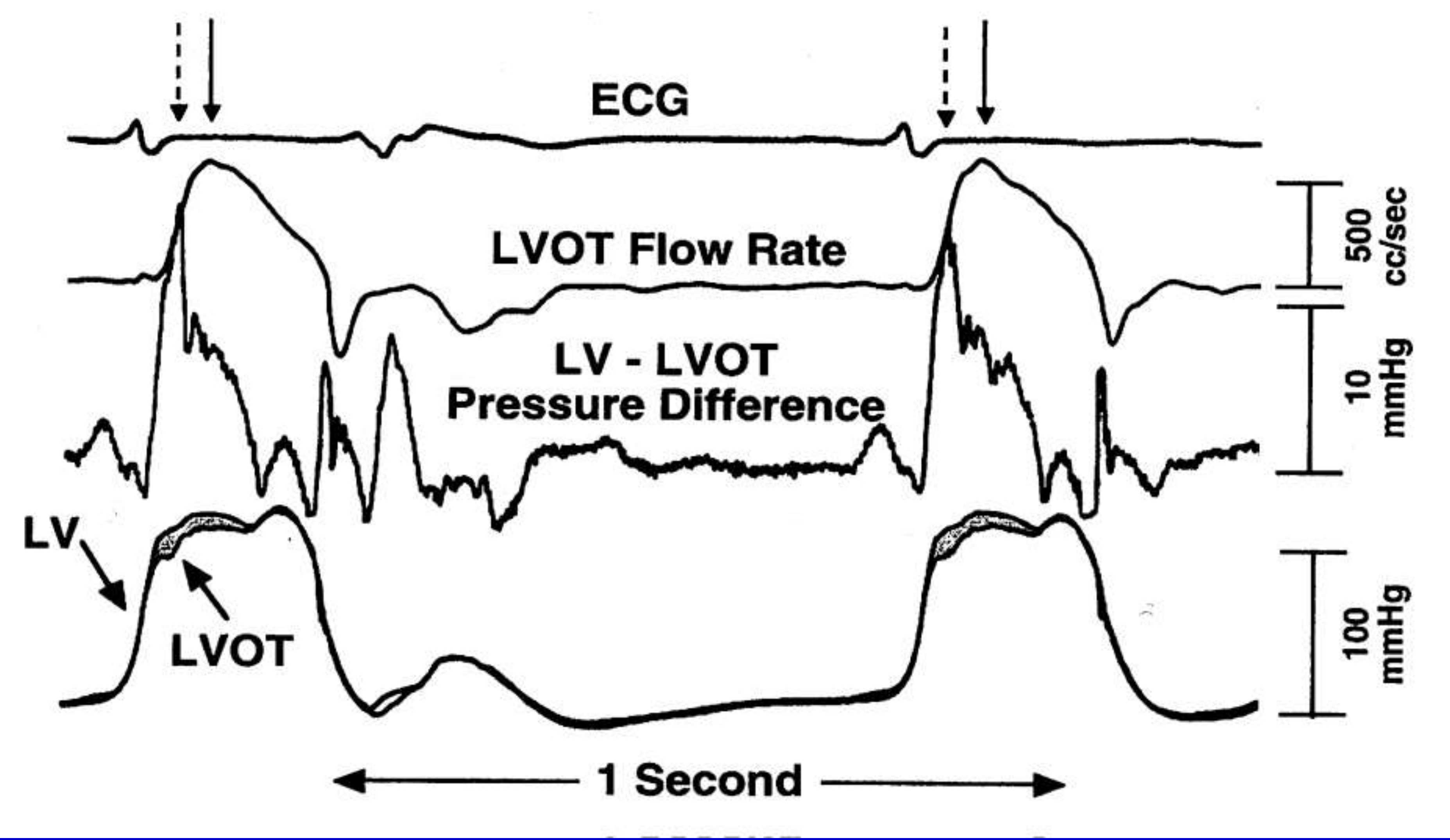
1. Electromechanical Delay, Q-M1
2. Isovolumic Contraction time
3. **Ejection**



- Ventricular force results in fiber shortening and less pressure rise.
- An early pressure gradient between the LV and Ao causes rapid acceleration of blood through the aortic valve.
- The later secondary pressure rise is called a tidal wave and is due to aortic wave reflection primarily from the renal artery level.
- If the reflection comes late (late afterload), relaxation would be accelerated.
- At the end of systole, there is brief aortic flow reversal to close the aortic valve.

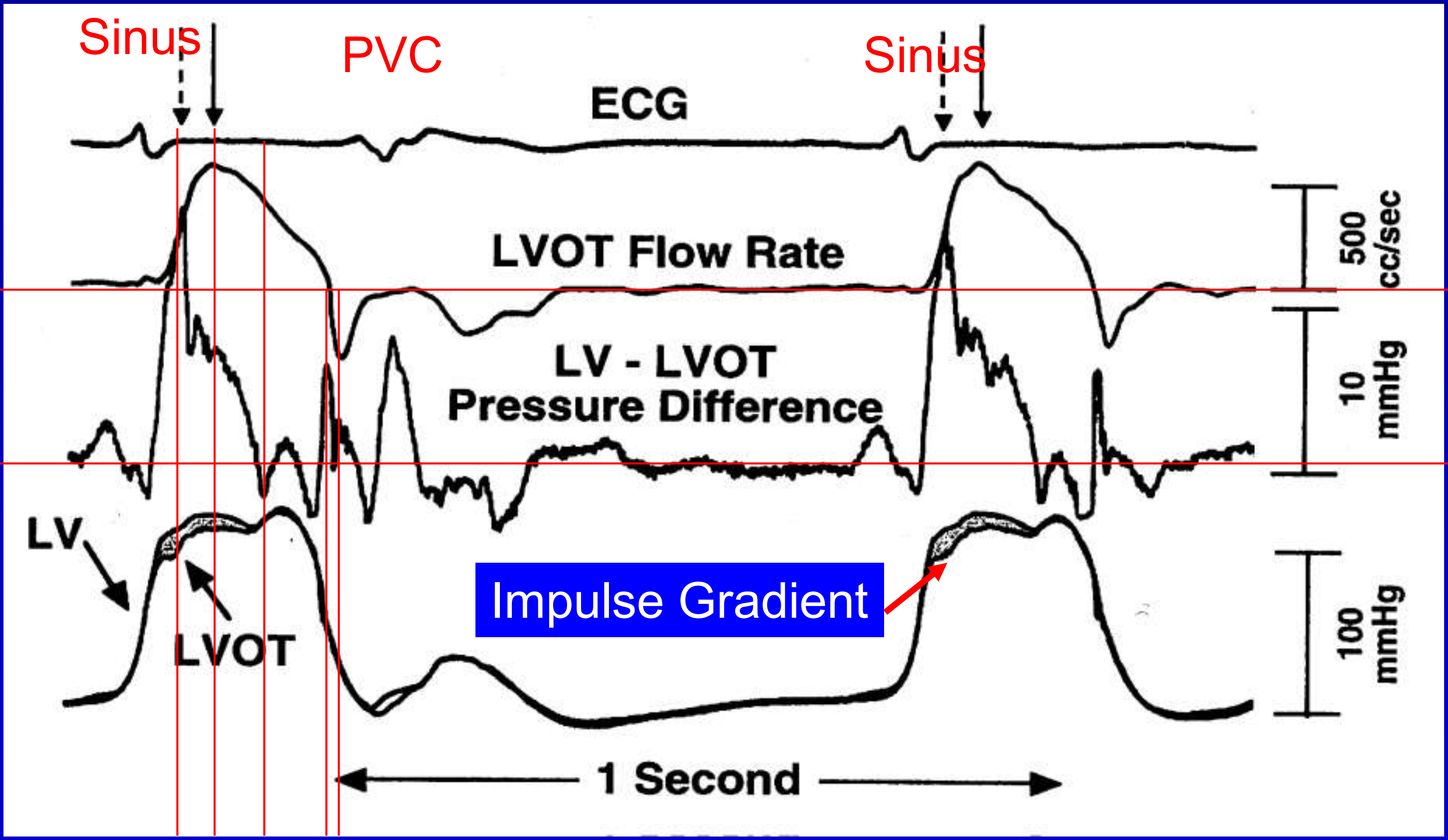
Begins with aortic ejection sound, ends with S2, normal about 0.28 sec
Shortened in myocardial failure, MR, and increased contractility (thyrotoxicosis)
Prolonged in aortic stenosis, HCM, but not necessarily aortic regurgitation or PDA

Left Ventricular Ejection



Murgo, JP. J Am Coll Cardiol 1998;32:1596

Left Ventricular Ejection



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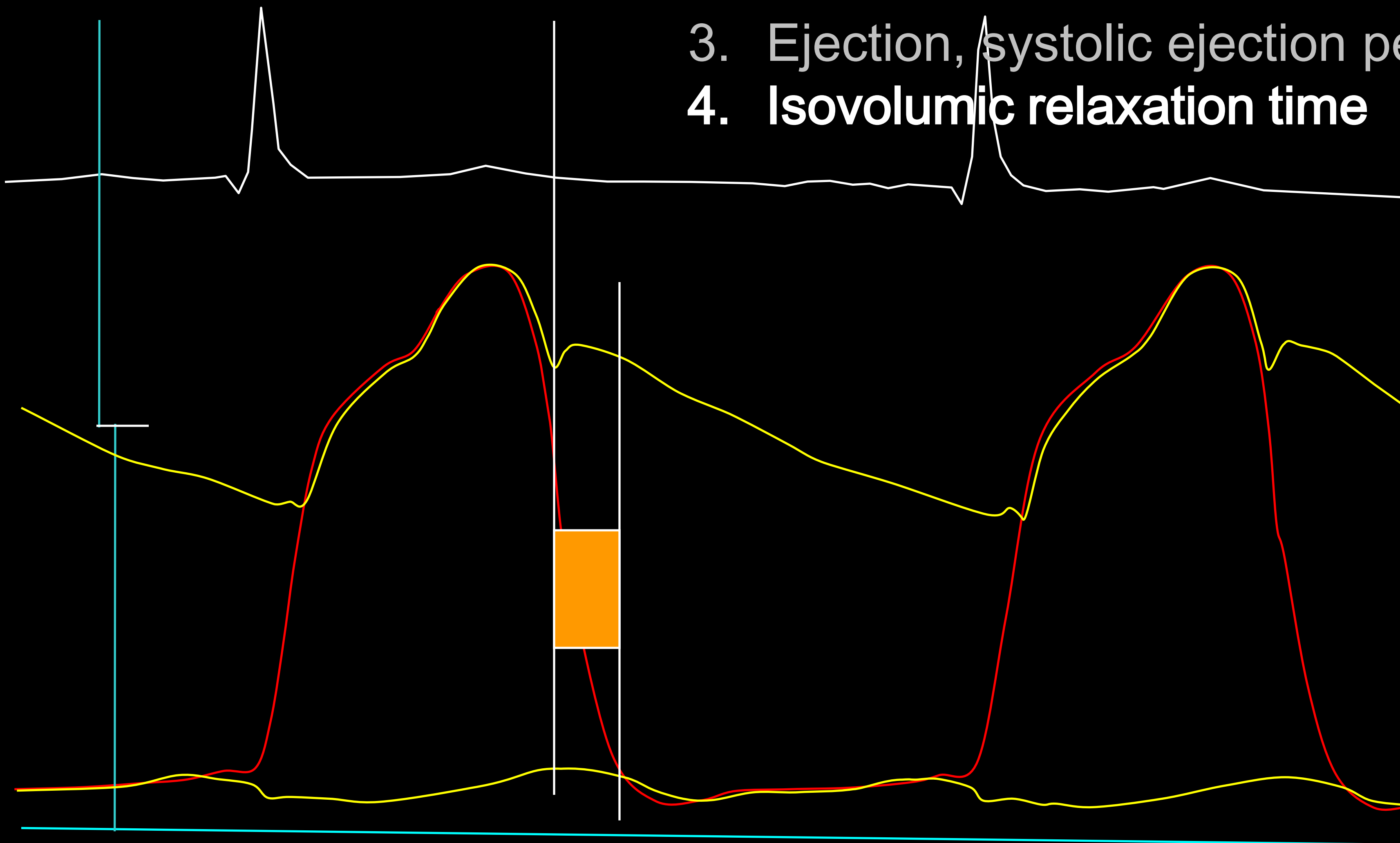
The Cardiac Cycle

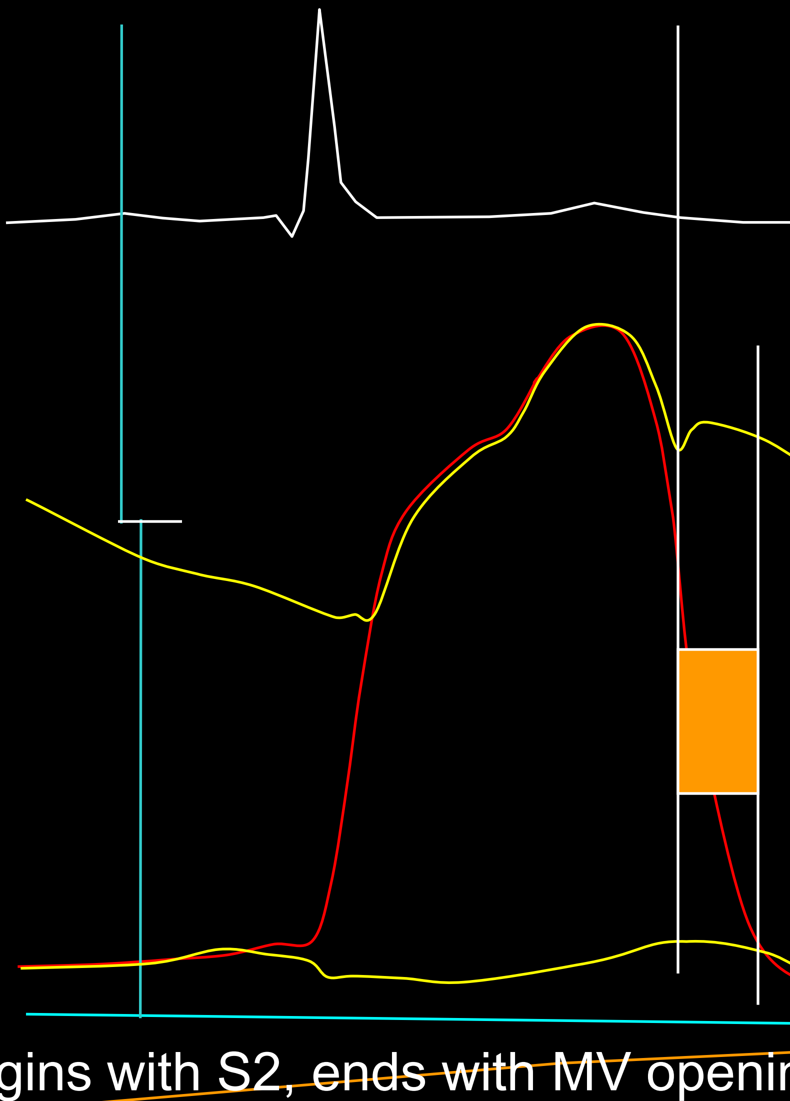
1. Electromechanical delay, Q-M1
2. Isovolumic contraction time
3. Ejection, systolic ejection perioc
4. **Isovolumic relaxation time**



Begins with S2, ends with MV opening, normal about 0.08 sec
Shortened in elevated LV filling pressures, mitral stenosis
Prolonged in impaired relaxation

The Cardiac Cycle

1. Electromechanical delay, Q-M1
2. Isovolumic contraction time
3. Ejection, systolic ejection period
4. **Isovolumic relaxation time**

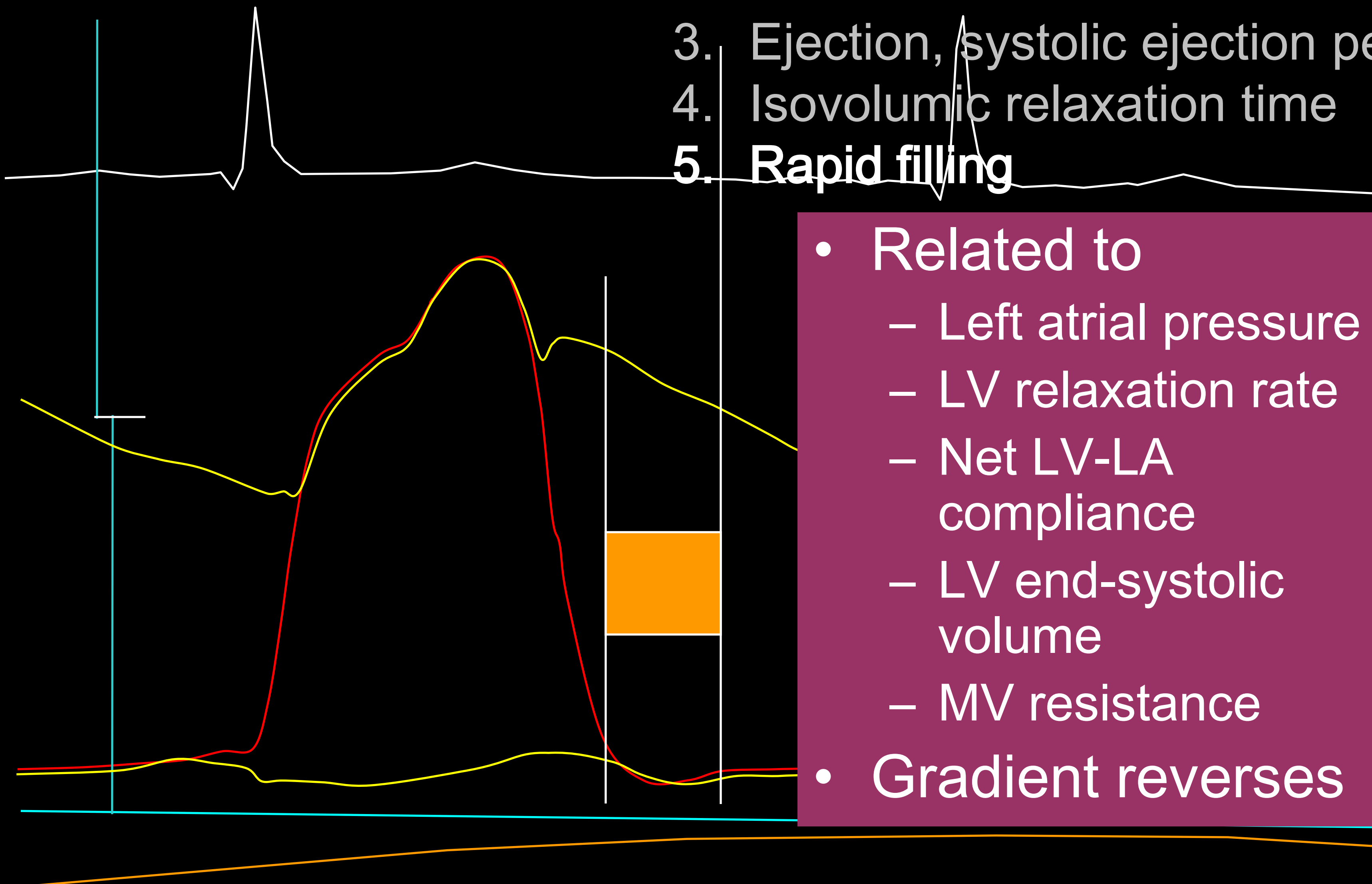


- Related to
  - Height of LV pressure at dicrotic notch
  - Rate of pressure decline
  - Height of LA pressure at mitral crossover
- Normally a monoexponential decay, characterize by time constant of relaxation (τ), analyzed from peak –dP/dt to 5 mmHg above LVEDP, normal value of τ is 25-40 msec
- Relaxation is considered 97% complete by 3* τ or about 140 msec after A2

Begins with S2, ends with MV opening, normal about 0.08 sec
Shortened in elevated LV filling pressures, mitral stenosis
Prolonged in impaired relaxation

The Cardiac Cycle

1. Electromechanical delay, Q-M1
2. Isovolumic contraction time
3. Ejection, systolic ejection period
4. Isovolumic relaxation time
5. **Rapid filling**



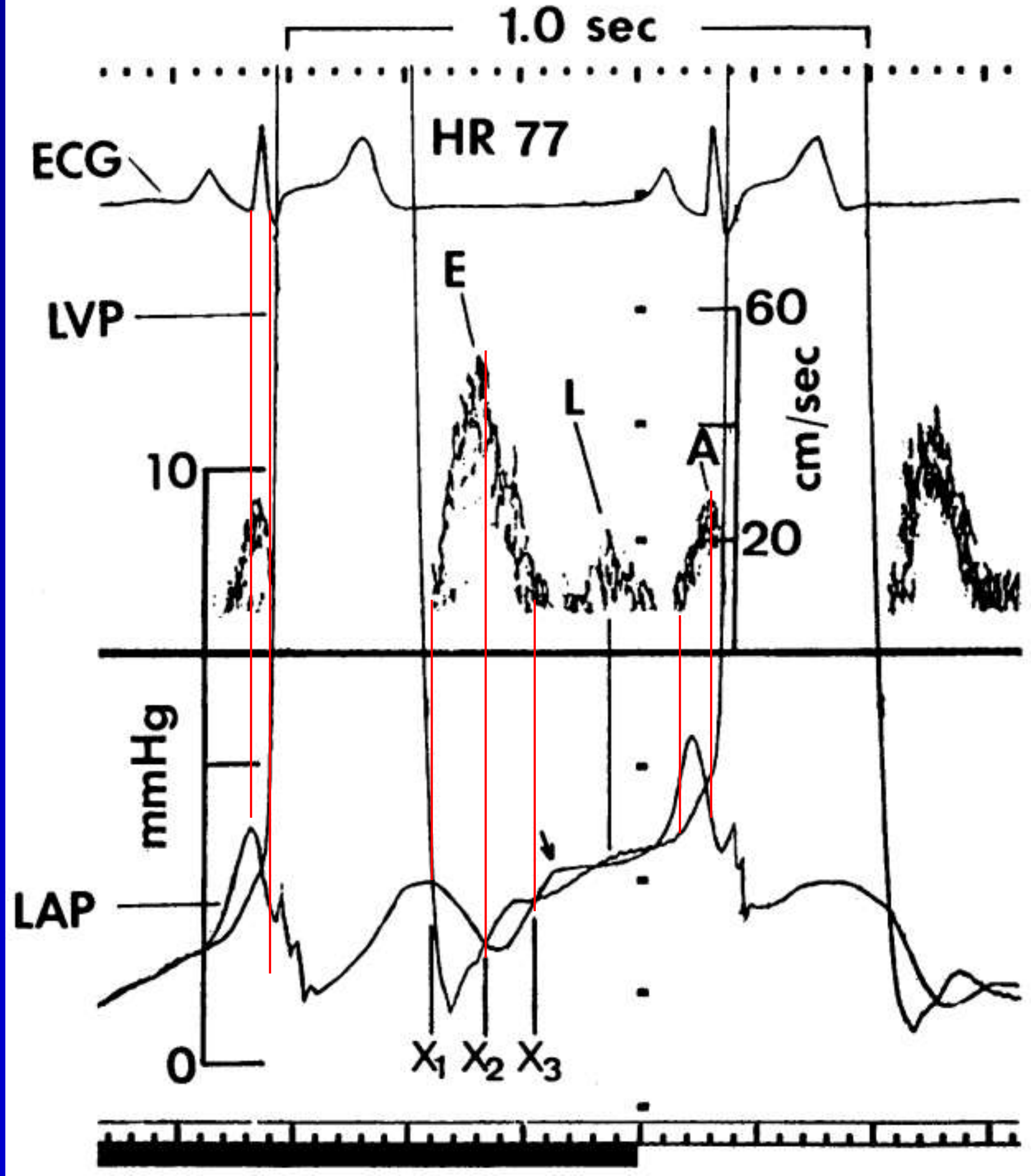
- Related to
  - Left atrial pressure
  - LV relaxation rate
  - Net LV-LA compliance
  - LV end-systolic volume
  - MV resistance
- Gradient reverses

Begins with mitral opening, ends with S3, normal about 0.10 sec

Pressure and Flow

High fidelity LA and LV pressures and Transmitral Doppler

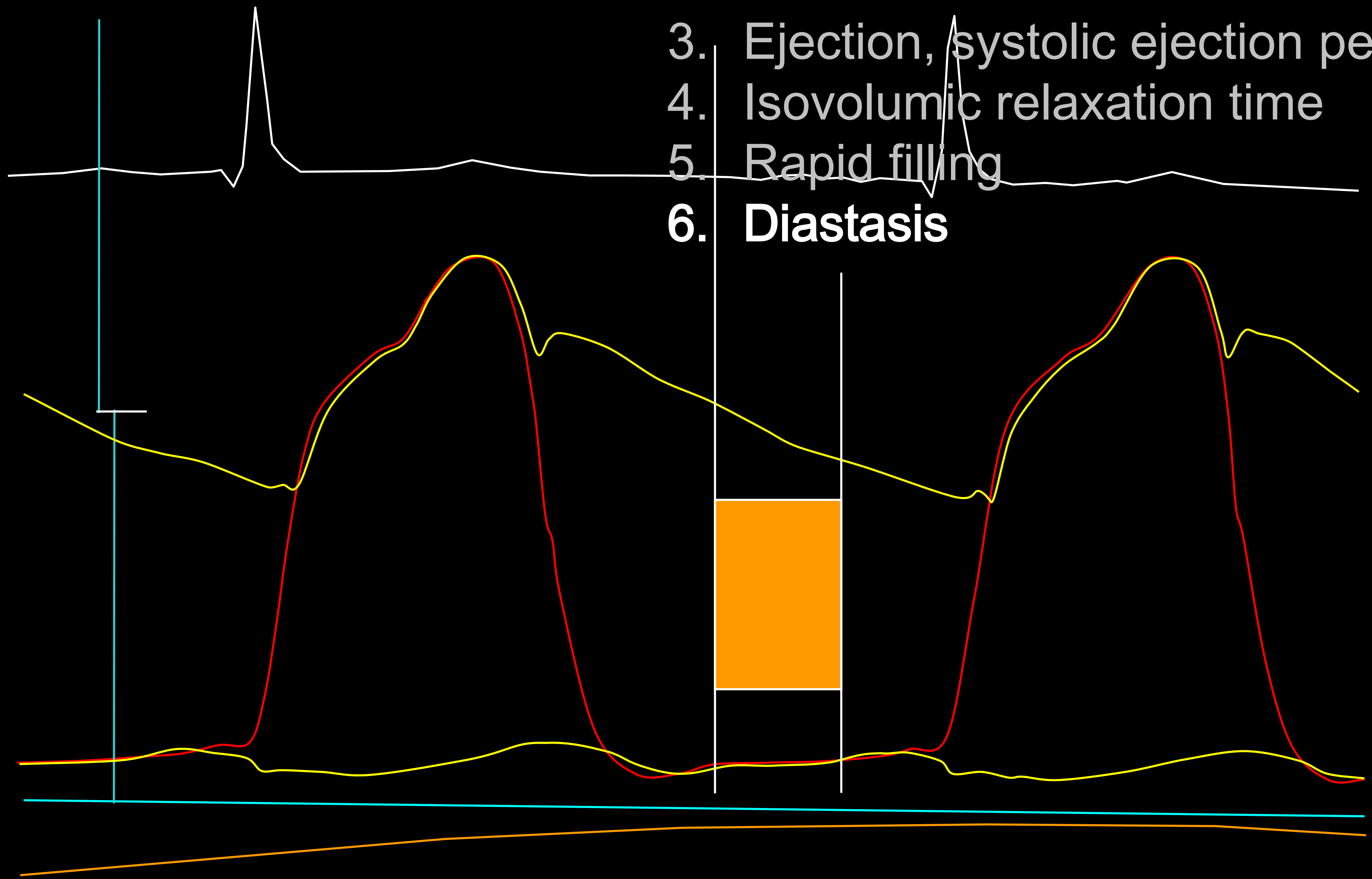
Closed chest canine



Courtois M et al. Circulation

The Cardiac Cycle

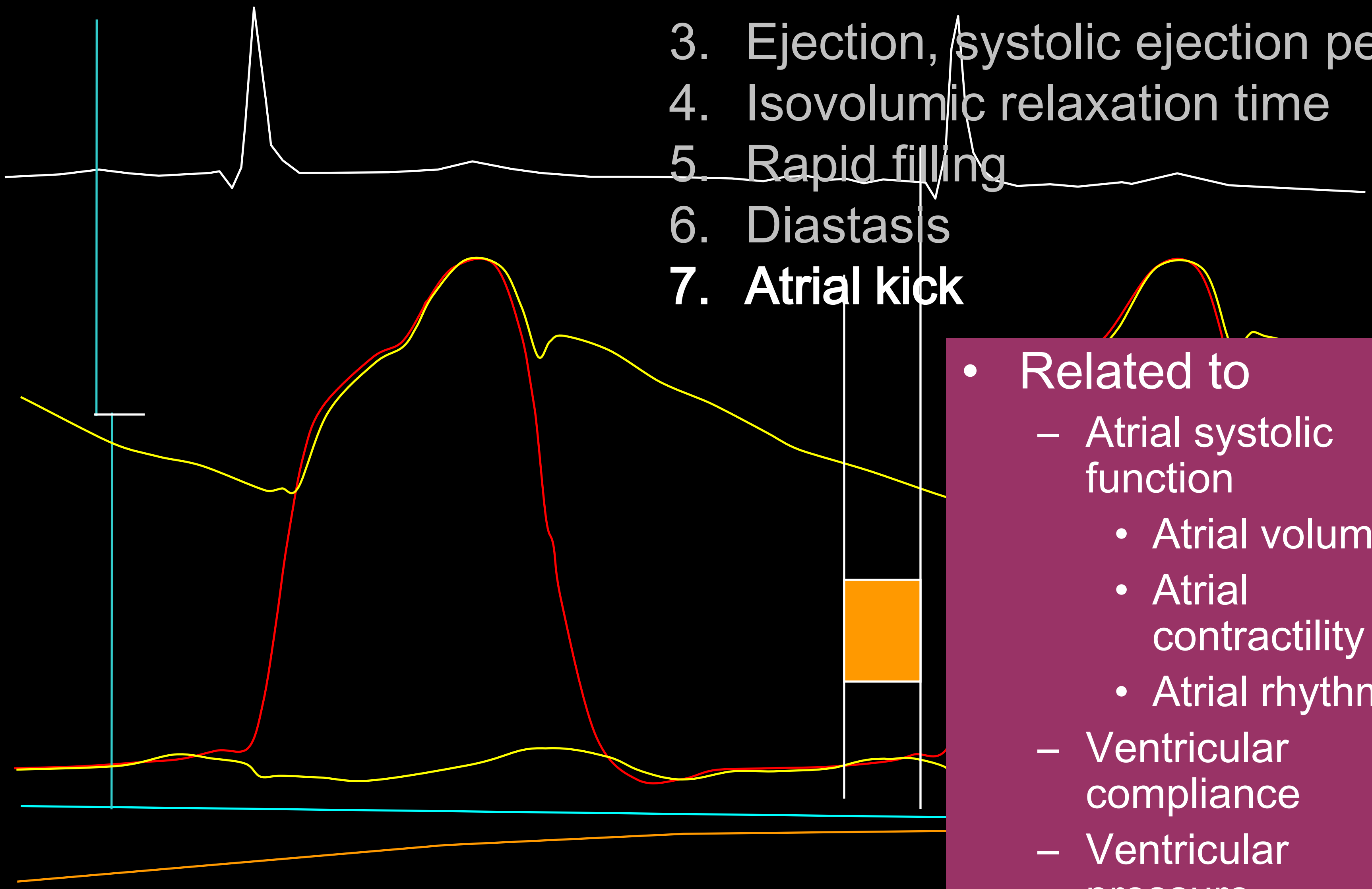
1. Electromechanical delay, Q-M1
2. Isovolumic contraction time
3. Ejection, systolic ejection period
4. Isovolumic relaxation time
5. Rapid filling
6. **Diastasis**



Begins with S3, ends with onset of atrial pressure rise, normal duration quite variable … Represents a form of "heart rate reserve"

The Cardiac Cycle

1. Electromechanical delay, Q-M1
2. Isovolumic contraction time
3. Ejection, systolic ejection period
4. Isovolumic relaxation time
5. Rapid filling
6. Diastasis
7. **Atrial kick**

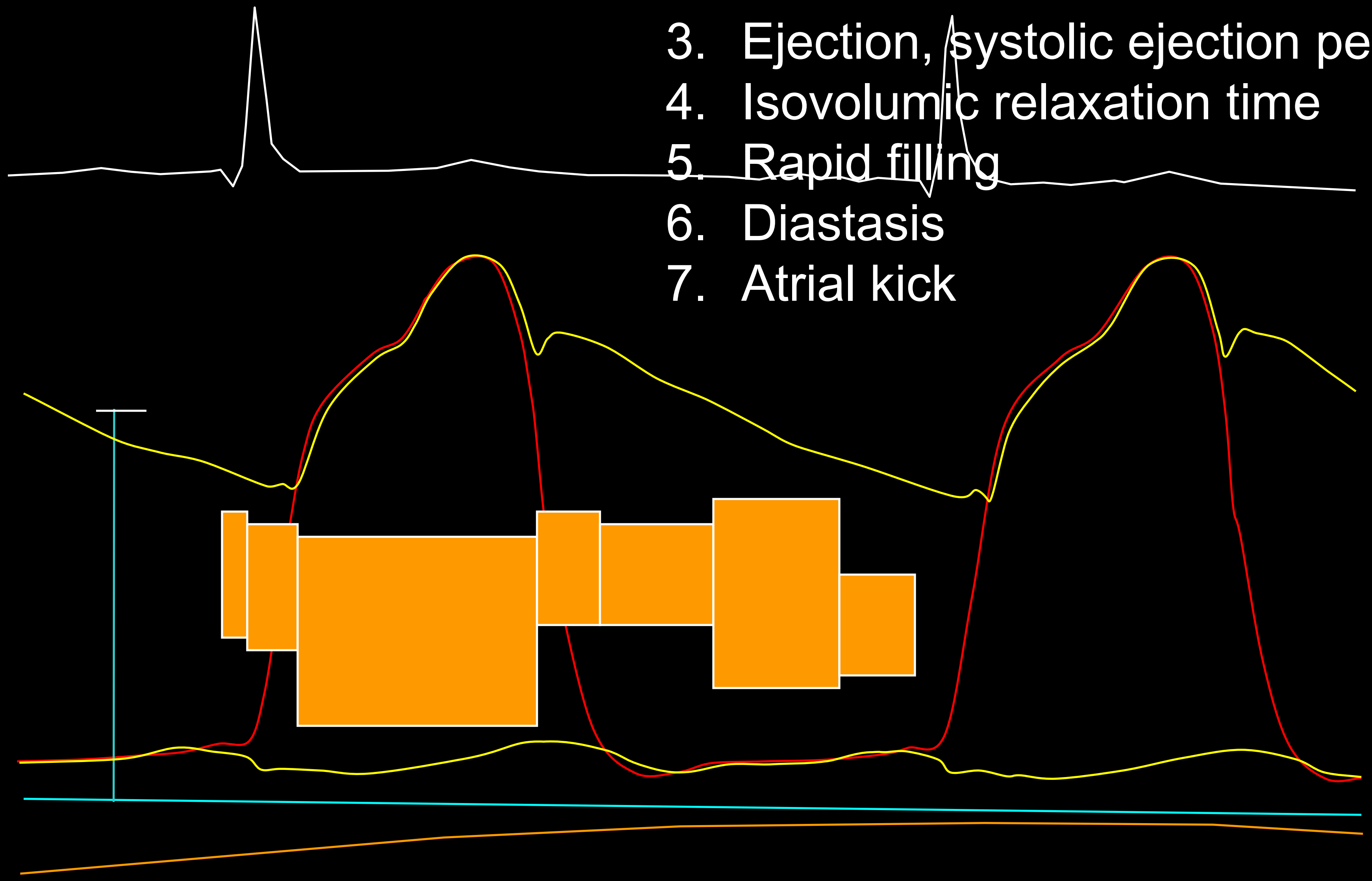


- Related to
  - Atrial systolic function
    - Atrial volume
    - Atrial contractility
    - Atrial rhythm
  - Ventricular compliance
  - Ventricular pressure

Begins with onset of pressure rise, ends with onset of QRS

The Cardiac Cycle

1. Electromechanical delay, Q-M1
2. Isovolumic contraction time
3. Ejection, systolic ejection period
4. Isovolumic relaxation time
5. Rapid filling
6. Diastasis
7. Atrial kick



The Cardiac Cycle and Auscultatory Events

- Right-sided events similar
- Hemodynamic effects on sounds

Assessing Pressure Tracings

1. Start with the ECG, note rhythm, rate and QRS width
2. Note the scales for pressure (note if there are 2 simultaneous pressures) and time (paper speed)
3. Identify the waveforms and obtain standard pressure measurements
4. Note respiratory effects
5. Reflect on the clinical significance of these
6. Observe the pressure waveforms for additional morphologic data and reflect on their clinical significance
7. Integrate all the information into the clinical context and reflect on patient management implications

Normal Values at BAMC

Location	Nml	Max	Resp Variation	
RA, a	9	?12	2	
RA, v	6	?12	2	
RA, X nadir	3-4			
RA mean	6	8	2	
LA, a	10	16		
LA, v	12		3-4	
LA mean	8	12		
RV systolic		27	35	2-3
RVED	5	7	1-2	
LV systolic	120	135	4-8	
LVED	10	12	3-4	
PA systolic		22	30	3-4
PA diastolic	12	15	3-4	
PA mean	15-17	18 (20)		4-5

Normal Hemodynamic Values

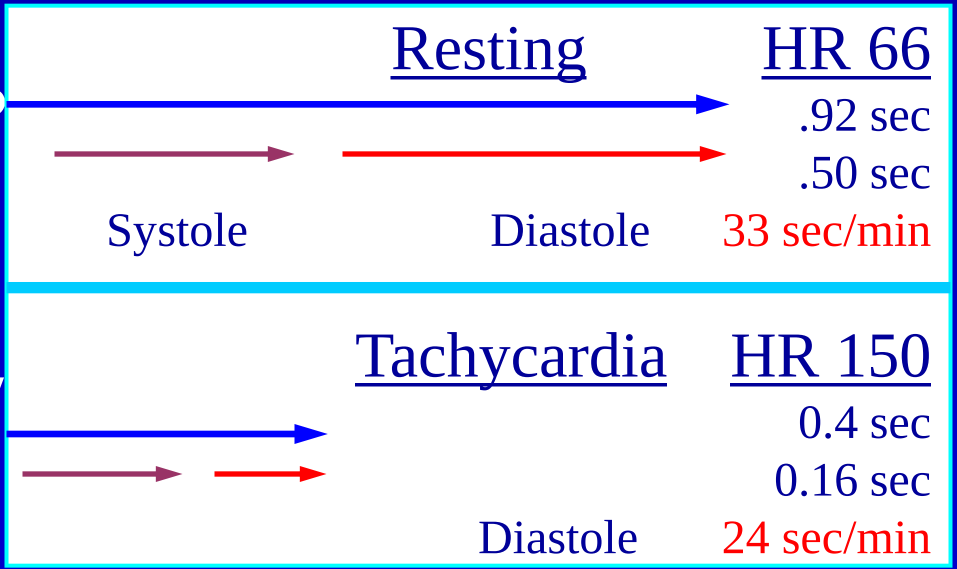
	Pressure	Saturation
RA mean	0-5	65-80
RV Systolic	10-25	
PA Systolic	10-25	
PA mean	5-15	
LA mean	0-10	95-100
LV systolic	85-150	
LV end-diastolic	0-10	
Ao systolic	85-150	
Ao diastolic	60-90	
Ao mean	70-100	

Criley and Ross, 1971

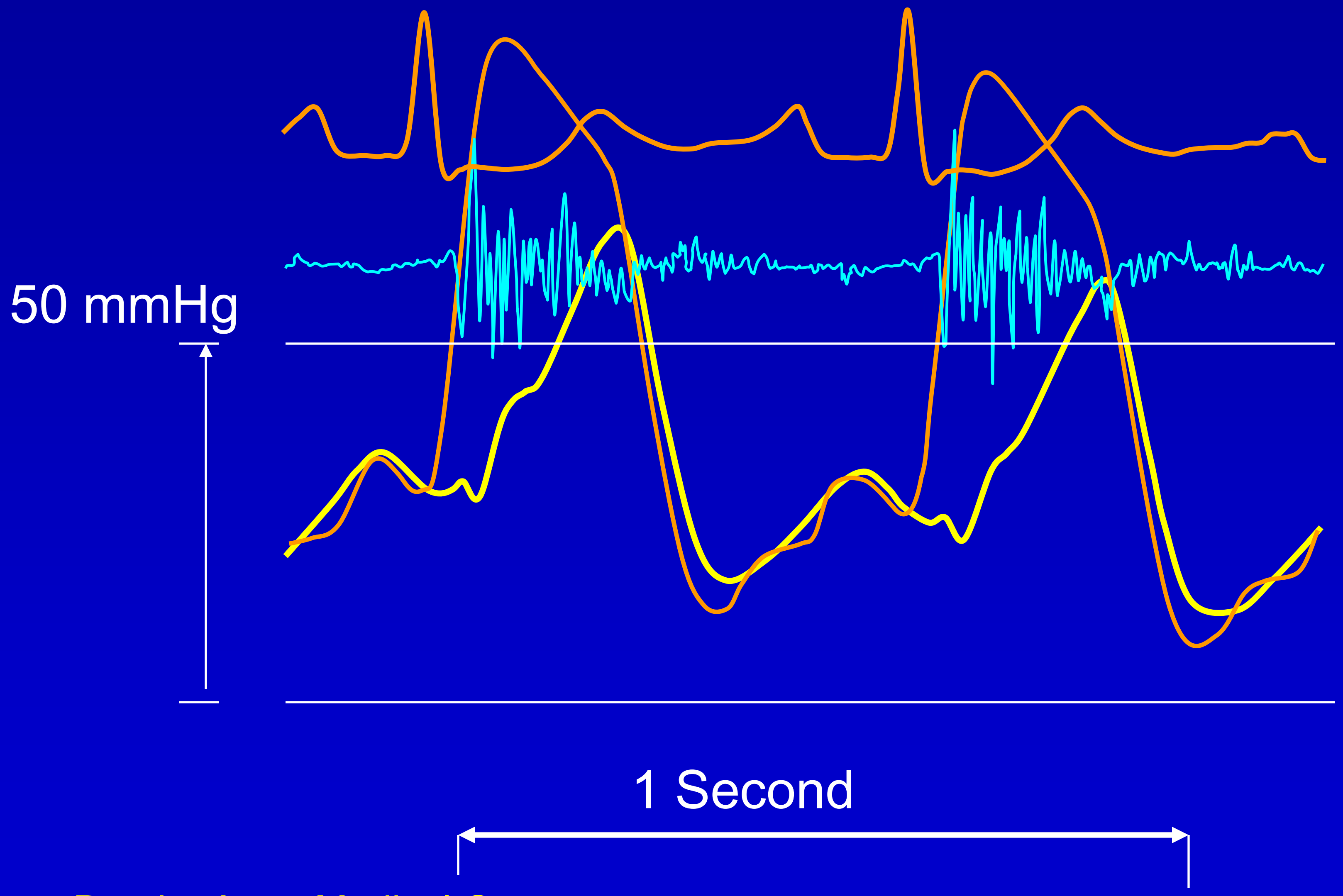
Causes of Myocardial Ischemia

- **Inadequate Supply**
  - Coronary
    - Obstruction
      - Spasm
      - Thrombosis
      - Steal
  - Severe diastolic ↓BP
  - Tachycardia
  - Cardiomegaly
  - Low capillary density
  - Anemia

- **Excessive Demand**
  - Tachycardia
  - Hypertension
  - Cardiomegaly
  - High contractility

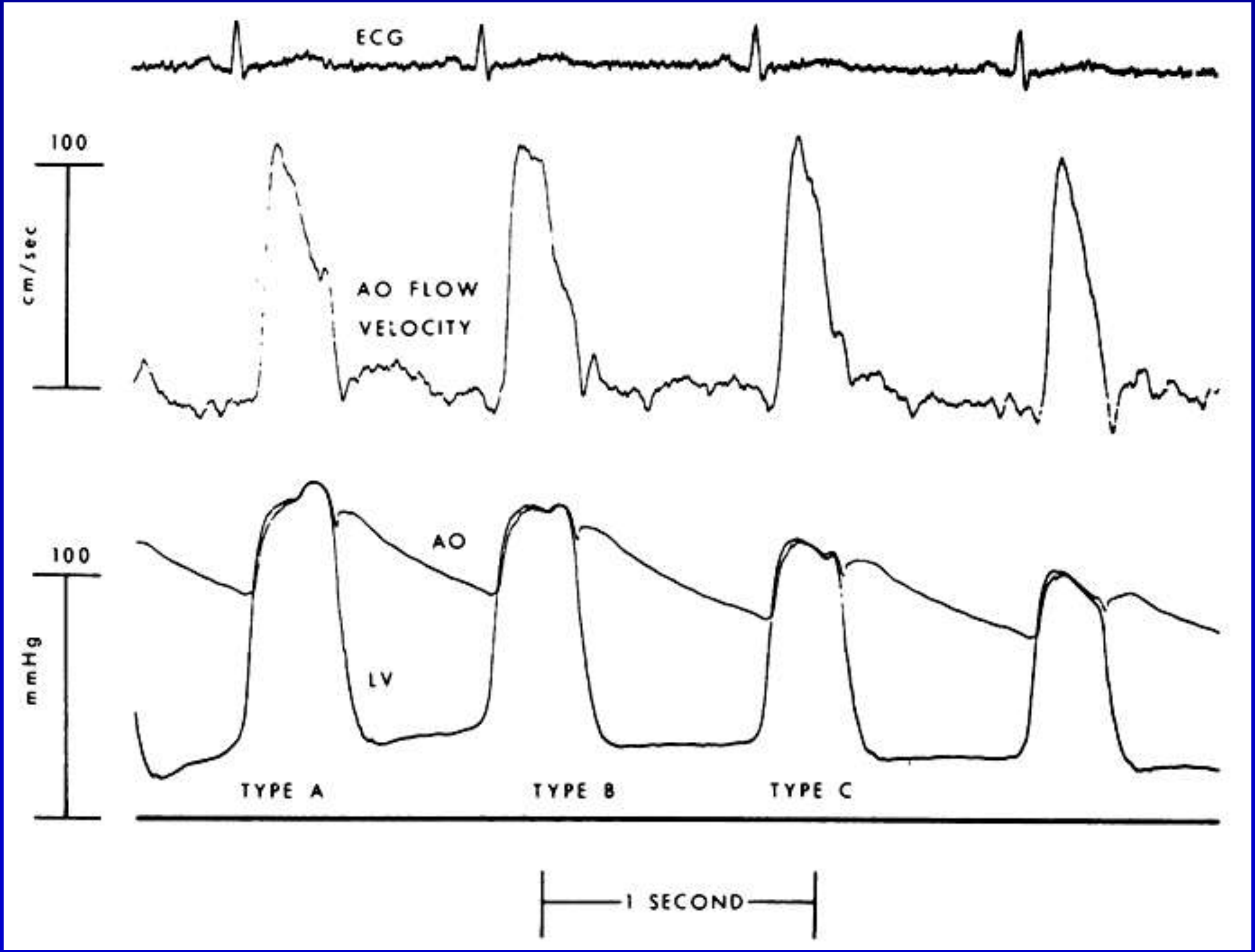


Heart Rate Effects on the Cardiac Cycle



From Brooke Army Medical Center

What is this?

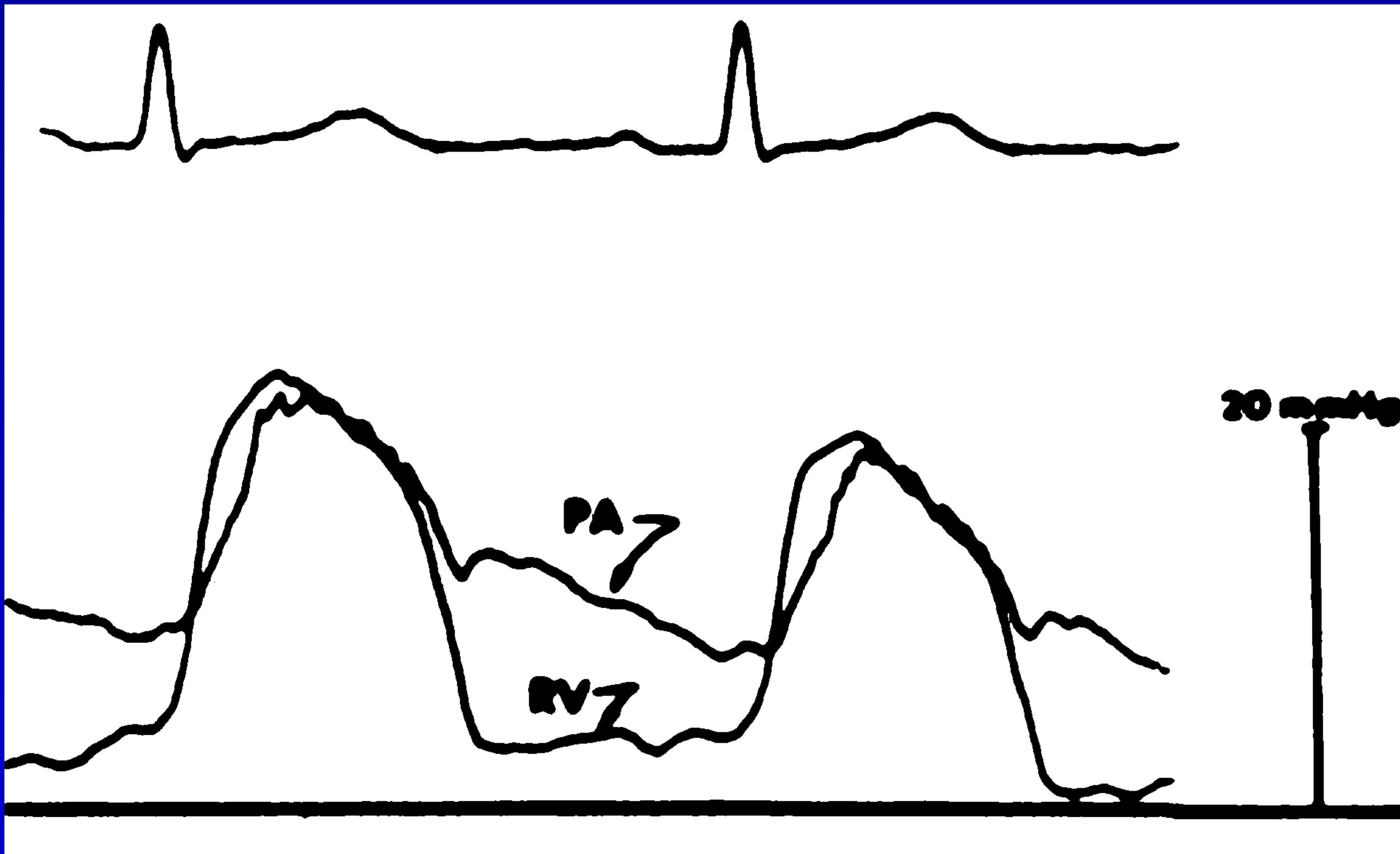


Grossman, 6ed p. 153 (Murgo)

What is this?

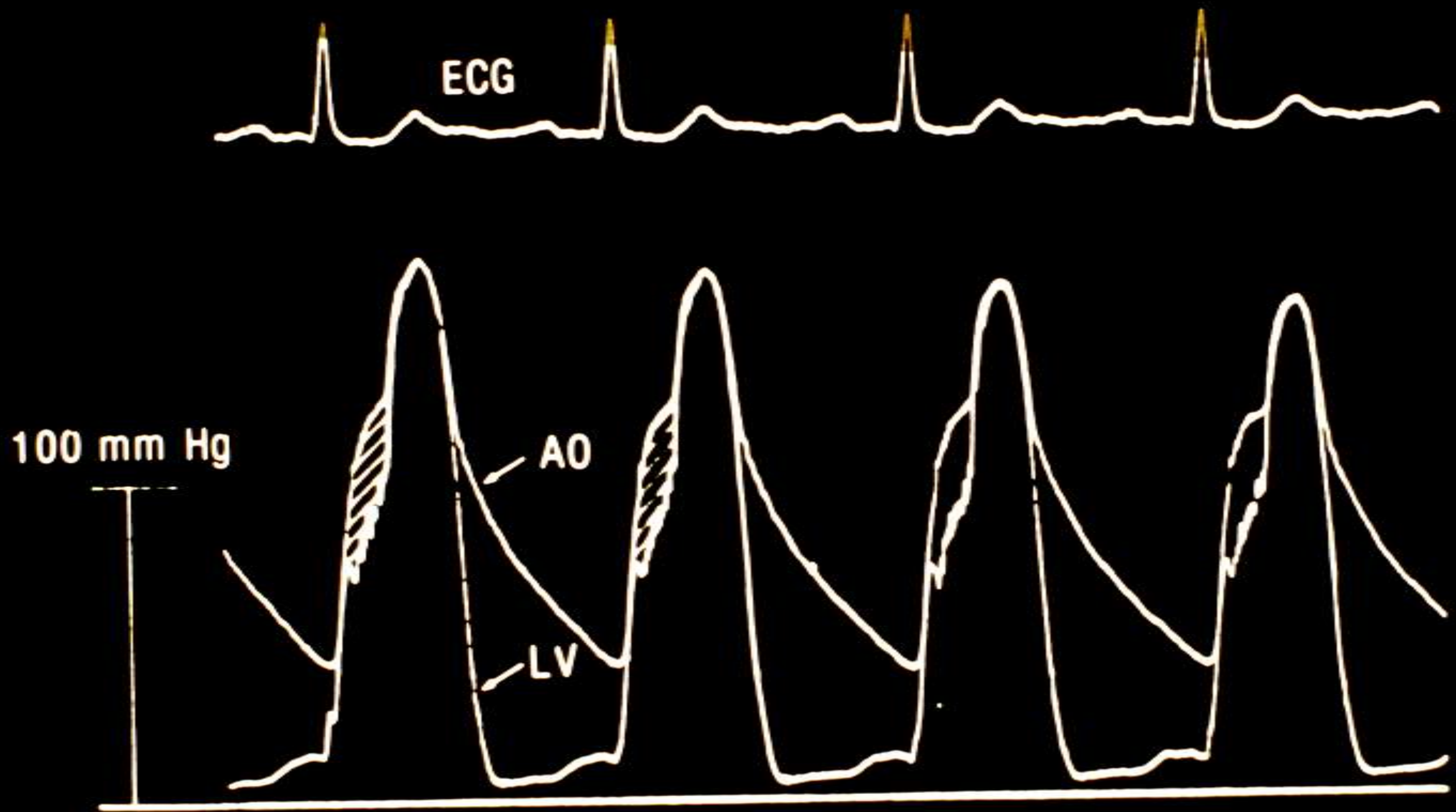
(Murgo)

What is this?

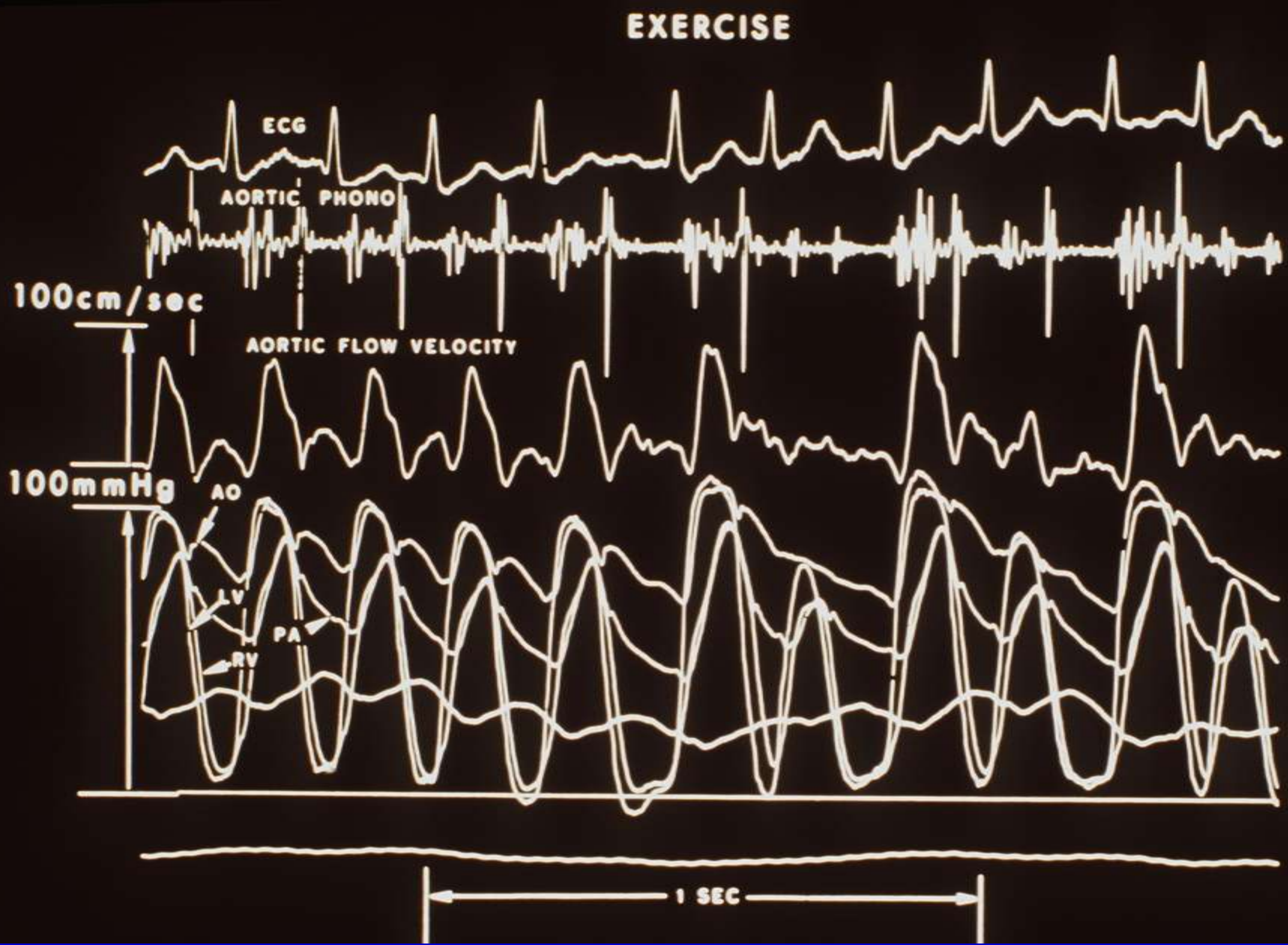


(Murgo)

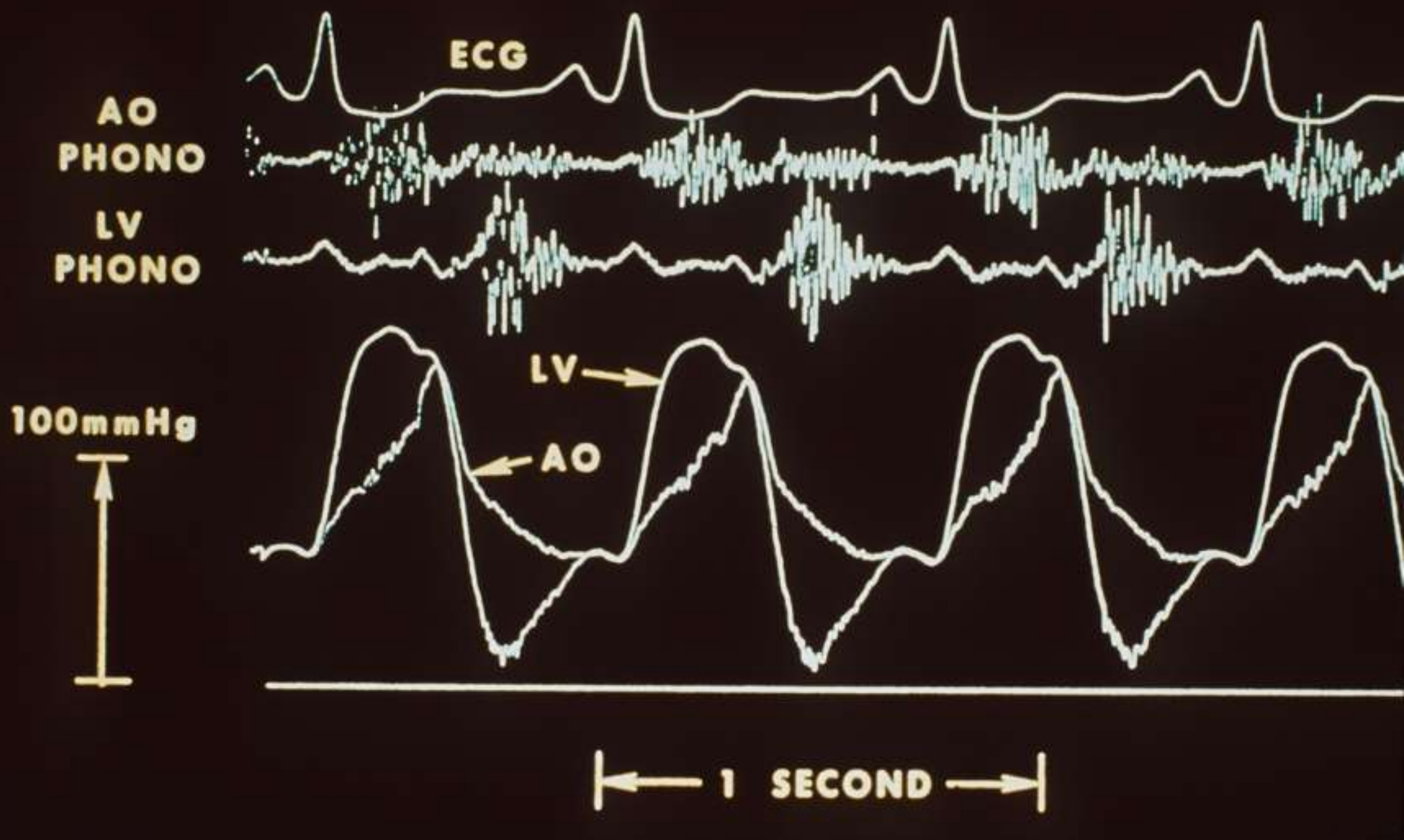
Diagnosis?



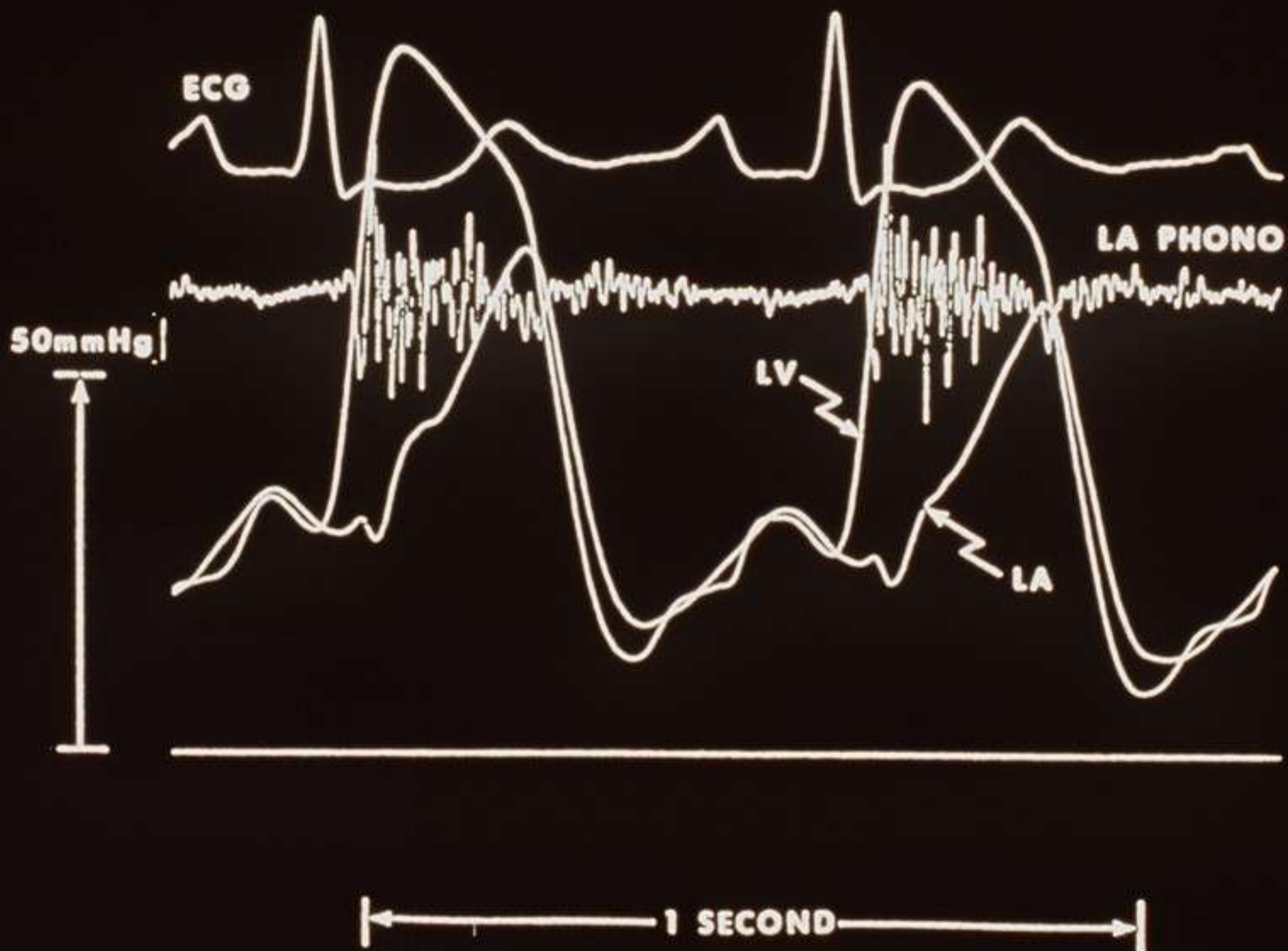
Unknown



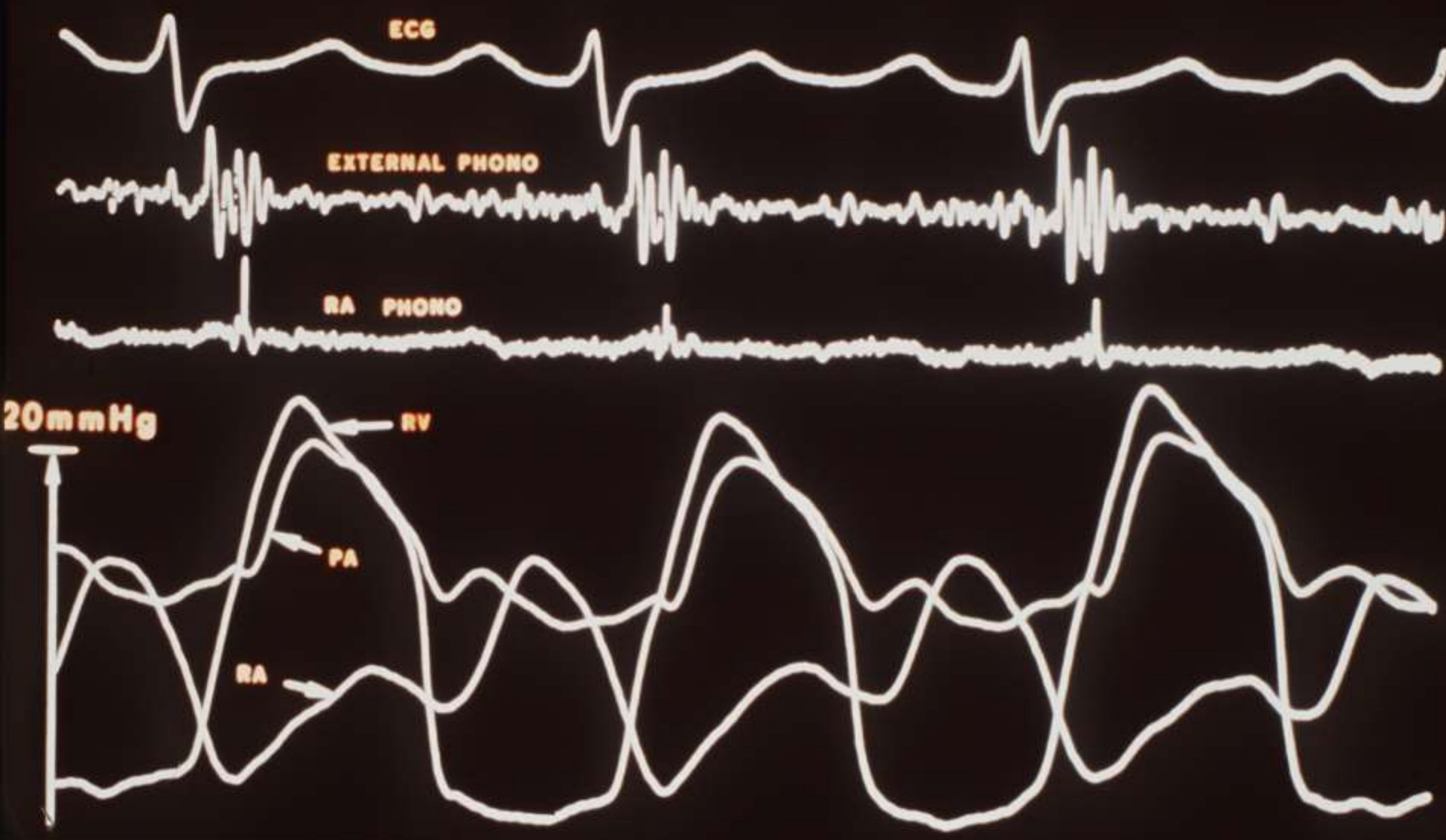
EXERCISE
ECG
AORTIC PHONO
100cm/sec
AORTIC FLOW VELOCITY
100mmHg
AO
LV
PA
RV
1 SEC

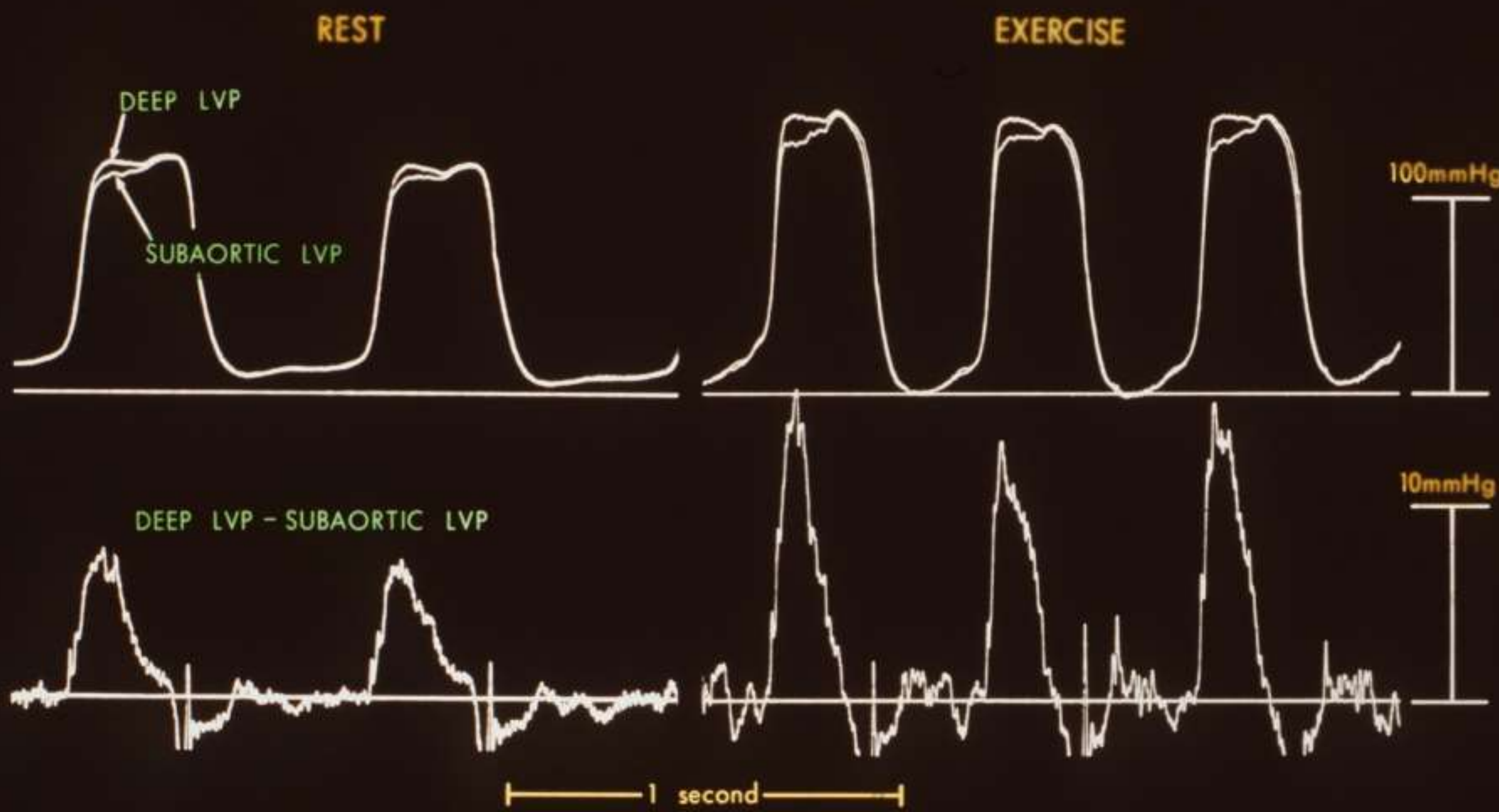

ECG
AO
PHONO
LV
PHONO
LV
AO
100mmHg
1 SECOND

Diagnosis?



Diagnosis?




REST
EXERCISE
DEEP LVP
SUBAORTIC LVP
100mmHg
DEEP LVP – SUBAORTIC LVP
10mmHg
1 second

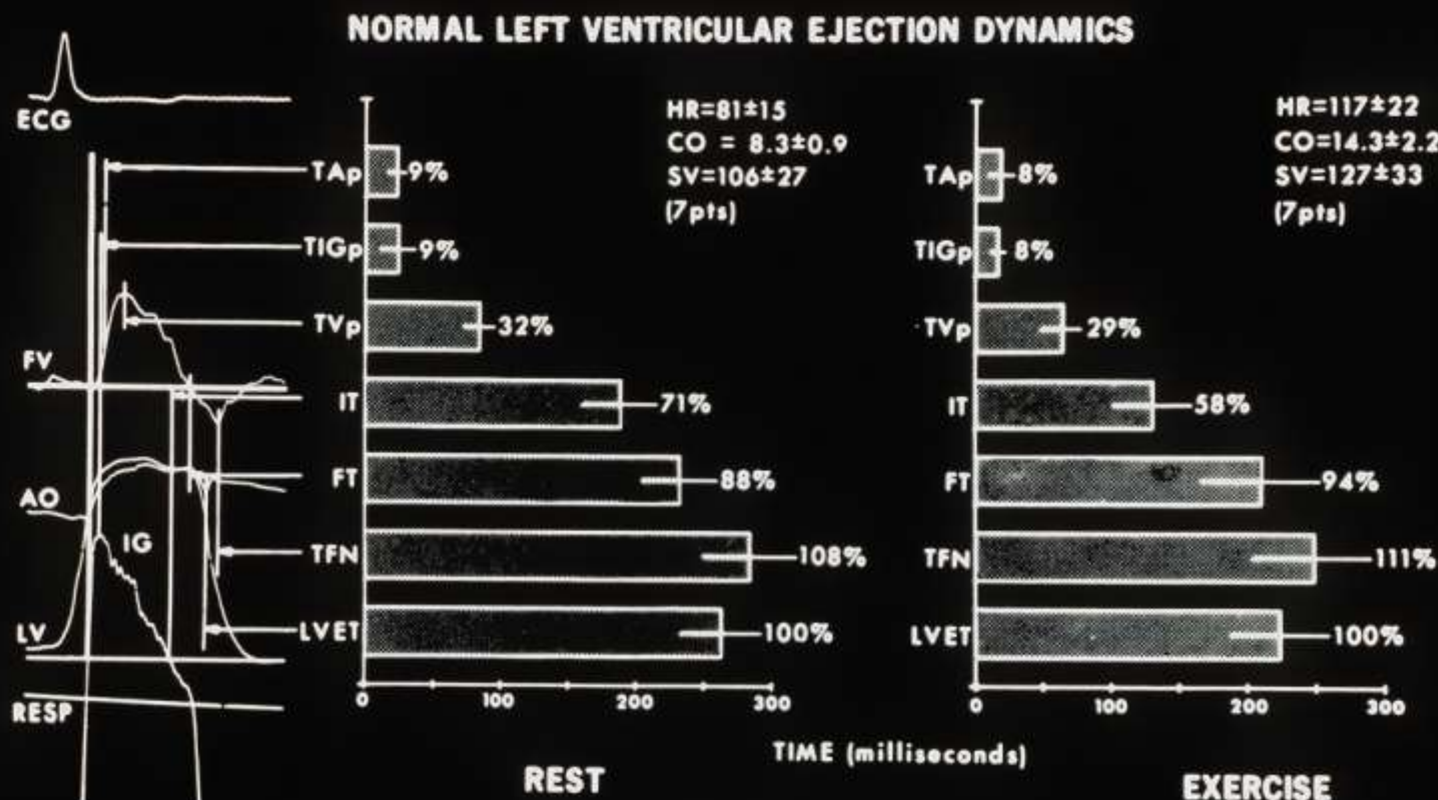
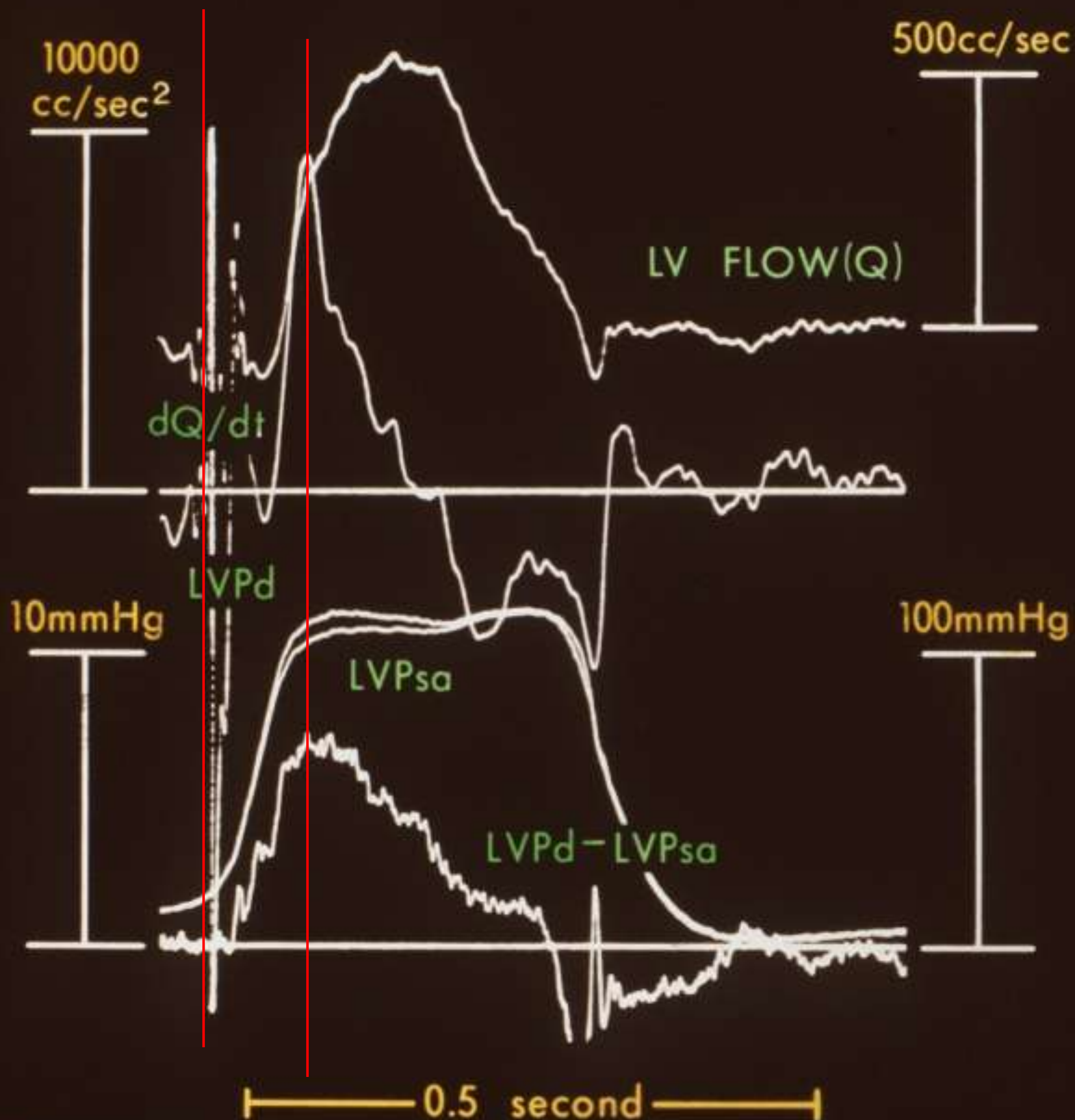


Figure 9

Systolic time intervals of pressure and flow velocity events during rest and exercise plotted against time and also expressed as a percent of left ventricular ejection time (LVET). Error lines represent ± one standard deviation. HR = heart rate (bpm); CO = cardiac output (L/min); SV = stroke volume (cc/beat); TA_p = time to peak acceleration; TIG_p = time to peak impulse gradient; TV_p = time to peak velocity; IT = impulse time; FT = positive flow time; TFN = time to negative flow notch. Other abbreviations as previously defined. See text for discussion.


10000
cc/sec²
500cc/sec
LV FLOW(Q)
dQ/dt
LVPd
10mmHg
100mmHg
LVPsa
LVPd − LVPsa
0.5 second