The Cardiac Cycle

Introduction

The cardiac cycle refers to a complete heartbeat from its generation to the beginning of the next beat, and so includes the diastole (relaxation), the systole(contraction) and the intervening pause. The frequency of the cardiac cycle is described by the heart rate, which is typically expressed as beats per minute. Each beat of the heart involves five major stages. The first two stages, often considered together as the "ventricular filling" stage, involve the movement of blood from the atria into the ventricles. The next three stages involve the movement of blood from the ventricles to the pulmonary artery (in the case of the right ventricle) and the aorta (in the case of the left ventricle).

Before you continue reading this sheet, I advise you to detach the last page {Wiggers Diagram} and **always** refer to it as you continue reading this sheet. It will make things easier to visualize and understand.

Now, the cardiac cycle (if you are looking at an ECG): it is the time between intervals: R-R Interval, P-P Interval… etc {any two consecutive points}.

During this cardiac cycle there are changes

1. **Mechanical changes** {Contraction (Systole) / Relaxation (Diastole)}.

2. **Electrical changes** {such as Action Potential or ECG}.

3. **Volume changes** {the volume of the ventricles concerns us more, we don't care about changes in the atrial volume.}.

4. **Sound Changes** {they are four heart sounds; we are concerned with only two of them}.

5. **Pressure changes**

So during one cardiac cycle we have one atrial systole, one atrial diastole. And we also have one ventricular systole, one ventricular diastole, and so on.

Remember that **volume** between the right and left ventricle is the **same.** But what **differs** is the **pressure** between them {left ventricle > right ventricle}.

For teaching purposes, we consider the heart rate to be 75 beats/min, and the time for one cardiac cycle is 0.8 seconds. Just to make things easier to understand and visualize. But practically, it could be anything else from (60-100) beats/min {in normal situations}.

What happens in the heart during One Cardiac Cycle?

1. Mechanical Changes

- The atrial systole takes 0.1 seconds. And the atrial diastole takes 0.7 seconds {the total is 0.8 seconds = the cardiac cycle}.

We have **AV delay**; so that the atria and ventricles do not contract at the same time. Therefore, atrial systole is followed by ventricular systole. In other words, once the atria finish there contraction, the ventricular contraction starts. The AV Delay takes 0.1 seconds.

- The ventricle systole takes 0.3 seconds. And the ventricular diastole takes 0.5 seconds {the total is 0.8 seconds = the cardiac cycle}.

Do not be confused to think that the ventricle diastole takes 0.4 seconds. This time (0.4 seconds) is the time where atrial and ventricular diastole overlaps {both ventricles and atria are in diastole}. While during the other 0.1 second, the atria are during systole (of the next cycle), and the ventricles are during diastole.

So the atria and ventricles work together, we consider this as mechanical changes that occur in heart.

Remember that mechanical changes are a consequence of electrical changes. This means that for mechanical changes to occur it should be preceded by electrical changes.

2. Electrical Changes

❖ ECG

Before atrial systole occurs we should record the **P Wave** in the ECG. And before ventricular systole occurs we should record the **QRS Complex** in the ECG. And before ventricular diastole occurs we should record the **T Wave** in the ECG.

❖ Action Potential

How many action potentials we have to record? The answer should be two; one for the atrium and one for ventricle.

The **first** {atrial} action potential corresponds to the **P wave** on the ECG (atrial depolarization). Whereas the **second** {ventricular} action potential includes **QRS complex** and the **T wave** together.

Now, by looking to the two action potentials; you should recognize that the atrial repolarization and the ventricular depolarization occur at the same time. Therefore, the atrial repolarization is not seen {masked}.

3. Volume & Sound Changes

As we mentioned earlier, we do not really care about the atrial volume; the ventricular volume is the important one. The blood volume of the right ventricle is equal to that of the left ventricle; the ventricles differ only in pressure (pressure in the left > right).

Before atrial contraction takes place, ventricular volume is 100 ml, for both the right and left ventricles.

Numbers are not to be memorized; they are only used for illustration.

Even before contraction of the atria, the AV valve is open because the atrial pressure is more than that of the ventricle (they open passively due to the pressure). This occurs at the beginning of ventricular diastole

How much is the atrial pressure?

The pressure in the atrium is almost **zero**. Accordingly, the ventricular pressure has to be less than zero (**negative**).

You may wonder how can we have negative pressure?! Our reference – when we say the pressure is zero – is the **atmospheric pressure {760 mmHg}**. So when the pressure is zero in the atrium, it means that the pressure is equal to the atmospheric pressure

The pressure in the ventricle is negative {-1 or -2}. This means that it less than the atmospheric pressure.

Atmospheric Pressure - 2 = 760-2 = 758mmHg.

When we say someone's blood pressure is 120/80; it means that it is greater than atmospheric pressure by this value. Which is equivalent to (120+760)/(80+760) = 880/840.

So to make things easier we consider **zero** is the pressure of the atrium. If you don't like dealing with negative numbers, you can consider the ventricular pressure to be 0; so the atrial pressure is +1 or +2.

During this period, the AV valve opens and blood goes from the atrium to the ventricle straight away. This is followed by atrial contraction, pushing a certain extra amount {25ml} of blood to the ventricles **faster**. Now the blood volume becomes 125 ml at the end of diastole of the ventricles. This is what we call the **end diastolic volume {EDV}.**

By how much does the atrial contraction contribute to this volume? 25%

But even if the atria don't contract {as in atrial fibrillation}; blood would also flow to the ventricles because the AV valves are open. But it will move with **fewer amounts** and **less speed** in this case (the volume in the ventricle would **increase** by **10 ml** only). This results in less contribution.

Q) Does that mean that we can live normally with only 75% efficiency? Yes

Since the atrial systole does not contribute that much to the **end diastolic volume {EDV}**, then its contraction is not essential for normal function of the heart. However, sometime we need this atrial contraction when the **heart rate is faster** than normal; because there is **no time for filling** during ventricular diastole.

Ventricular Systole

The ventricle is guarded by two valves: the **AV valve** and the **Semilunar** valve. The semilunar valve on the left separates the aorta from left ventricle {aortic valve}, whereas the semilunar valve on the right separates the pulmonary trunk from right ventricle {pulmonary valve}.

The aortic pressure during diastole is 80 mmHg, and the pulmonary pressure during diastole is 8 mmHg.

When the ventricle starts to contract, its pressure is going to increase above zero {that of the atrium}. Therefore, the blood tries to move from the ventricles back to the atria: The **AV Valve closes**. Why? This happens because the pressure will gradually build up in the ventricles, exceeding that of the atria. Thus, the blood tries to move from the ventricles to the atria; the AV valves will shut.

This creates a **sound**. And this sound is called **LUBB** {the first heart sound because of closure of AV valve). This corresponds to the **QRS complex** on the ECG.

During this stage, the four valves of the heart {two AV & two semilunar} are closed. And the volume in the ventricle does not change. Therefore; we call this phase **Isovolumic Contraction**.

Isovolumic Contraction: is a short phase in which ventricular volume is constant and the four valves are closed. By the end of this phase the pressure increases very rapidly, and when it reaches higher than 80 mmHg {in left ventricle} causing the semilunar valve to open.

This leads to the first **rapid ejection** (about 70%), then the **slow ejection** (about 30%). Until the end of systole, the volume of blood that stays in the ventricle called the **end systolic volume {ESV}.** It is equal to **55 ml**.

The fraction of the EDV that is ejected called **ejection fraction** usually equal to about 60%.

The amount of blood ejected in each beat (cardiac cycle) from either right or left ventricle is called the **stroke volume**. And here it equals {125 – 55 = 70 ml/beat}.

Stroke volume = end diastolic volume {EDV} – end systolic volume {ESV}

If we want the stroke volume in one minute we multiply it by the heart rate (in this case its 75 beats/min); this is what we call the cardiac output:

Cardiac Output (ml/minute) = Stroke Volume X Heart Rate

During systole the pressure {in the left ventricle} is very high, its value is higher than the aortic pressure which makes the blood flow from the ventricle to the aorta, and then to the systemic circulation.

When blood flows, its pressure will become less and less until it becomes less than **80 mmHg** in case of left ventricle (in right ventricle it gets less than 8 mmHg). So the blood tries to move from the aorta back to the left ventricle; closing the semilunar {aortic} valve. The AV valves are still closed, and this is the **diastolic** phase where the 4 valves are closed; which is called **Isovolumic Relaxation**.

Usually **Isovolumic Relaxation** takes longer time than **Isovolumic Contraction**

The closure of semilunar valve will cause the 2nd heart sound {**DUP**}

During ventricular systole, the AV valves are closed. Therefore, there is a filling of blood inside the atria. **Deoxygenated** blood in the **right** atrium & **oxygenated** blood in the **left** atrium.

Diastasis: is slow filling of ventricle before atria contract.[1] (Refer to the figure in the last page)

The pressure in the **Isovolumic Relaxation** phase keeps decreasing until it becomes lower than the atrial pressure; causing the AV valve to open. **Rapid** filling occurs, then **slow** filling.

Before the atrial systole, the blood volume in the ventricle rises up to 100 ml {passively by pressure gradient}. When the atria contract, another 25 ml are added. Total = 125 ml = **end diastolic volume {EDV}**.

So we have:

Rapid Filling in Ventricular Diastole & Rapid Ejection in Ventricular Systole

To sum things up:

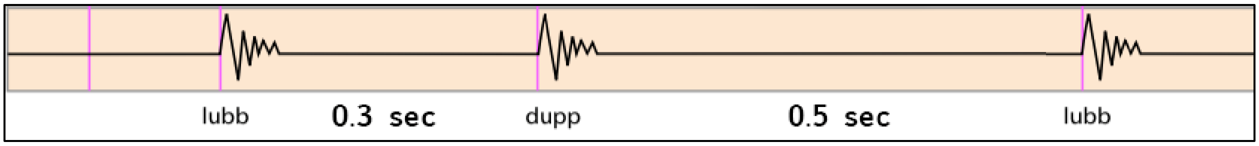
- Closure of AV valve gives us the **first** heart sound: **LUBB** {occurs at the beginning of the ventricular systole}.
- Closure of Semilunar valve gives us the **second** heart sound: **DUPP** {occurs slightly after the end of ventricular systole}, or at beginning of its diastole.

What is the time between the 1st and 2nd heart sounds?

≈ **0.3 sec** {approximately the same time of ventricle systole}

Whereas the time between the second heart sound {**DUPP**} and the **next** first heart sound {**LUBB**} is about **0.5 sec** {the total is 0.8 seconds = the cardiac cycle}.

[1] Diastasis is the middle stage of diastole during the cycle of a heartbeat, where the initial passive filling of the heart's ventricles has slowed down, but before the atria contract to complete the active filling.



There are sounds due to the movement of blood around a closed valve {it sounds like murmur}. We may also hear other sounds. The third heart sound is heard when there is rapid filling of blood from atria into the ventricles {opening of the AV valve}. Also atrial contraction gives us the 4th heart sound. But usually, we hear only hear the **two** previously mentioned heart sounds.

Pathological conditions:

If a patient has MI {Myocardial Infarction}, and there is a damage to the papillary muscle. So the chordae tendineae cannot pull the valve down. What will happen?

Blood will go from the ventricle into the atria. It is what we call: **Prolapse Valve** or **Valve Incompetence**.

In this case, the blood is regurgitating and when blood regurgitate it will give a sound. So we first hear **LUBB** and then a sound of murmur before we finally hear the **DUPP**. This is systolic {ventricle contraction} murmur; diagnosed as **AV valve incompetence.**

Whereas if we hear the murmur between the DUPP and the second (next) LUBB, it due to of **Semilunar incompetence.**

In children, there might be separation of the 2nd heart sounds {the aortic and pulmonary semilunar valves don't close at the same time} so we hear LUBB, DUPP DUPP.

The Phonocardiograph will record the heart sounds

We already know that (in normal conditions) the stroke volume is the same for both ventricles. However, if the stroke volume of right ventricle is 70 ml, whereas the stroke volume of the left ventricle is 69 ml, the difference is 1 ml per beat. In one minute: 70 ml {if we consider the heart rate to be 70 beats/min}.

Therefore in one min 70 ml will accumulate in the left ventricle, and after one hour the volume will be 4200 ml (multiply by 60).

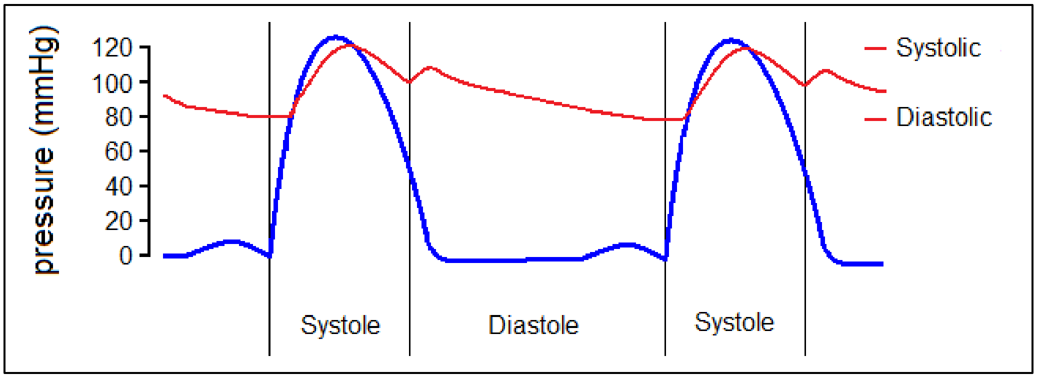
This extra volume will regurgitate back to left atrium and eventually back to the lungs; which is abnormal and incompatible with life.

Normally, there might be difference in one beat or another but the next time it will compensate.

4. The pressure changes

We will talk about the change of pressure in the left ventricle

- Pressure in the left ventricle is different from that of the right ventricle.
- If the pressure in left ventricle before atrial systole {during diastole} is zero; the pressure in atria will be +1 or +2.
- When the atria contact the pressure will increase, and it may reach up to +5 mmHg.
- This is followed by ventricle contraction, the AV valve will close {1st heart sound) **LUBB**. The Isovolumetric Contraction phase starts {both AV valve and aortic Semilunar valves are closed}.
- Now there will be sharp increase in pressure until it reaches the aortic pressure {80 mmHg}; once it exceeds it, the aortic valve will open, and *it keeps rising to be higher than the aortic pressure.*
- Why the ventricular pressure must be higher than the aortic pressure?? There must be a pressure gradient that maintain the flowing of blood from the ventricles to the aorta.



At the <u>end of the ventricular systole(last 1/3)</u>, the <u>aortic pressure</u> will be <u>higher</u> than the ventricular pressure, **although the blood is still moving from the ventricle to the aorta**; this happens because of the blood's momentum. Momentum is a force and the pressure is a force (force per unit of area)

When the force of the aortic pressure overwhelms the force of the blood's momentum, it closes the aortic semilunar valve, starting the **Isovolumic Relaxation** phase {both valve aortic semilunar and the AV (mitral/bicuspid) valve are closed}

The maximum pressure in the ventricle during systole is 120mmHg, while the aortic maximum pressure will be slightly less than this, approximately 118 mmHg when the pressure starts to decrease after the first decrease the Semilunar valves close , and after the second decrease the AV open First SV close then AV open) when the pressure decreases the blood tries to return back from the Aorta to the ventricle.
When the aorta pushes blood to the closing semilunar valve, the blood is compressed and press on the wall of the aorta and the <u>aortic pressure slightly</u> rises, and makes a peak: called <u>**Dicrotic Notch** or **Incisura**</u>.

So the Dicrotic notch is due to the increase in pressure around a closed semilunar valve>>> Why ? Because of the momentum of the blood.

Location	Minimum Pressure mmHg	Maximum Pressure mmHg
Left Ventricle	0	120
Aorta	80	120
Right Ventricle	0	25
Pulmonary Trunk	8	25

What does it mean when we say someone blood pressure is 110/70?

We mean that during the *left ventricular systole the aortic pressure and ventricular pressure reaches a* ***maximum*** *of* ***110 mmHg***. Whereas *during left ventricular diastole the aortic pressure reaches a* ***minimum*** *of* ***70 mmHg****.*

The Waves of Atria

First rise in pressure in atria occurs during atrial systole which causes a wave called atrial pressure wave: **A wave.**

After atrial systole, the ventricle systole begins. And when the ventricle contracts, blood tries to regurgitate towards the atria; causing the AV valve to close {because of high pressure in ventricle}. This also increases the pressure inside the atrium {because of the force of blood on its wall}. This causes another waves called: **C wave**

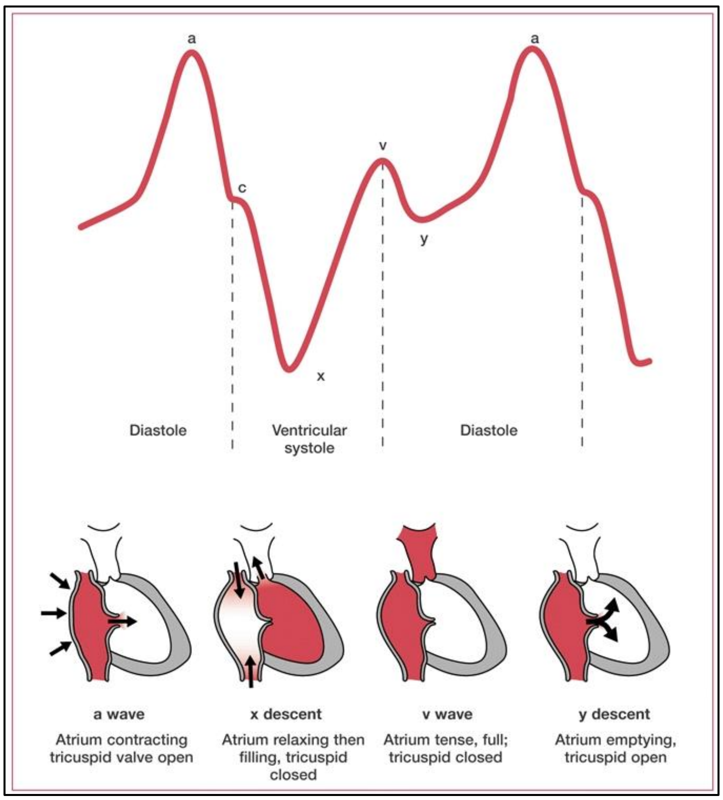
After that the pressure inside the atria start to develop due to venous filling {The AV valve is closed during this phase} until it reaches a maximum just before the ventricular diastole **{V wave}**. This occurs just before the AV valve opens due to the drop in ventricular pressure, and the rapid filling occurs.

YOU SHOULD REMEMBER EACH WAVE HAPPENS AT THE SAME TIME WITH WHICH WAVE

Q) A wave happens concurrently with P wave of the ECG

Q)Zero wave of atrial Action potential happens at the same time with ……..

Q)the first heart sound happens concurrently with QRS



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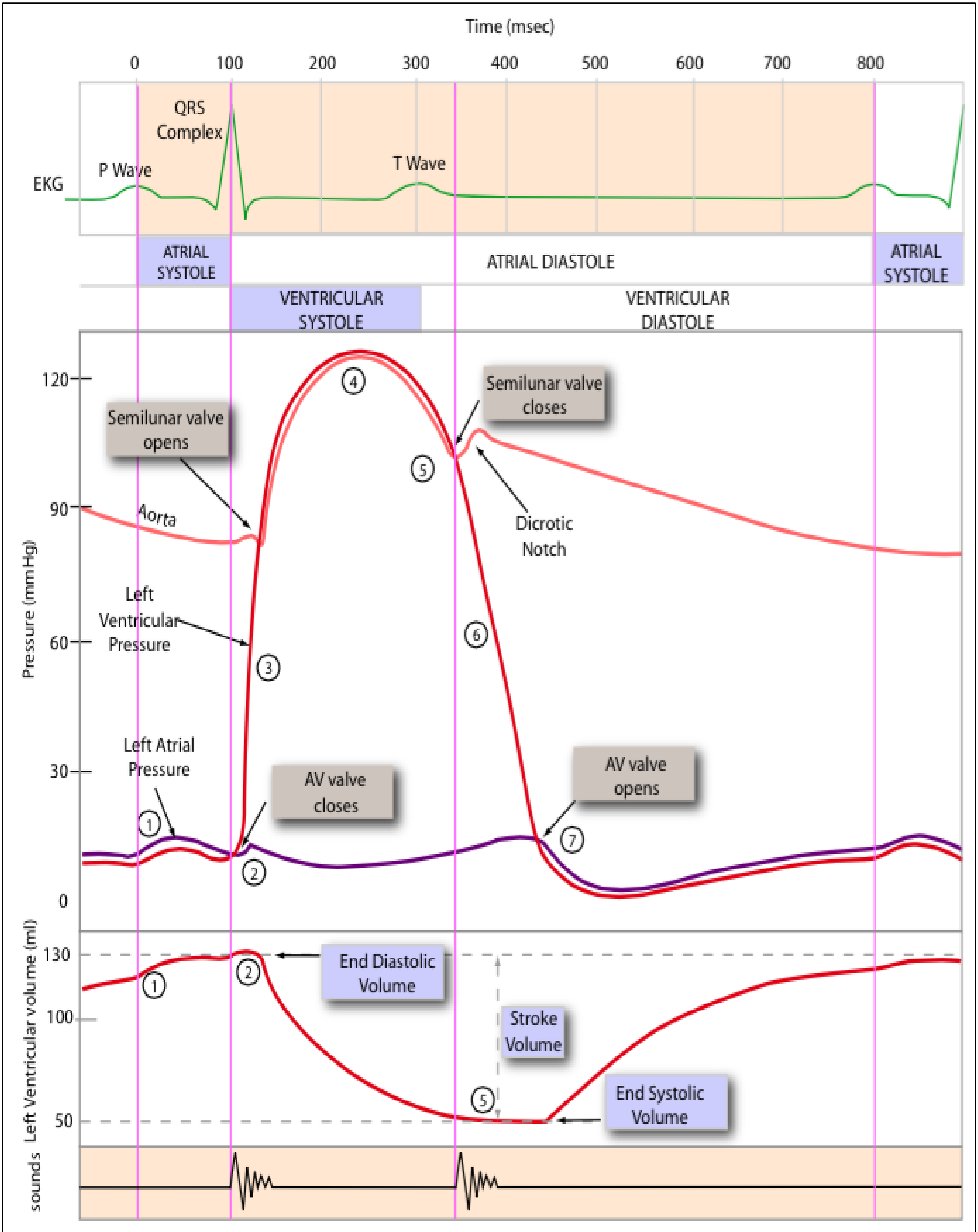
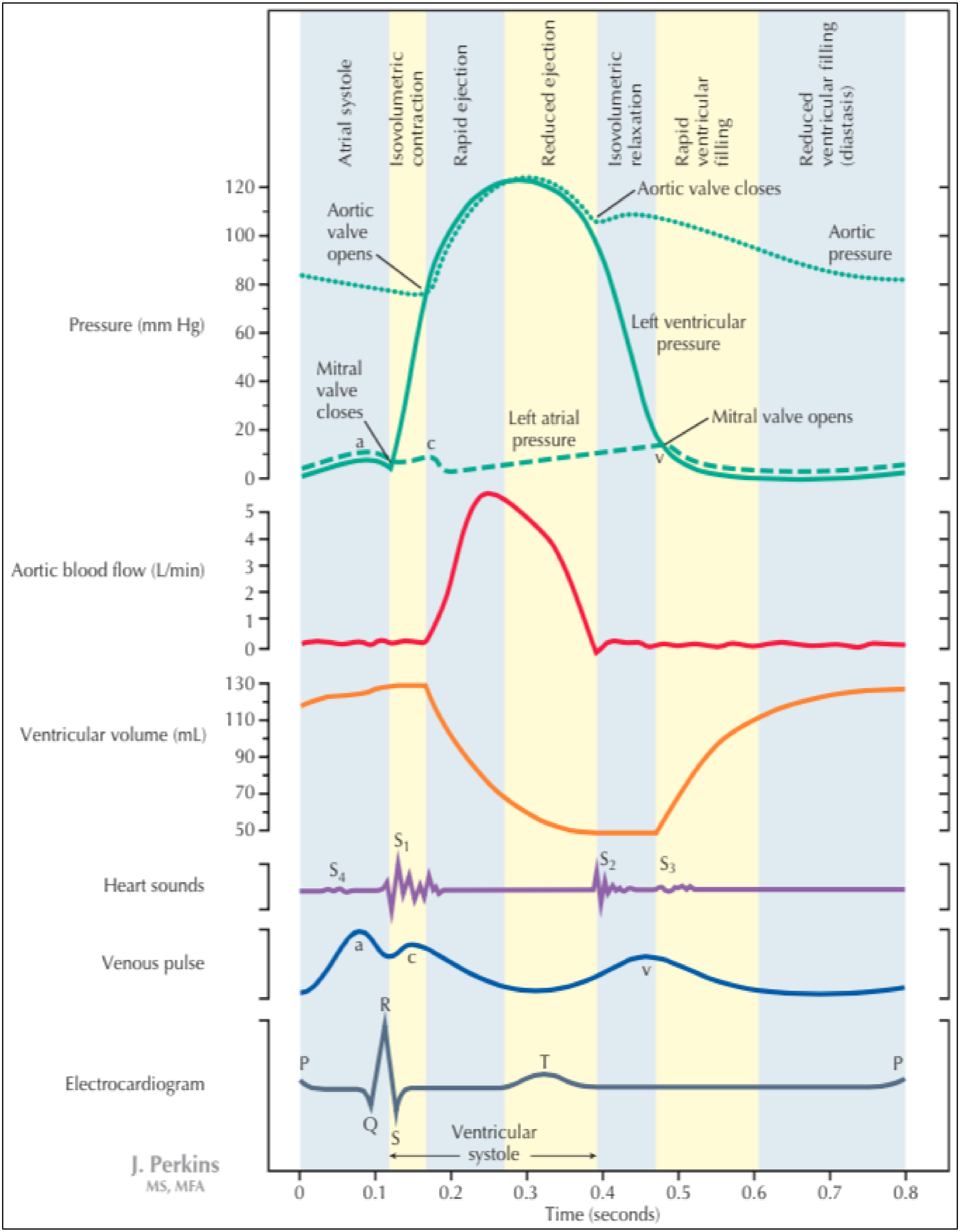

Time (msec)
0
100
200
300
400
500
600
700
800
EKG
P Wave
QRS Complex
T Wave
ATRIAL SYSTOLE
ATRIAL DIASTOLE
ATRIAL SYSTOLE
VENTRICULAR SYSTOLE
VENTRICULAR DIASTOLE
Pressure (mmHg)
120
90
60
30
0
Semilunar valve opens
Semilunar valve closes
Aorta
Dicrotic Notch
Left Ventricular Pressure
Left Atrial Pressure
AV valve closes
AV valve opens
1
2
3
4
5
6
7
Left Ventricular volume (ml)
130
100
50
End Diastolic Volume
Stroke Volume
End Systolic Volume
sounds



Atrial systole
Isovolumetric contraction
Rapid ejection
Reduced ejection
Isovolumetric relaxation
Rapid ventricular filling
Reduced ventricular filling (diastasis)
Pressure (mm Hg)
120
100
80
60
40
20
0
Aortic valve opens
Aortic valve closes
Aortic pressure
Left ventricular pressure
Mitral valve closes
Mitral valve opens
Left atrial pressure
a
c
v
Aortic blood flow (L/min)
5
4
3
2
1
0
Ventricular volume (mL)
130
110
90
70
50
Heart sounds
S_4
S_1
S_2
S_3
Venous pulse
a
c
v
Electrocardiogram
P
R
Q
S
T
P
Ventricular systole
J. Perkins
MS, MFA
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Time (seconds)