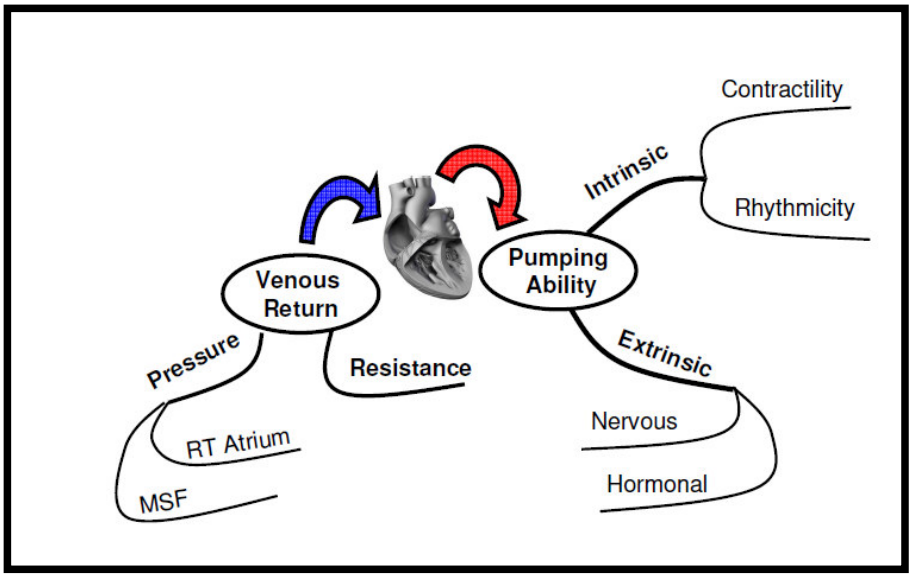
Cardiac Output
(C.O.)

Is the volume of the blood pumped by each ventricle per minute (5 Litre)

- ***Stroke volume:*** Is the volume of the blood pumped by each ventricle per beat.
- Stroke volume = End diastolic volume – End systolic volume
- So.. Cardiac output = stroke volume **X** heat rate.

N.B: ***Cardiac index*** is the cardiac output per minute per square meter surface area (3.2 L/min/m^2).

Regulation of Cardiac Output



I - Pumping ability of the heart.

A. Intrinsic regulation:

Is the regulation of pumping ability of the heart without the aid of nerves or hormones., including:

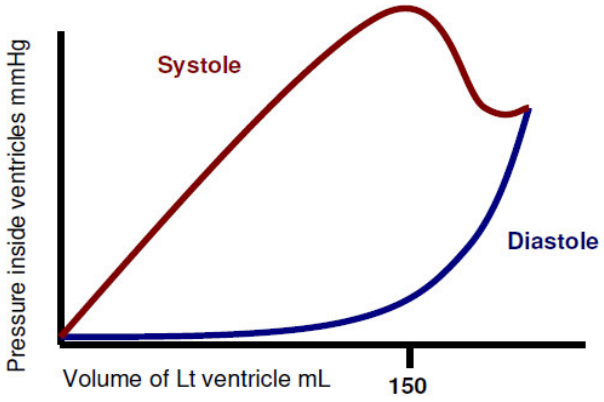
1. Regulation of contractility:
    a) Effect of Preload.
    b) Effect of afterload.
2. Regulation of rythmicity.

Effect of Preload :

- ***Frank-Starling Law:***

Within limit, the greater the cardiac muscle is streached during cardiac filling → the greater will be the force of contraction → the greater will be the stroke volume.

- This curve shows the relation between Cardiac filling (Preload) and the pressure inside ventricles during systole & diastole.



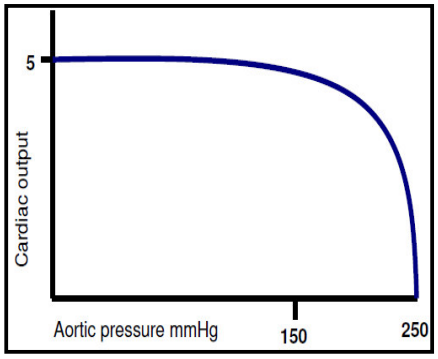
a) Diastolic Pressure curve:

- Till 150 ml , diastolic pressure doesn't increase greatly → easy blood flow from atria.
- More than 150 ml → pressure increase rapidly → maximum stretch of cardiac fibrous tissue & pericardium.

b) Systolic Pressure curve:

- Till 150 ml , systolic pressure increase rapidly till it reach its maximum.
- More than 150 ml → decrease systolic pressure due to separation of actin & myosine filaments → ↓ number of cross bridges → ↓ contraction.

Effect Of Afterload :



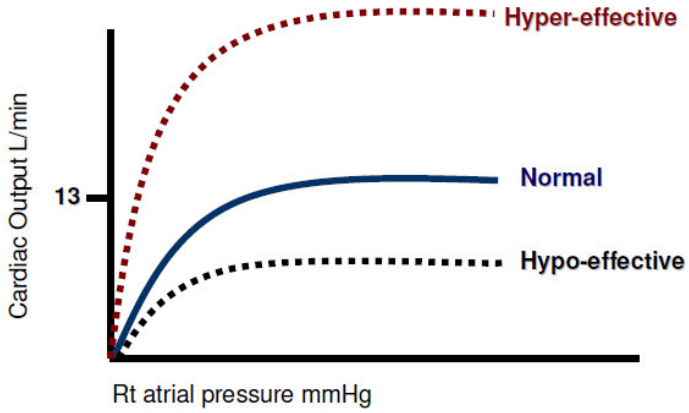
- The afterload is the aortic pressure.
- Ventricle contract isometrically until ventricular pressure is more than aortic pressure → isotonic contraction.
- Within limit, the greater the afterload → the greater will be the force of contraction.
- Excessive increase in aortic pressure → decrease cardiac output

Intrinsic Regulation of rythmicity:

↑ atrial filling → stretch S-A node → its stimulation → ↑ heart rat.

Q. ***What is <u>Cardiac Function Curve</u> ?***

- This curve shows the relation between right atrial pressure & cardiac output.



This curve shows the following:

- The more the right atrial pressure → the more the cardiac output until a plateau is reached.
- ↑ right atrial pressure → ↑ ventricular filling → stretch the ventricle → ↑ contractility → ↑ cardiac output.
- The plateau level is ***13 L/minute*** in normal cardiac curve.
- ↑ plateau level → Hyper-effective heart , and ↓ plateau level in hypo-effective heart.

a) <u>Cause of Hyper-effective heart:</u>

1) Sympathetic stimulation → ↑ heart rate & cardiac contractility → double the plateau level.
2) Hypertrophy of cardiac muscle:
   - Is increase in cardiac muscle mass & its contractility due to increase cardiac overload (as in athletes) → double the plateau level

Combined 1, 2 (as in marathon runner) → ↑ plateau up to 40 L/minute

b) <u>Causes of Hypo-effective heart:</u>

1) Parasympathetic stimulation or sympathetic inhibition
2) Excessive afterload as in hypertension.
3) Heart disease:
   - Congenital heart disease - Valve disease
   - Cardiac arrhythmia
   - Diseased cardiac muscle as myocarditis

B. Extrinsic regulation:

It may nervous or hormonal.

Nervous regulation of pumping ability :

1. Sympathetic stimulation:

- ***Pathway:*** Vasomotor centre in medulla oblongata → Lateral horn cells of upper 4 thoracic segment → preganglionic fibers → cervical ganglia → postganglionic to the heart.

- ***Function:***
  1) ↑ heart rate to 200 beat/minute. Sympathetic stimulation → noradrenaline release → ↑ Na permeability & ↓ K permeability at S-A nodal membrane → ↑ prepotential slope → ↑ heart rate
  2) ↑ cardiac contraction. Noradrenaline → ↑ cAMP in cardiac muscle → ↑ contractility.
  3) Vasodilatation of coronary blood vessels.

2. Parasympathetic stimulation:

- ***Pathway:*** cardiac inhibitory centre → dorsal nucleus of the vagus → terminal ganglia in the wall of the heart → post ganglionic fiber to he atria (**Not the ventricle**)
- ***Function:***

  1) ↓ heart rate → may stop atrial beat but not the ventricle that escape from vagal inhibition. Parasympathetic stimulation → acetyl choline → ↑ K permeability in S-A node → ↓ prepotential slope → ↓ heart rate.
  2) ↓ cardiac contractility to lesser extent as it supply atria only.
  3) Vasoconstriction of coronary blood vessels.

N:B:

- There are continuous tone from sympathetic & parasympathetic system to the heart but the parasympathetic tone predominate.
- Nervous regulation affect mainly the heart rate that affect the cardiac output.

Q. How does heart rate affect cardiac output ?

C.O. = S.V. **X** H.R.

- ***In denervated heart:***

  a) Heart rate (60-160 beat/minute) → no change in cardiac output. Explanation: ↑ heart rate → ↓ diastolic period → ↓ cardiac filling → ↓ S.V. → constant C.O.
  b) Heart rate more than 160 b/min → ↓ cardiac output. The marked reduction in S.V. can't be compensated by the increase in heart rate → ↓ C.O.
  c) Heart rate less than 60 b/min → ↓ cardiac output. The marked increase in S.V. can not compensate the decrease in heart rate.

- ***In intact heart:***

  – Sympathetic stimulation → ↑ heart rate to 200 b/min → ↑C.O. Explanation:
    1) Sympathetic stimulation → ↑ heart rate and cardiac contractility.
    2) Sympathetic stimulation → ↓ systolic period → allow more time for diastole.

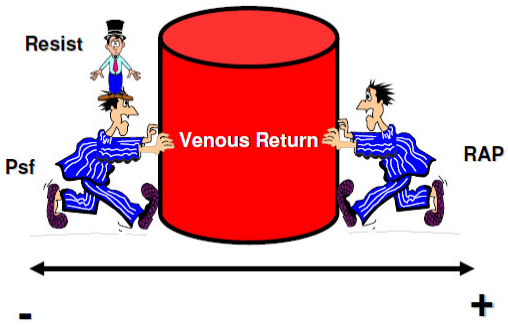
Hormonal regulation of pumping ability :

- Catecholamine & xanthines → ↑ cAMP → ↑ cardiac contractility → ↑S.V. → ↑ C.O.
- Drugs:
  a) Digitalis → +ve ionotrope → ↑ C.O.
  b) Quinidine, hypoxia, hypercapnia & ischemia → ↓ contractility → ↓ C.O.

II – Venous return.

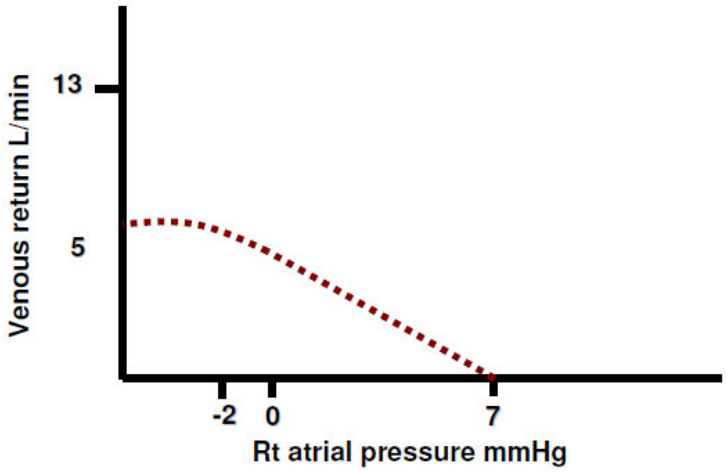
Venous return is affected by:

1. ***Right atrial pressure (PRA)***
2. ***Mean systemic filling pressure (Psf)***
3. ***Resistance to venous return***



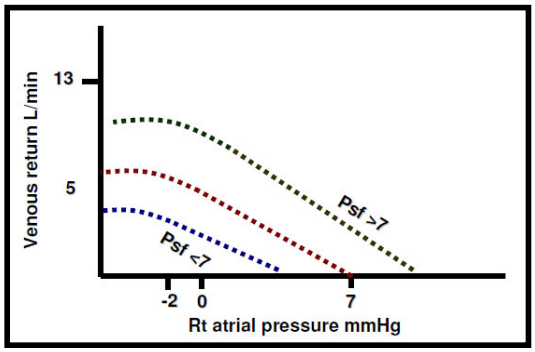
1. Right atrial Pressure (PRA):

- Also called Central venous pressure CVP.
- Normal value from -2 to +2 mmHge. Average is zero.
- It is regulated by the balance between pumping ability of the heart & venous return
- ↓ to less than -2 mmHg in case of sever ↓ in venous return as in hemorrhage.
- ↑ up to +30 mmHg in serious heart disease.
- Relation between PRA and venous return is demonstrated in the **venous return curve:**



- Venous return curve show the following:
  - ↑PRA more than Zero → ↑back pressure against venous return → ↓ venous return
  - Venous return is zero when PRA reach 7 mmHg
  - ↓PRA below zero → ↑ venous pressure → reaching plateau when PRA is -2
  - ↓PRA below -2 → no further increase in venous return due to collapse of veins entering the chest

2. Mean systemic filling pressure (Psf):

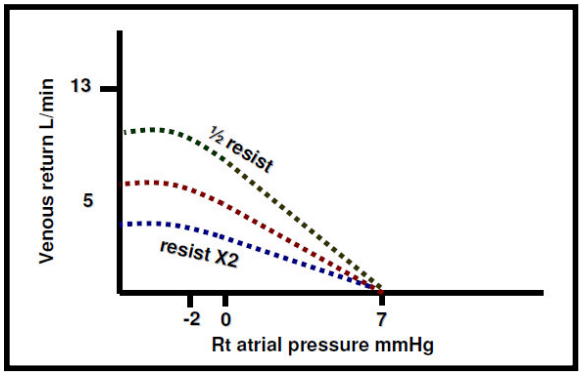


- Is pressure measured in systemic circulation after clamping large vessels at the heart.
- Normal value -7 mmHg.

- ***Importance of Psf:***
  1) Measure the degree of filling of systemic circulation
  2) Affecting Venous return curve as follow:
     - i- ↑Psf →shift curve upward to the right
     - ii- ↓Psf → shift curve downward to the left.

- **Factor affecting Psf:**
  1) ***Blood volume:*** ↑ blood volume → ↑Psf.
  2) ***Sympathetic tone:*** ↑sympathetic tone → V.C. → ↑Psf
  3) ***Skeletal muscle contraction:*** → compress veins from outside →↑Psf.

3. Resistance to blood flow:



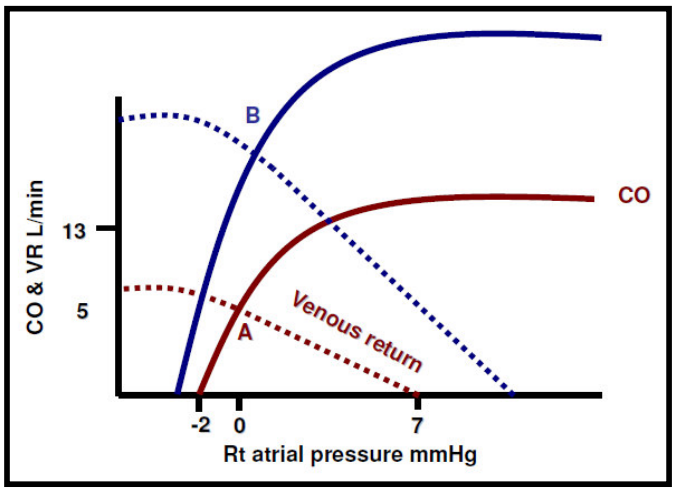
- Resistance occurs in veins (2/3) and arterioles.
- ↑resistance to blood flow → ↓ venous return
- This curve show effect of different resistance on venous return curve:
  1) ↓ resistance to 1/2 normal → double the venous return.
  2) ↑ resistance twice → ↓ decrease venous return to 1/2 normal.

N.B.

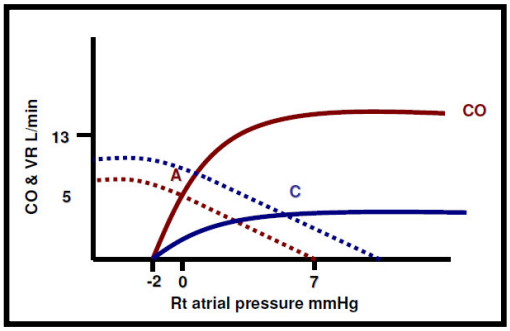
1) ***Mean circulatory pressure:*** is the equilibrated pressure in systemic circulation after one minute of cessation of cardiac blood flow.
   - It is almost equal to Psf (due to small capacity of pulmonary circulation).
2) **The most important** determinant of venous return is the gradient between Psf & RAP.
   - If RAP = Psf → venous return is zero (whatever will be the resistance to blood flow).

Relation between C.O. & venous return curve.

Right atrial pressure affects both C.O & venous return



- A steady state is reached at (A) point (intersect between C.O curve & venous return curve.
- **In resting condition:**
  - Psf = 7 mmHg
  - PRA = zero
  - Venous return = C.O. = 5 L/min.
- **In muscular exercise:**
  a) ↑ venous return due to:
     i- ↑Psf due to sympathetic V.C. & skeletal muscle contraction.
     ii- ↑ arteriolar vasodilatation →↓ peripheral resistance.
  b) ↑ C.O. due to:
     i- Sympathetic stimulation → ↑ all properties of the heart → hyper-effective heart.
  - The new steady point (B):
    Psf = 20 mmHg.
    PRA = up to 2 mmHg
    Venous return = C.O. = 22 L/min



- **In heart failure:**
  a) ↓ C.O. → ↓ arterial blood pressure →↓ glomerular filtration in kidney → ↓ urine formation → ↑blood volume → ↑ venous return (shifted upward)
  b) ↓ cardiac contractility → more ↓ in C.O. (shifted downward).
  - The new steady point (C): C.O. = venous return = 3 L/min

Variation in C.O.

I. Physiological variation:

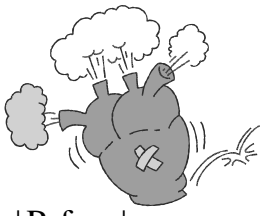
- ↑ **C.O. :**
  - **E**xcitement & stress
  - **E**ating
  - **E**xercise
  - ↑↑**E**nvironmental temperature
  - **E**mberyo (Pregnancy) !! ☺
- ↓ **C.O. :**
  - Standing from lying position
- **Age:**
  - The Cardiac index. rise rapidly till it reach maximum at age of 10 year then decline gradually to lower value in age of 80
- **C.O.** not changed by sleep or moderate ↑Environmental temp.

II. Pathological variation:

- **↑ C.O.**

  It increase in conditioned associated with decrease peripheral resistance as:
  1) ***Beri beri:*** thiamine deficiency in diet → ↓ cellular ability to use nutrient → peripheral V.D. → ↓ peripheral resistance.
  2) ***Anemia:*** ↓ blood viscosity & peripheral V.D. caused by hypoxia → ↓ peripheral resistance.
  3) ***Arteio-venous fistula:*** Shunt of blood from large artery to large vein → ↓ peripheral resistance.
  4) ***Hyperthyroidism:*** ↑ O2 consumption & accumulation of metabolites → peripheral V.D. → ↓ peripheral resistance.
- **↓ C.O.**

  A. ↓ ***pumbing ability:***
  - Congenital heart diseas.
  - Valvular heart disaes
  - Myocarditis

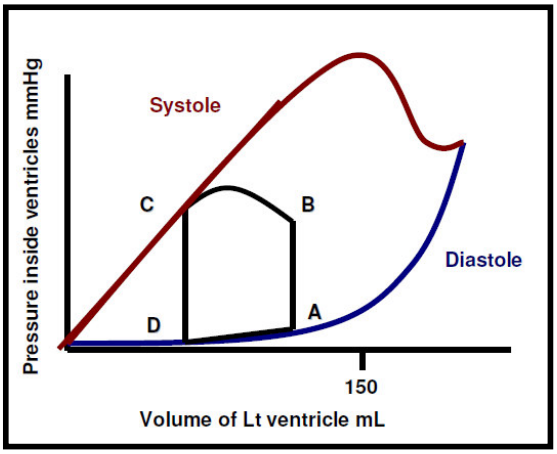


  B. ↓ ***Venous return:***
  - ↓ blood volume: as hemorrhage → ↓Psf →↓ venous return
  - Acute Venous dilatation as in anaphylactic shock.

Cardiac Work Output

- **Stroke work output:**
  - Is the amount of energy converted to work by the heart during each heart beat.
- **Minute work output:** is the total amount of energy that the heart converts in one minute.
  Minute work output = Stroke work output X heart rate/min.
  - This work has two forms:
    1. ***External work:***
       - Is the work performed to pump stroke volume against the mean arterial blood pressure (*volume-pressure work).*
       - External work of Lt. ventricle = stroke volume X mean systemic blood pressure.
       - External work of Rt. ventricle = stroke volume X mean pulmonary blood pressure
    2. ***Kinetic work:***
       - Is the work performed by the heart to give velocity to the blood in the vascular system.
       - The kinetic work is only 1% of the total work so it can be neglected.

Volume – Pressure Curve of Lt ventricle.

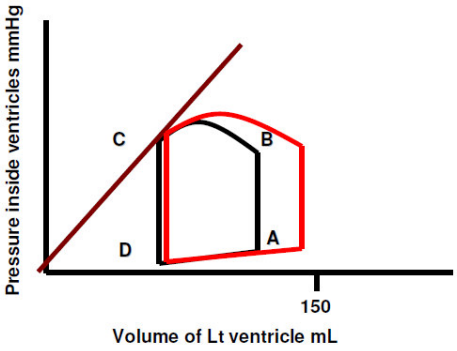


- **<u>Phase I:</u>** ***(filling phase)***
  - It represent the period of ventricular filling during diastole
  - At (**A**) point the end diastolic volume is 115 ml. & mitral valve close
- **<u>Phase II:</u>** ***(Isometric contraction phase)***
  - Ventricle is closed chamber → ↑ pressure but constant volume
  - at point (**B**), EDV not changed & aortic valve open.
- **<u>Phase III:</u>** ***(Ejection phase)***
  - More ↑ in pressure due to ventricular systole but decrease in volume.
  - At (**C**) point, End systolic volum = 45 ml & aortic valve closes.

- **Phase IV:** ***(Isometric relaxation phase)***
  - The ventricle is closed chamber → ↓ in pressure but constant volume
  - At (**D**) point ESV = 45 & mitral valve opens

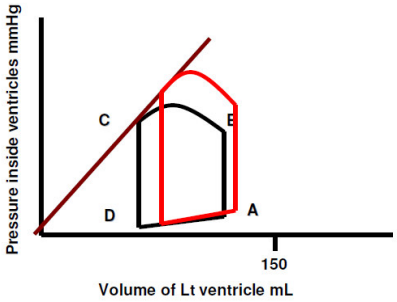
Factor Affecting External work output:

1. Preload:



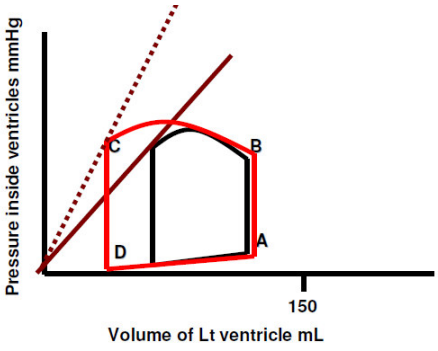
- ↑ mean Lt atrial pressure → ↑EDV and pressure from point A to A^{-}
- Provide after load is constant Ejection start at the same point (B^{-} = B)
- Provide that contractility is constant, so initial point of relaxation (C^{-}) Fall on contractility line.
- *Conclusion:* ↑ area of volume pressure curve → ↑ external work output of Lt ventricle

2. Afterload:



- ↑ aortic pressure → ↑ point at which ejection occurs (B^{-})
- Provide contractility is constant, so initial point of relaxation move up to fall on contractility line
- Conclusion: ↓ stroke volume but ↑ external work due to ↑ area of volume pressure curve

3. Change in contractility:



- ↑ contractility →↑ the slope of contractility line → ↑↑ area of volume pressure curve → ↑ external work output & vise versa

NB:

- Minute work output is affected by preload, afterload, contractility + heart rate.
- ***Sympathetic stimulation*** to the heart:
  a) ↑ venous return → ↑ preload.
  b) ↑ mean arterial blood pressure → ↑ afterload
  c) ↑ cardiac contractility.
  d) ↑ heart rate

  a, b, c & d → ↑ minute work output of the heart.