The ventricular pressure-volume relation

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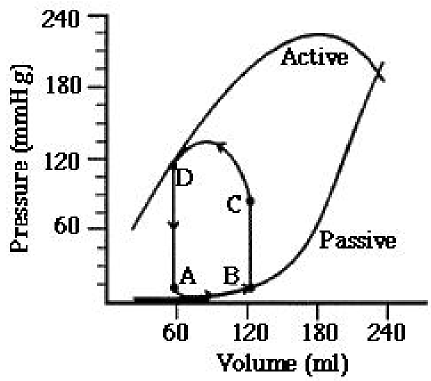
Outline

- Ventricular pressure-volume relation
- Elastance as concept for contractility
- Frank-Starling law
- The heart as a pump

The ventricular pressure-volume relation



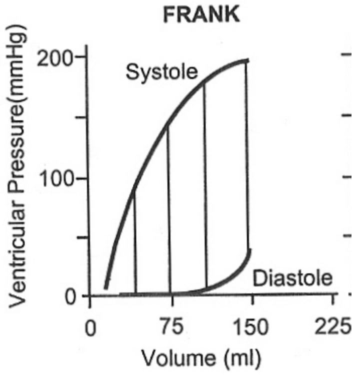
- Isovolumic contraction
  - Occurs at end diastole
  - ⇒ Increase in pressure
  - ⇒ Aortic valve (AV) opens

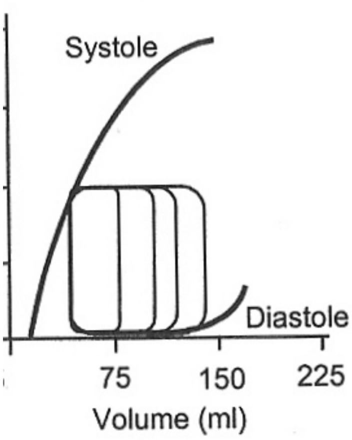
- Isobaric contraction
  - In systole
  - Volume decreases
  - Pressure ≈ constant
  - Pressure < aortic pressure ⇒ AV closure

- Isovolumic relaxation
  - ⇒ Decrease in pressure
  - ⇒ Mitral valves opens
  - Diastole begins
  - Filling of LV starts

- Isobaric (almost) filling until end diastole

The Frank-Starling law

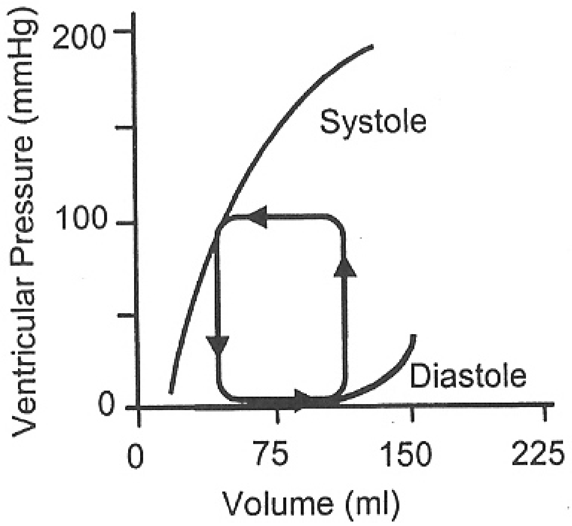


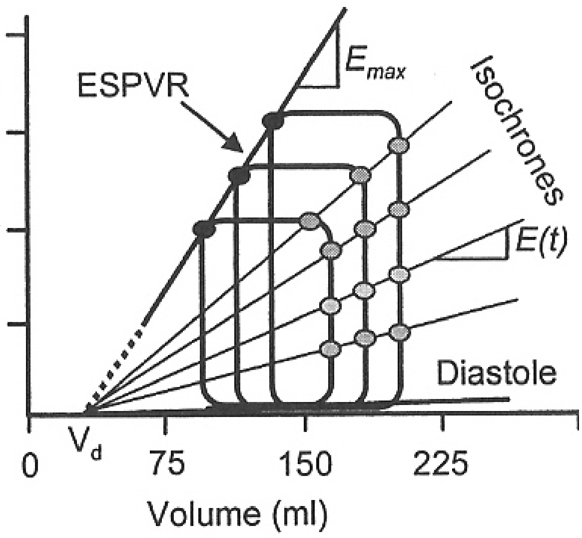


- Frank experiments
  - Isovolumic contractions
  - Variation in diastolic volume
  - Non-linear maximal pressure-volume relation
  - Frog hearts

- Starling experiments
  - Ejecting hearts
  - Constant load (aortic pressure) with Starling resistor
  - Increase in filling ⇒ increase in Stroke Volume (SV)

The varying elastance model



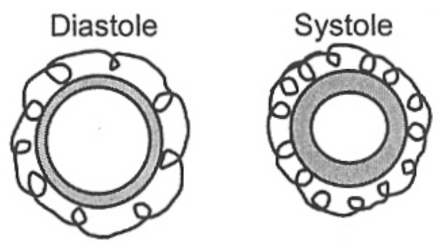


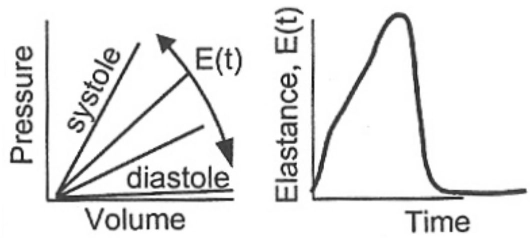
- Mark time points in PV-loops
- Isochrones: connect points at same times

- Elastance E(t)
  - Slope of the isochrones
  - Minimum at diastole
  - E_{max} at end systole

The varying elastance concept

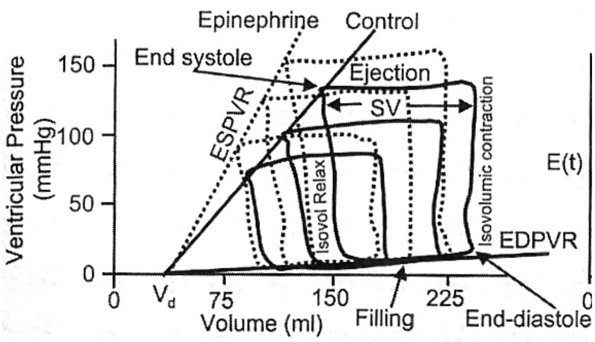
- Muscle stiffness increase from diastole to systole
- The change in stiffness is assumed to be unaffected by changes in load
- Units $mmHg/ml$
- Equivalent to $E - modulus$ for a linear spring
- Normalized by E_{max} and time to peak





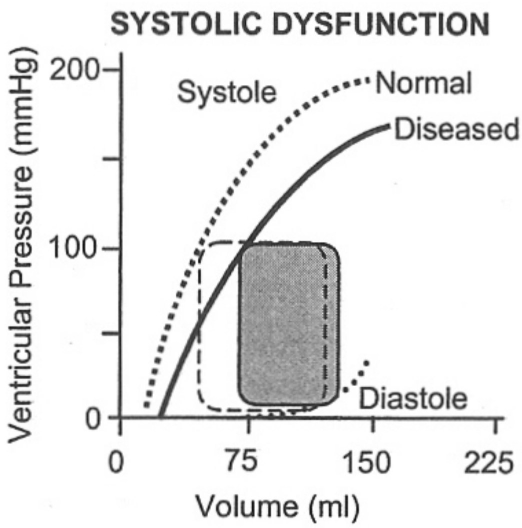
- Normalized curves are the same in mammals
- Useful for lumped models of the heart

Determination of E_{max}

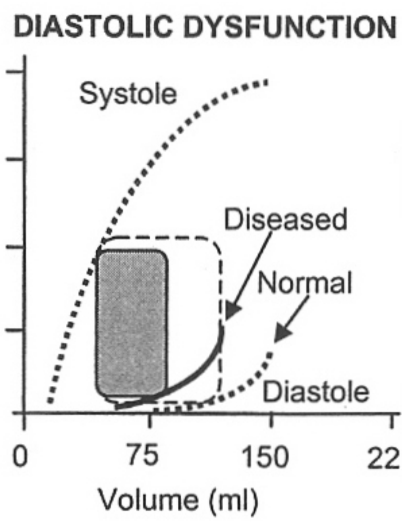


- E_{max}: Maximal elastance
- Several PV-loops needed
- Quick measurements to avoid changes in contractility
- Diastolic filling (DF) is preferred
- Changes in DF obtained with balloon in vena cava
- Volume measurements by e.g. US, X-ray, MRI
- Pressure measurements are invasive
- Noninvasive estimates of aortic pressure?

Systolic and diastolic dysfunction



- Decreased cardiac output
- If not compensated by HR for DF



- Stiffer LV $\Rightarrow$ higher filling pressure
- Decreased CO
- Increased pulmonary venous pressure
- Shortness of breath

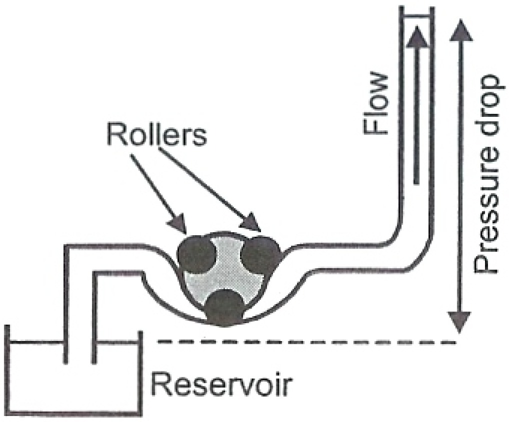
Relevance of ESPVR, E_{max}, and E_{min}

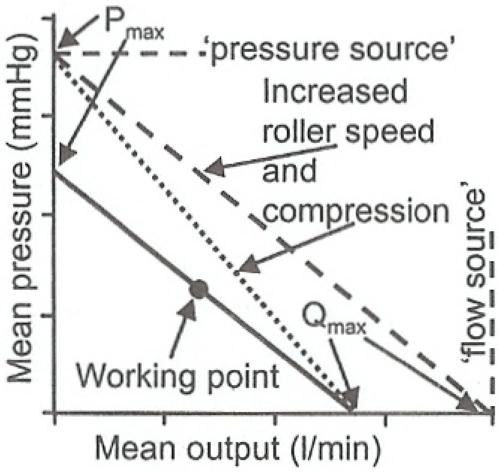
- ESPVR, E_{max}, and E_{min} important pump measures
- Often used in animal research
- Clinical still limited but increasing
- $E(t)$ depend on size (heart and body)
- Normalized to compare mammals
- $E_{\text{max}}/E_{\text{min}}$ better measure for contractility in disease?

Limitations of the varying elastance concept

- Only for the whole ventricle
- No distinction of agents which decrease ESPVR
  - Asynchronous contraction
  - Local ischemia
  - Local infarction
- The PV-relations are not straight lines
- ESPVR are curvilinear $\Rightarrow$ E_{max} is pressure-dependent
- Local approximations in working range
- The load-dependence of ESPVR are minor

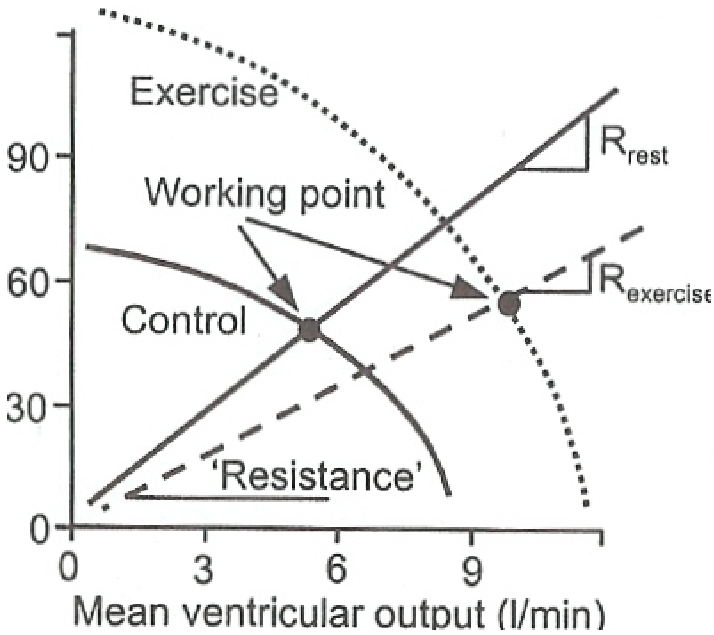
The pump function graph





- Constant
  - Roller speed
  - Tube compression
- Change load of pump
- Pump function graph results

Pump graph during exercise

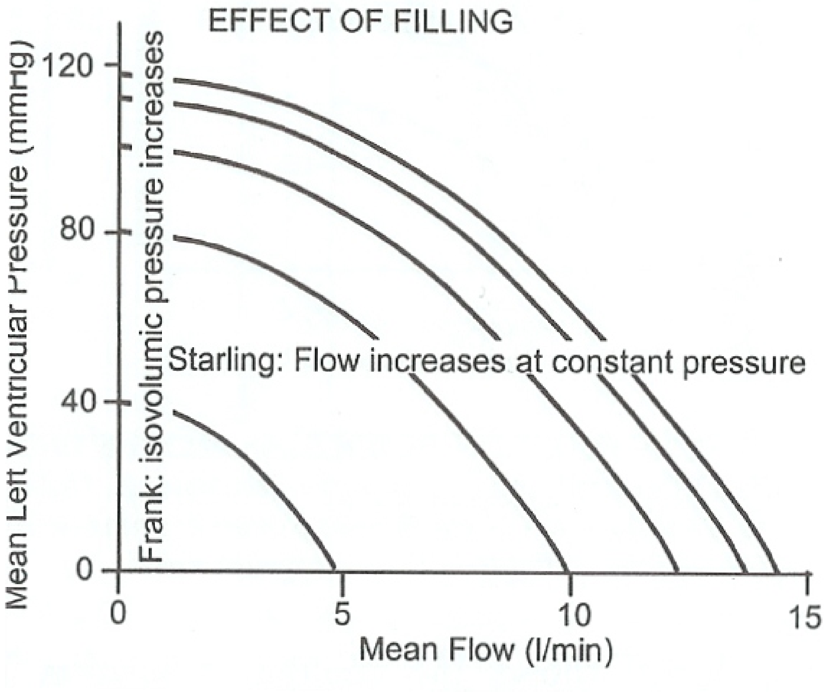


- Vascular resistance decreases during exercise

$\Rightarrow$ Decreased slope of pump function graph

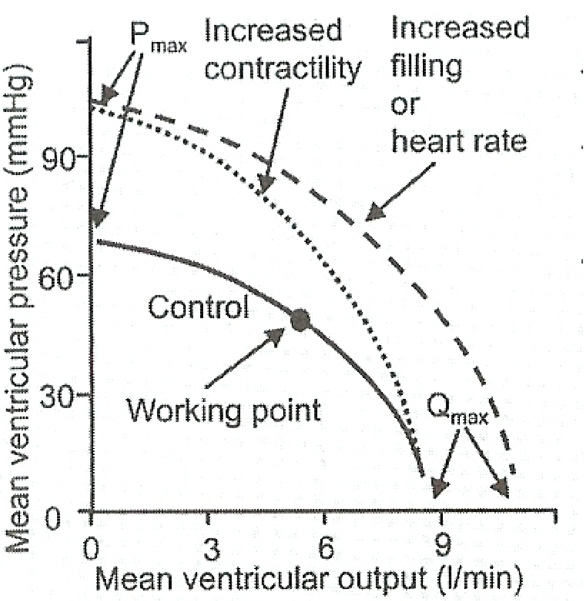
- Large changes in CO with small changes in pressure

Effect of filling



- With increased filling the graph moves outward
- This effect also follow from Frank-Starling

Pump function Summary



- Higher load $\Rightarrow$ lower flow
- Contractility $\Rightarrow$ graph rotates around Q_{max}
- Diastolic filling and HR $\Rightarrow$ translate graph in $\|$-manner
- Keep constant contractility, filling and HR for determination of pump function graph

Summary

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- Frank-Starling law
- The heart as a pump