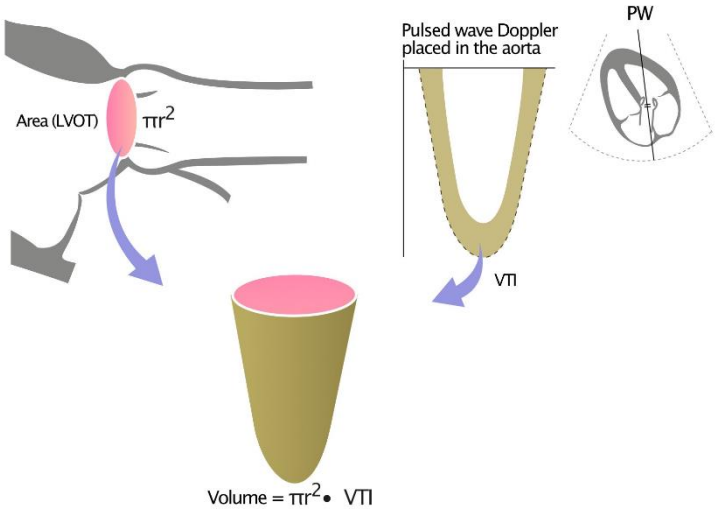
Left Ventricular Systolic Function

Assessing left ventricular systolic function

- Patients with Systolic Heart Failure also known as "Heart Failure with Reduced Ejection Fraction (HFrEF)" will commonly present with shortness of breath, orthopnea, paroxysmal nocturnal dyspnea (PND), exercise intolerance, irregular heartbeats, and edema in the bilateral upper and lower extremities. This is usually accompanied by cardiogenic pulmonary edema and B-lines on ultrasound.
- One of the most commonly used surrogates in assessing systolic function in these patients is done by measuring the **Left Ventricular Ejection Fraction (LVEF)**.
- It is a reliable way to assess left ventricular systolic function in patients ranging from symptoms of chest pain, shortness of breath, myocarditis, to the hypotensive crashing patient.

Stroke volume (SV): Stroke volume is the volume of blood pumped from the left ventricle into the aorta during systole.

It is easily calculated by measuring VTI (Velocity Time Integral), using pulsed wave Doppler, in the aortic valve. The stroke volume is the product of VTI and area of the LVOT



Left Ventricular Ejection Fraction (LVEF): Ejection Fraction (EF) is a percentage of blood pumped by the LV with each contraction. Many factors can affect ejection

fraction including preload, afterload, and contractility. A normal EF ranges from 55-69%, and is calculated using the following equation:

Ejection fraction (EF) in percentage is defined as: EF (%) = SV/EDV x 100

Ejection fraction (EF) is basically a percentage, of how much blood the left ventricle pumps out with each contraction. For example, an ejection fraction of 60 percent means that 60 percent of the total amount of blood in the left ventricle is pushed out during each systolic contraction

	Hyperdynamic	**Normal**	**Mildly Reduced**	**Moderately Reduced**	**Severely Reduced**
Ejection Fraction	≥70%	55-69%	45-54%	30-44%	<30%

Qualitative Approach to Assessing Ejection Fraction:

Ejection fraction can be estimated visually. This means that the ejection fraction is estimated by means of eyeballing the two-dimensional video clips. This method is obviously subjective and requires a substantial amount of experience. However, studies indicate that eyeballed ejection fraction correlates well with quantitative assessments of ejection fraction.

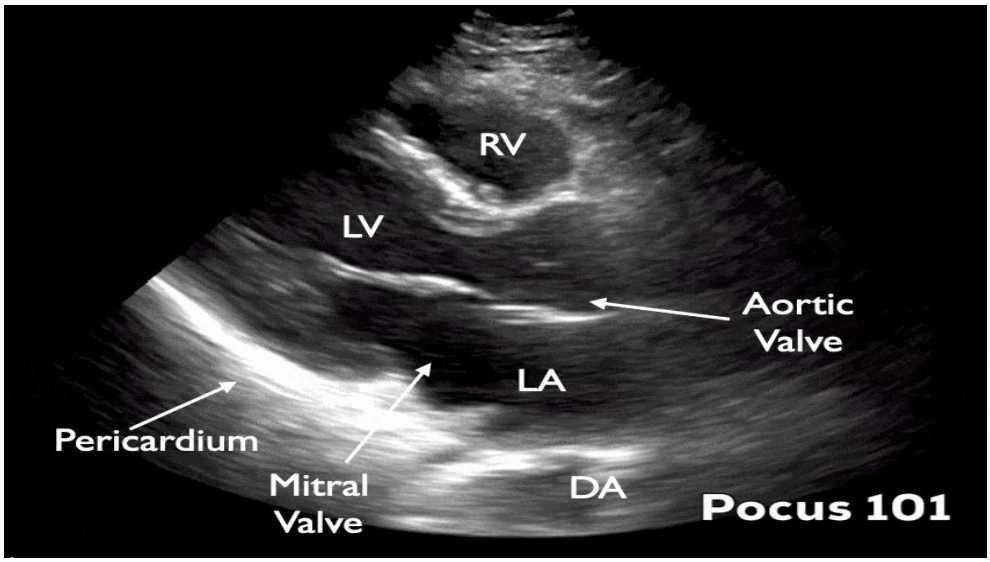
Qualitatively assessing left ventricular ejection fraction allows for rapid assessment of systolic function. Especially when time does not lend itself to time-consuming tracings and calculations. To assess LVEF qualitatively, make observations about both the LV muscle and mitral valve movement.

The most common views to assess for left ventricular ejection fraction are the parasternal long axis, parasternal short axis (mid-papillary level), and apical 4 chamber view.

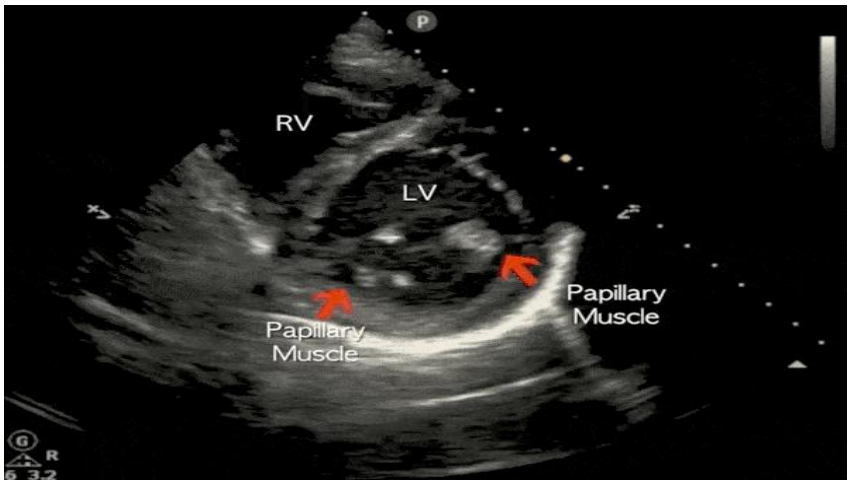
Here are the two most practical things to assess when looking at LVEF Qualitatively:

1. Look at how well the left ventricle walls are moving. Are the LV walls coming close to each other during systole?
2. Look at how well the anterior mitral valve leaflet is moving. Is it coming close to the intraventricular septum during diastole?
    - If the left ventricular walls are moving well and coming close together during systole and the anterior mitral valve leaflet is almost touching the septum during diastole then the patient likely has a normal ejection fraction.
    - Conversely, if the left ventricular walls are barely moving during systole and the anterior mitral valve leaflet is barely moving during diastole the patient likely has a low ejection fraction.

- Obtain a PSLA view.
- Observe the walls of the left ventricle; are the walls pulling in evenly? Are they pulling in too much, or not enough?
- Observe the mitral valve function; how close does it come to the septum? The closer it comes the better the function.



- Obtain a PSSA view at the mid-papillary level.
- Observe the cardiac muscles in a similar fashion as the PSLA view. Ensure that all sides of the wall are moving inward equally.
- To assist with seeing this, you may place a finger in the center of the ventricle and watch how the wall contracts. This will make hyperdynamic/hypodynamic regions stand out more.



The qualitative approach may underestimate true LVEF. This technique is operator-dependent but the more you do the more accurate you will become.

Quantitative Approaches to Assessing LVEF:

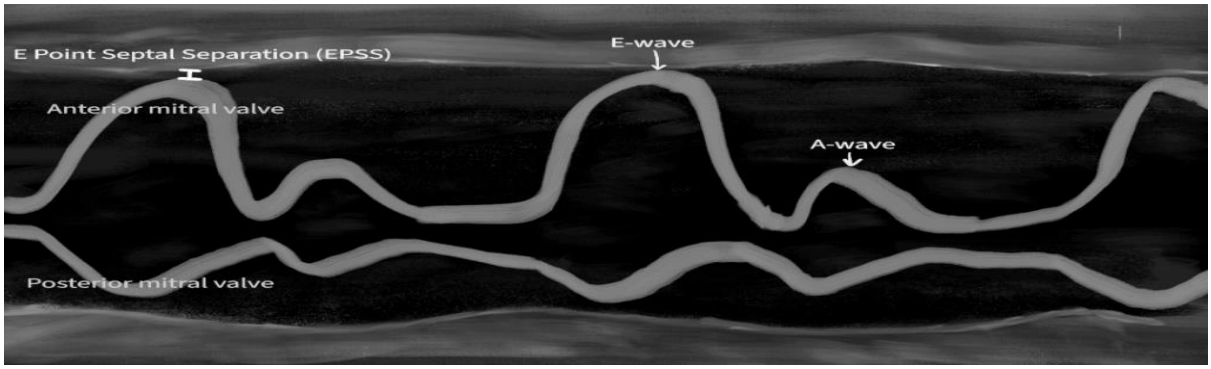
There are multiple ways to quantitatively assess for left ventricular ejection fraction.

Note: All of these techniques are not absolutely necessary and the majority of the time Quantitative assessment of ejection fraction is not always better as well because if you get the measurement at the wrong angle or cut, it can drastically give you false values. Make sure to understand each technique and its limitations prior to implementing it into your own practice.

1. **E-Point Septal Separation (EPSS)**

   E-Point Septal Separation (EPSS) refers to the distance between the anterior leaflet mitral valve and the septum when the mitral valve has reached maximum excursion during early diastolic filling. The larger the EPSS distance the worse the ejection fraction. Watch video https://youtu.be/s4suV5lDB5g

   - The most crucial step in obtaining EPSS is finding a good PSLA view and a horizontally-oriented LV.
   - Place the M-mode cursor over the tip of the mitral valve as the anterior leaflet travels towards the LV septum.
   - In M-mode, measure the distance between the mitral valve's "E-wave" (symbolizing the left atrium's passive filling of the LV) and the LV Septum.



Watch Video M Mode (Step by Step guide for EPSS on pptx)

- According to cardiac MRI data, EPSS measurements <8mm are considered to have a normal LVEF while distances, 8-18mm are mild/moderately reduced EF, and >18mm are suggestive of severely reduced LVEF.
- After the EPSS measurement is obtained, it can be also inserted into the following equation to calculate LV ejection fraction (LVEF):

LVEF = 75.5 – (2.5 x EPSS)

- **Limitations:** Obtaining EPSS is limited in pathological diseases that impact the function of the mitral valve (ex: mitral stenosis, mitral valve repair, mitral valve calcification).

2. **Fractional Shortening**

- Fractional Shortening is an M-mode measurement of the percent change in diameter between Left Ventricle End Diastole Diameter (LVEDD) and Left Ventricle End Systolic Diameter (LVESD). The following equation allows for the percentage calculation of the size reduction:

$$\textbf{FS (\%) = (LVEDD-LVESD)/LVEDD x 100}$$

1. Obtain PSLA view
2. Select M-mode and place the cursor in the middle of the LV being careful to not include the mitral valve or papillary muscle.
3. Freeze the M-mode image.
4. Measure the LVEDD (max diameter) and LVESD (minimum diameter)
5. The ultrasound will give you an ejection fraction reading.
6. See Video https://youtu.be/ERGxpZ4qdYI

The caveat is that this value does not express ejection fraction since it is measuring a distance and not a volume.

Here is a reference table for fractional shortening:

	Male	**Female**
Normal EF	25-40%	27-45%
Mildly Reduced EF	20-24%	22-26%
Moderately Reduced EF	15-19%	17-21%
Severely Reduced EF	≤ 14%	≤ 16%

Fractional Shortening	**Percentage (%)**
M-Mode	>25%
Direct 2D Measurement	>18%

The ultrasound machine computes the ejection fraction by converting the diastolic and systolic diameters into volume measurements using the following Teichholz equation:

$$\mathbf{V_d = [7/ (2.4 + LVEDD)] \times LVEDD^3}$$

$$\mathbf{V_s = [7/ (2.4 + LVESD)] \times LVESD^3}$$

$$\mathbf{LVEF = (V_d - V_s)/ V_d}$$

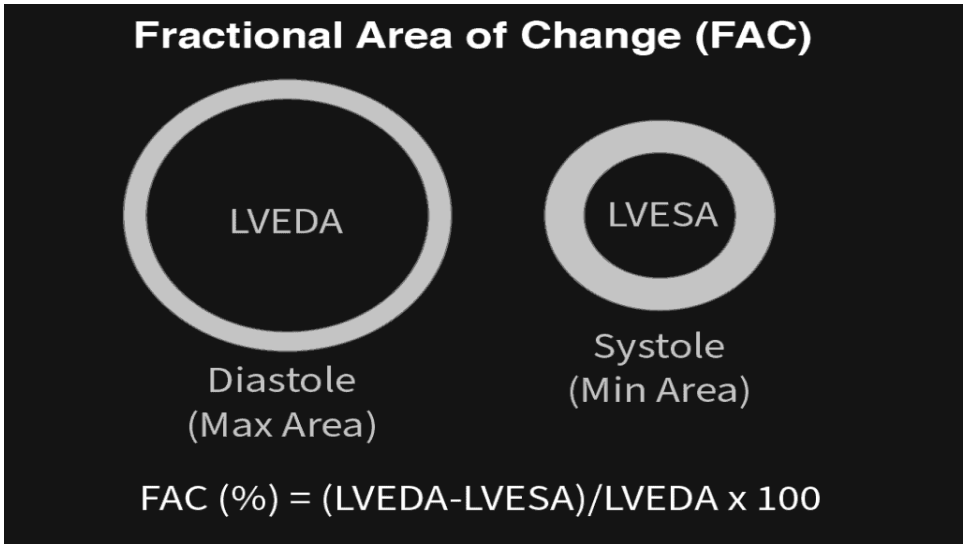
Limitations: For accurate delineation of change in diameter:

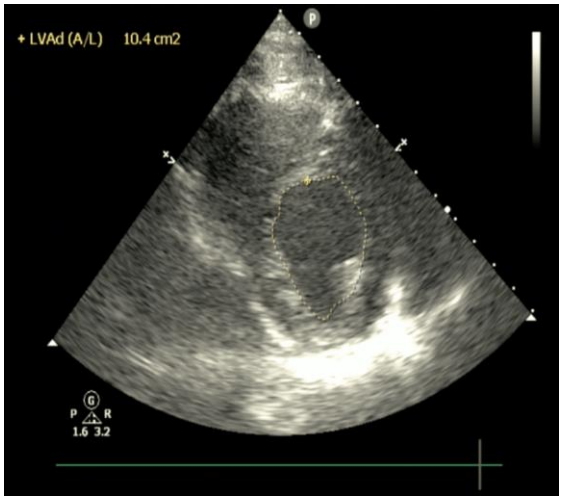
- **M-mode line must cut the LV perpendicularly**. This can be ensured with optimal image quality or with the use of an ultrasound machine that enables anatomic M-mode.
- Other limitations of fractional shortening are evident in **certain arrhythmias**, in which end-diastole and end-systole are not clearly delineated, making this calculation impossible.
- **Regional wall motion abnormalities** also interfere with correct calculation, as the diameter of the left ventricle is not representative of the ventricular size.
- Ventricular activation must be normal. For example, in the setting of left bundle branch block (LBBB), fractional shortening is not representative of ventricular function, since the activation proceeds abnormally.
- Left ventricular geometry must be normal.

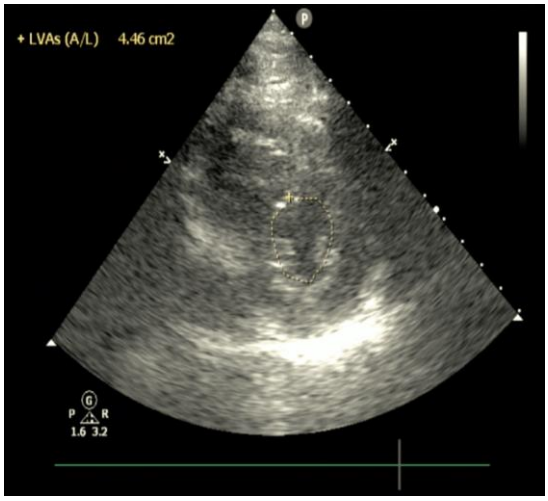
Advantages of fractional shortening

- If ventricular geometry is normal and there are no regional wall motion abnormalities, then fractional shortening correlates strongly with ejection fraction. Similar to ejection fraction, fractional shortening is affected by preload and afterload. It possible to calculate fractional shortening using measurements in 2D.

3. **Fractional Area Change (FAC)** is a **two-dimensional echocardiographic parameter** measures ejection fraction by comparing the area of the left ventricle when viewing the mitral valve view during systole and at diastole. It is calculated as the percentage change in the area of a chamber between systole and diastole. The formula for FAC is: **FAC = (Chamber area in diastole - Chamber area in systole) / Chamber area in diastole.**
   FAC (%) = (LVEDA-LVESA) /LVEDA x 100
   - Obtain PSSAx view at the level of the papillary muscles.
   - At the end of diastole (maximum area), measure the area of the left ventricle to obtain the LVEDA.
   - At the end of systole (minimum area), measure the area of the left ventricle to obtain the LVESA.
   - Insert values into the equation to obtain fractional area change.







Here is a reference table for how Fractional Area Change correlates to Ejection Fraction:

Fractional Area Shortening	**Ejection Fraction**
60%	75%
50%	66%
40%	54%
30%	42%
20%	29%
10%	15%

Limitations: Regional wall disfunction can alter measurement, and may over- or under-estimate global function.

4. **<u>Simpson Method</u>**
   Monoplane

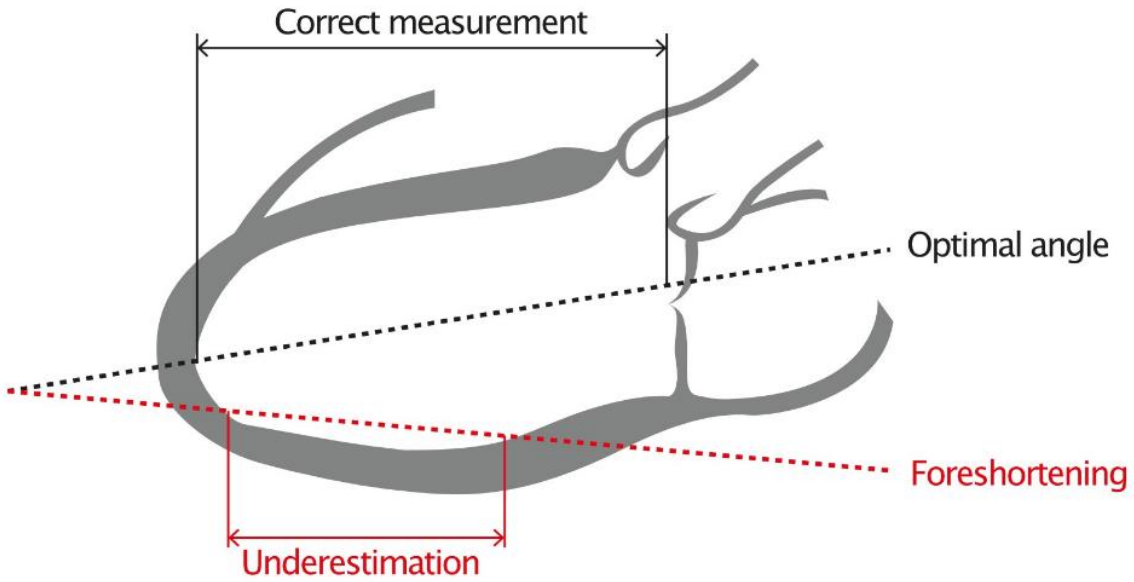
Biplane: The technique involves multiple tracings using the apical 4 and 2 chamber views in both diastole and systole

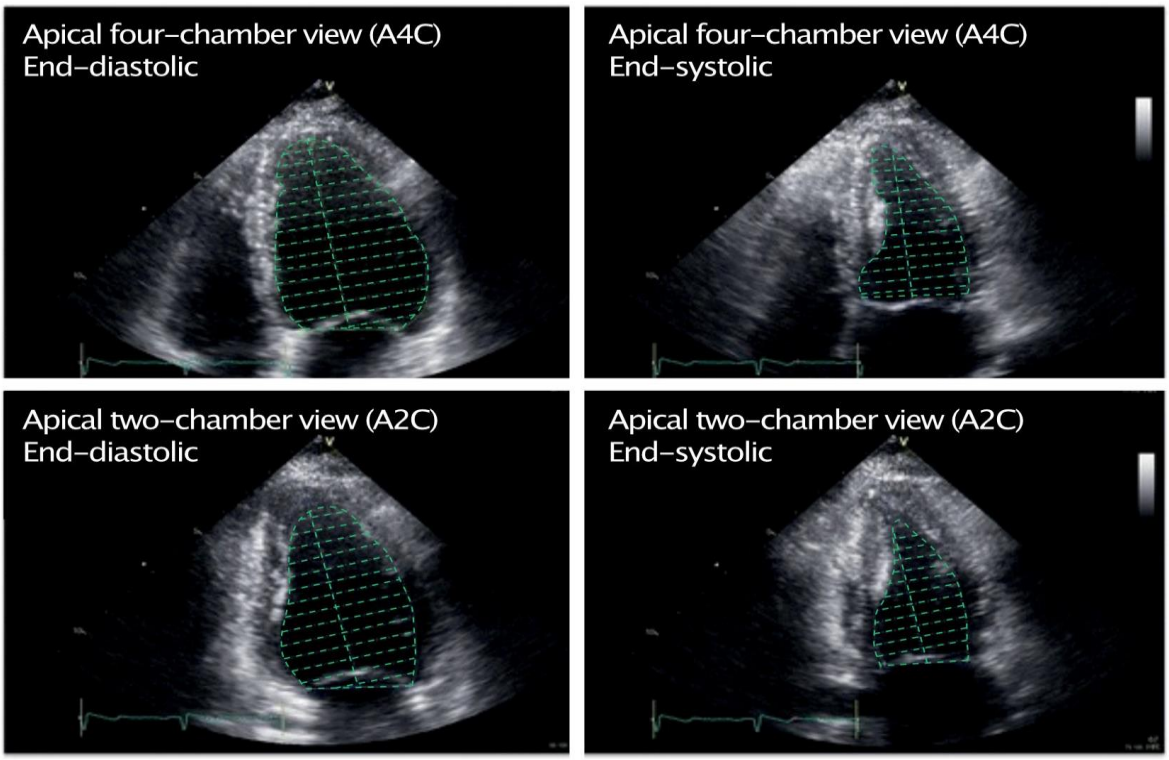
- Simpson's biplane method requires making four simple measurements in order to obtain end-diastolic volume (EDV) and end-systolic volume (ESV), which are then used to calculate ejection fraction:

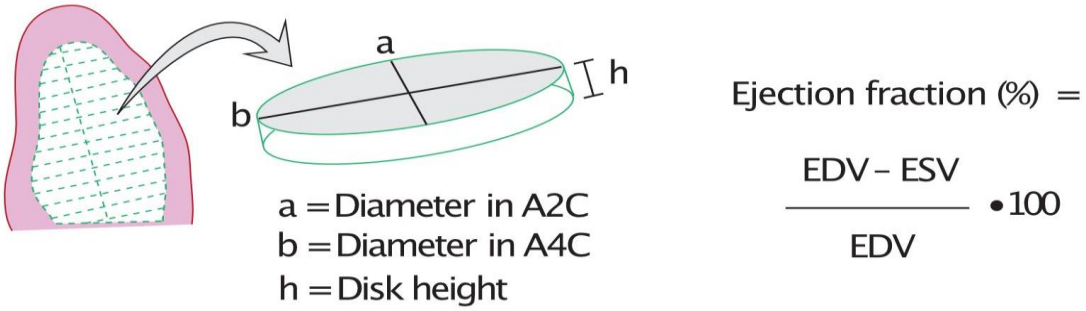
EF = (LVEDV-LVESV)/LVEDV x 100

- It is the best measure of ejection fraction, but it is difficult, time-consuming, and the most operator-dependent technique.
- **Watch video** https://youtu.be/Gf2ElPncNMM
- Simpson's biplane method requires tracing (i.e., drawing a line along) the endocardium in apical four-chamber view (A4C) and apical two-chamber view (A2C) in diastole and systole. The entire endocardium, from mitral annulus to mitral annulus must be traced. The ultrasound system then divides the area into a number of equal disks and reconstructs these so that volumes can be calculated.
- **<u>Foreshortening and underestimation of ejection fraction</u>**

  When visualizing the left ventricle from apical windows, small angle errors may lead to large differences in ventricular dimensions. Actually, all angle errors lead to underestimation of ventricular volumes.







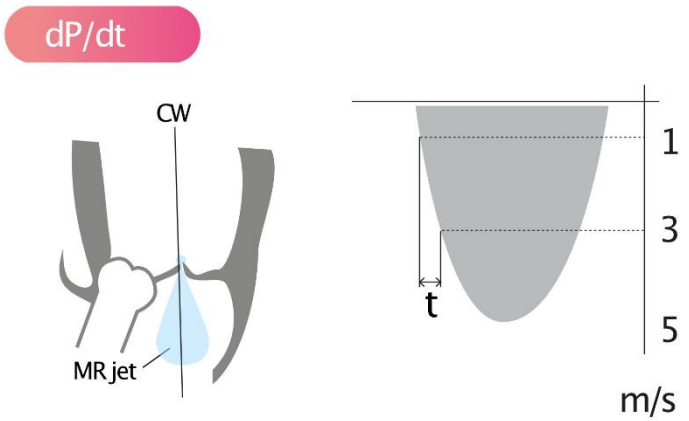
- **Limitations**: Although this is the most accurate form of calculating EF, the accuracy of this measurement will depend on image quality. Beware of foreshortening, as this will alter your calculations. Additionally, arrhythmias or regional wall motion abnormalities may not allow for the depiction of end-systole vs end-diastole.
- Lastly, one of the greatest difficulties of the Simpson Method is accurately tracing the endocardium correctly and not including other structures such as the papillary muscles. Here is a great https://youtu.be/1361b4Shetw describing how to do this.

5. **Ejection acceleration time (EAT):** Ejection acceleration time measures the maximum systolic velocity (m/sec) in the LVOT. This parameter correlates well with left ventricular systolic function.

$$EAT = v_{max}/time$$

6. **dP/dt:** The rate at which the ventricular pressure rises expressed by the term dP/dt, which is the rate of change in pressure (dP) with time (dt).
   In the setting of mitral regurgitation, left ventricular systolic function can be estimated by studying the acceleration of the regurgitant jet.
   The better the systolic function, the greater the increase in left ventricular systolic pressure, and, thus, the greater the acceleration in the regurgitant jet.
   d*P*/d*t* represents the rate of increase in pressure within the left ventricle. Hence, dP/dt is a proxy for the capacity of the left ventricle to generate pressure during systole. It represents a marker of global contractile function.
   If the LV systolic function becomes impaired, the rate of rise in pressure is slower & therefore dP/dt starts to fall.

   dP/dT is measured by placing continuous wave Doppler in the MR jet (mitral regurgitation jet) during the isovolumetric contraction (i.e. the contraction occurring between mitral valve closure and aortic valve opening). Left atrial pressure is constant during this phase, which implies that the acceleration in MR jet speed is due to increase in left ventricular pressure. If confined to early systole, during isovolumic contraction, it is a relatively load-independent measure of ventricular contractility.



dP/dt is calculated from the slop of velocity between 1 & 3 m/sec by applying the following formula:

dP/dt [mmHg/s] = (P2-P1) x 1000/t [ms]

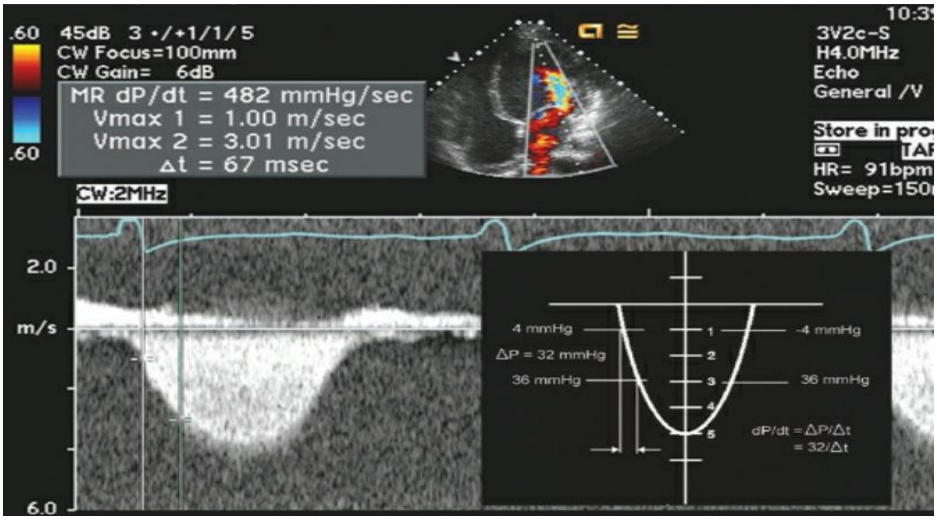
As we are measuring the slop between 1 and 3 m/sec (which represents the difference P2-P1 (36-4 mmHg), More specifically, dP/dt is derived by measuring the time interval (s) elapsing for the MR jet to accelerate from 1 m/s to 3 m/s. Then, the constant 32 is divided by the time interval in order to approximate left ventricular pressure:

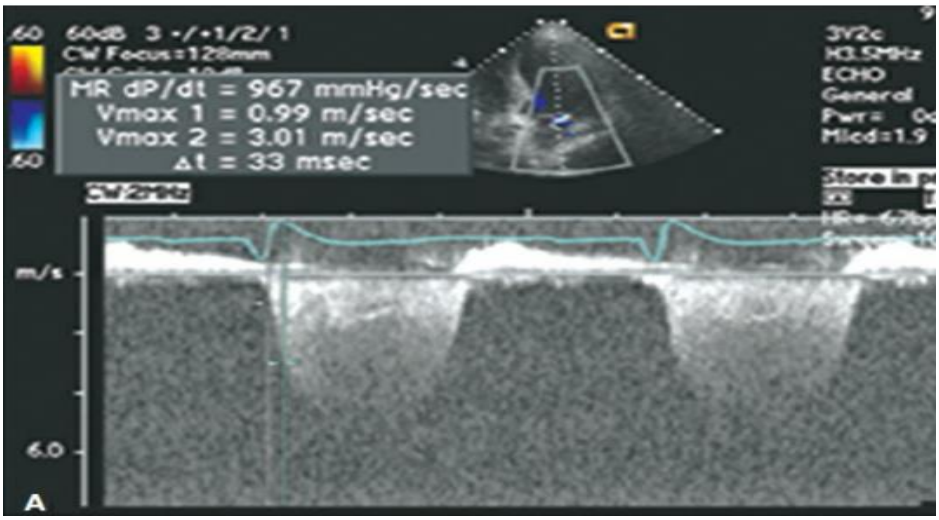
dP/dt=32/t

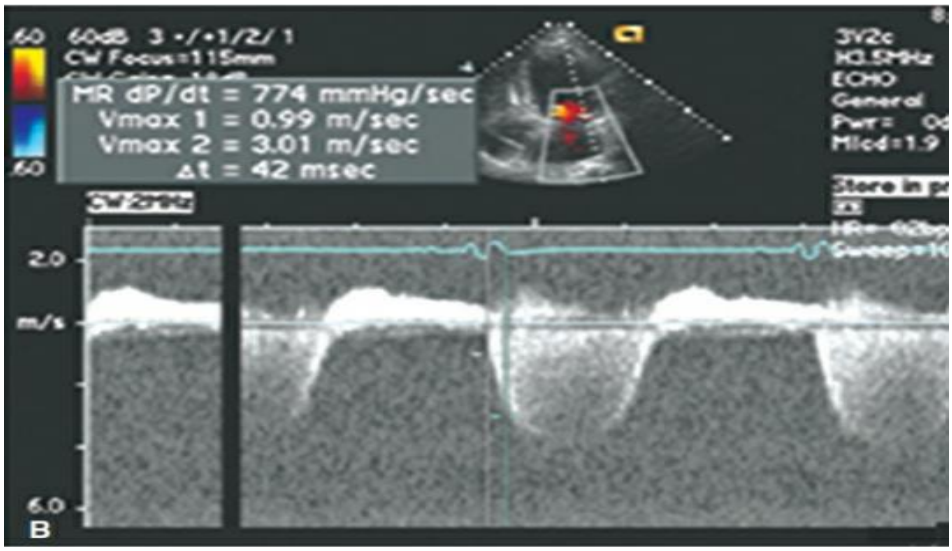
Limitations:

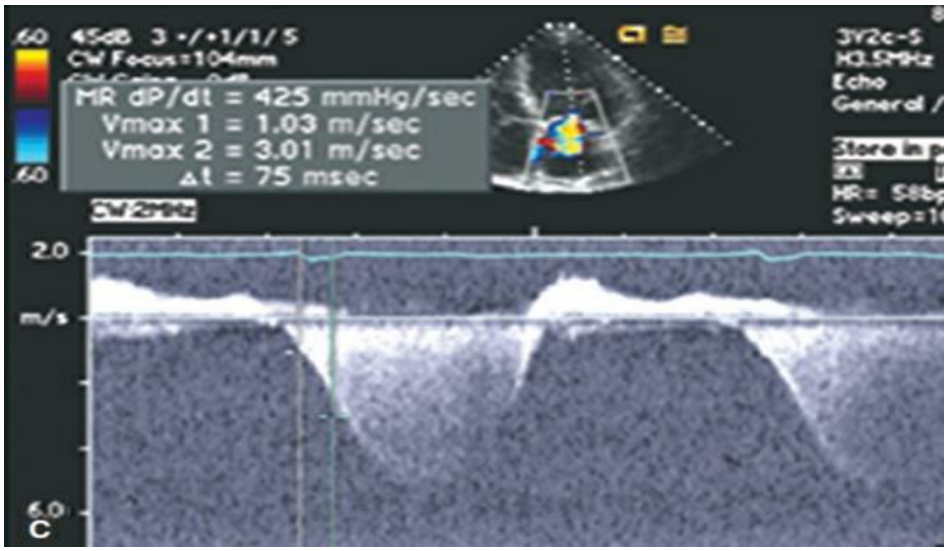
- You need to have mitral regurgitation
- You need a good mitral regurgitation CW Doppler spectral signal
- Is not reliable If the mitral regurgitation is acute
- Is not reliable if there is significantly increased afterload (aortic stenosis or systemic hypertension)

Watch Video http://youtu.be/R4s4dpNj4_E?si=Rc_2JpR78os4zmv









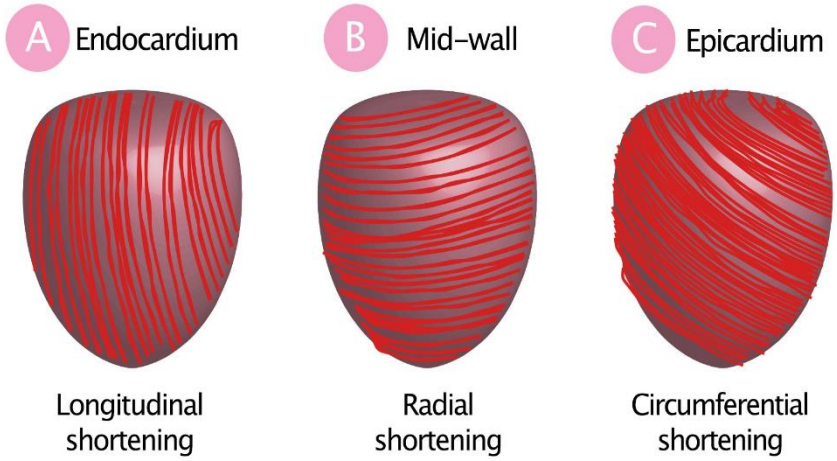
EF grade	**Values**
Normal	>1200 mmHg/sec
Borderline	800-1200 mmHg/sec
Reduced	<800 mmHg/sec
Severely Reduced	<500 mmHg/sec

7. **Strain, strain rate and speckle tracking: Myocardial deformation**
   First, we will learn about how the myocardium fibers are contract.
   Endocardium:
   - **Oriented:** longitudinally (from base to apex)
   - **Contraction:** contraction yields longitudinally shortening.

   Myocardium/ Mid wall/Middle layer:
   - **Oriented:** circularly around the short axis.
   - **Contraction:** contraction yields radial shortening.

   Epicardium:
   - **Orientation:** approximately 60˚ in relation to the mid wall fibers.

- **Contraction:** contraction in this layers results in twisting (rotating) motion of the entire left ventricle. Basal segments rotate clockwise & the apex rotates counterclockwise. This rotating or twisting, contraction is called circumferential shortening.



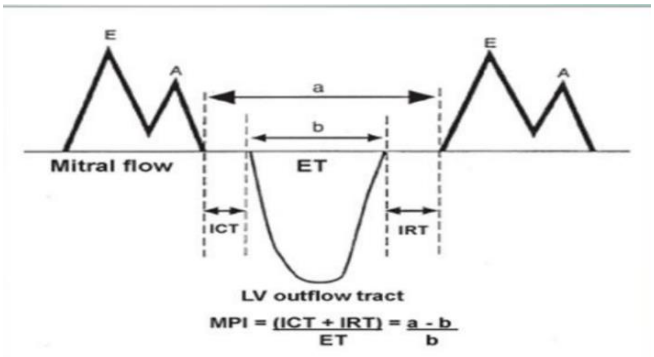
We will discuss about strain and strain rate soon.

8. **MYOCARDIAL PERFORMANCE INDEX**
   - The Tei index or myocardial performance index (MPI) is a parameter for global ventricular performance. The Tei index consists of 3 variables which are derived from Doppler spectrum.

The formula is: **MPI = (IVCT + IVRT) / ET**

IVCT = Isovolumetric contraction time, IVRT = Isovolumetric relaxation time, ET= Ejection time

- It is derived by comparing the total systolic time i.e., from mitral valve closing to MV opening with the systolic time in actual aortic flow (ET)
- Total systolic time is defined as Isovolumetric contraction time + Ejection time + Isovolumetric relaxation time.
- The myocardial performance index essentially divides the total isovolumic times (IVCT + IVRT) by the ejection time (ET).
- This index is referred to as the MPI or Tei index.
- Normal < 0.40. increasing values means worse ventricular function



Factors that effects Ejection Fraction

- **Preload:** A rapid increase in preload (e.g., by increasing venous return to the heart in supine position) leads to an immediate increase in ejection fraction & vice versa.
- **Afterload: A** decrease in afterload (e.g., by means of decreased resistance in the systemic circulation) leads to an increase in ejection fraction & vice versa.
- **Left Ventricular Volume:** Ejection fraction is also affected by left ventricular volume (size). For example, athletes have large ventricular dimensions and often lower ejection fraction (athlete's heart produces significantly larger stroke volumes, which satisfy the body's oxygen demand despite smaller ejection fractions), as compared with non-athletes (individuals with small ventricular volumes tend to have high ejection fractions as a compensatory mechanism with greater ejection fractions).

Reduced Ejection Fraction

Numerous conditions can lead to reduced ejection fraction.

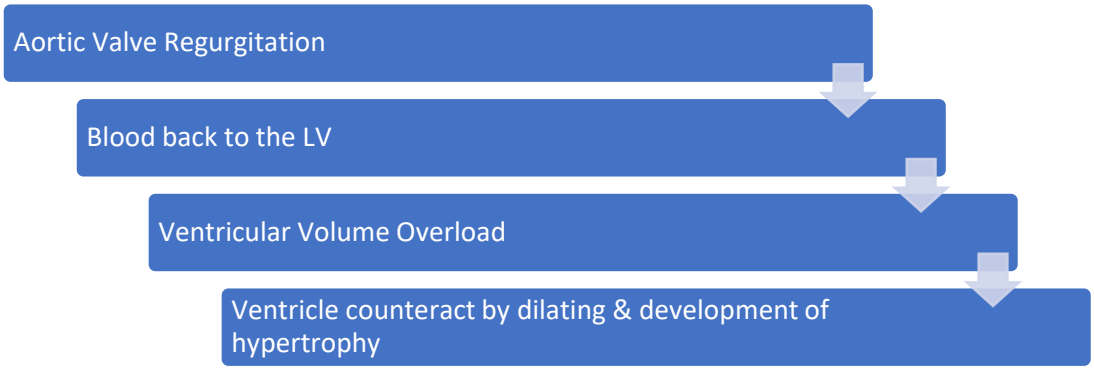
- Cardiomyopathy,
- valvular heart disease,
- diabetes, hypertension,
- renal failure,
- ischemic heart disease (coronary heart disease) is among the common causes.

Let's discuss some of them

Aortic Valve Regurgitation: In the setting of aortic valve regurgitation, blood regurgitates from the aorta back to the left ventricle. This results in:

Dilation prevents the volume overload from causing pressure overload & the development of hypertrophy enables the ventricle to eject larger volumes of blood. Thus, dilation & hypertrophy mitigate (lowers) the consequences of volume overload.

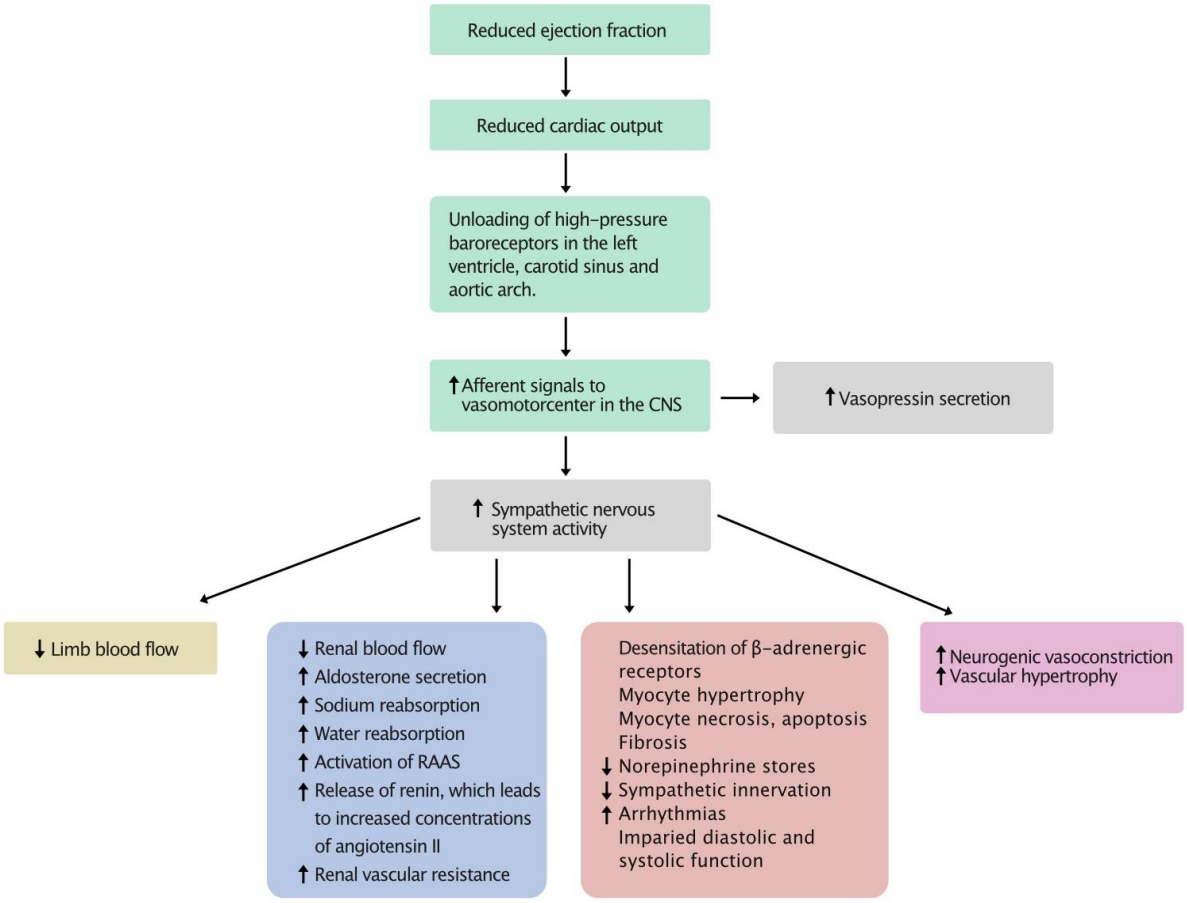
Unfortunately, the long-term effects of dilation & hypertrophy are remodeling of the myocardium & neurohormonal disturbances that gradually impair contractility & lead to the development of myocardial fibrosis. Ultimately, contractility of individua; muscle fibers worsen & ejection fraction deteriorates.



CORONARY ARTERY DISEASE – coronary heart disease may lead to acute myocardial infarction, which implies that some myocardium permanently ceases to contract, and overall ejection fraction is reduced.

Impaired ejection fraction triggers neurohormonal mechanisms (see below) that are initially beneficial, but in the long run cause deterioration of the condition. Symptoms of heart failure (e.g., dyspnea, impaired performance, edema, etc.) develop sooner or later.

Neurohormonal activation in heart failure with reduced ejection fraction



- Increased sympathetic activity leads to **increased heart rate** and initially **increased contractility**, which may temporarily alleviate symptoms, but the long-term effects of sympathetic activity are devastating. Beta-blockers, which reduce the activity of sympathetic fibers, improve both cardiac function and survival dramatically in heart failure.
- Increased sympathetic activity leads to increased secretion of **aldosterone**, **renin** (activation of **RAAS**) and consequently increased concentrations of **angiotensin II**. This results in increased blood pressure and retention of salt and water. This subsequently results in **increased cardiac preload** and, in the long term, **volume overload**.
- In cardiac muscle, sympathetic activity results in **desensitization of beta-adrenergic receptors**, diminished norepinephrine stores, **hypertrophy, fibrosis, apoptosis and increased risk of arrhythmias**. Ultimately, this leads to further impairments in systolic and diastolic function.
- Sympathetic stimuli **to peripheral vessels** result **in hypertension and vascular hypertrophy**.
- When compensatory mechanisms are not sufficient to maintain normal intraventricular pressure, ventricular dilatation commences. The dilatation may initially lead to increased contractility in individual muscle fibers (refer to Frank-Starling's law), but contractile function deteriorates gradually.