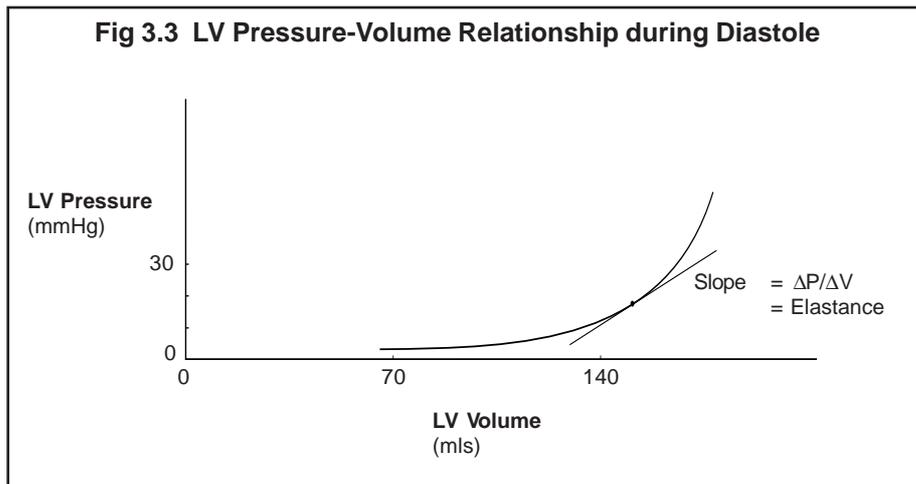


## Pressure-Volume Loop

*Can you draw a diastolic elastance curve for the left ventricle?*



*How would you measure elastance at any point on the curve?*

This curve has pressure on the y-axis and volume on the x-axis. The slope of the curve is the ventricular elastance (or 'stiffness'). The compliance (or 'distensibility') at any point is mathematically the inverse of the slope of the line at that point.

The relationship is a curve rather than a straight line. For this particular curve, the elastance is increasing as left ventricular volume increases. At the end-diastolic point, both the volume at this point (end-diastolic volume) and the pressure (end-diastolic pressure) have been used as indices of left ventricular preload. The increase in elastance especially at large end-diastolic volumes means that the relationship between these two variables is not a linear one.

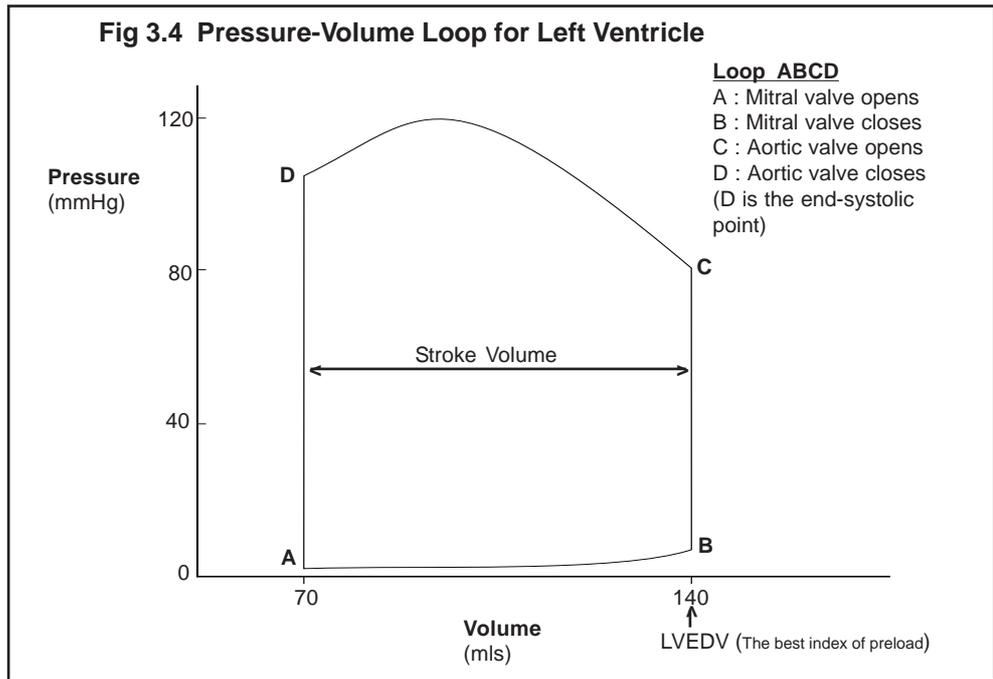
**[Comment:** The correct term to use when referring to this curve is 'elastance' as the pressure change (y-axis, dependent variable) in the ventricle is in response to the volume change (x-axis, independent variable). During systole, the pressure change (due to ventricular contraction) is the cause of the volume change so compliance is probably the correct term. In the curve for the cerebral pressure-volume relationship drawn on p67, 'intracranial elastance' is correct and the commonly used term 'intracranial compliance' is strictly incorrect. In the respiratory system, the volume changes are occurring in response to pressure changes so compliance is the correct term in this situation. This may seem a trivial point but it has been discussed recently in the literature and there is a move to use correct terminology. Anyway, in the exams, 'compliance' seems to be the preferred term but this may change. In this book, the term compliance is sometimes used even though this may be strictly incorrect. Alternatively, the uncommitted 'pressure-volume relationship' is used as in the graph titles.]

*What is the significance of the shape of the curve?*

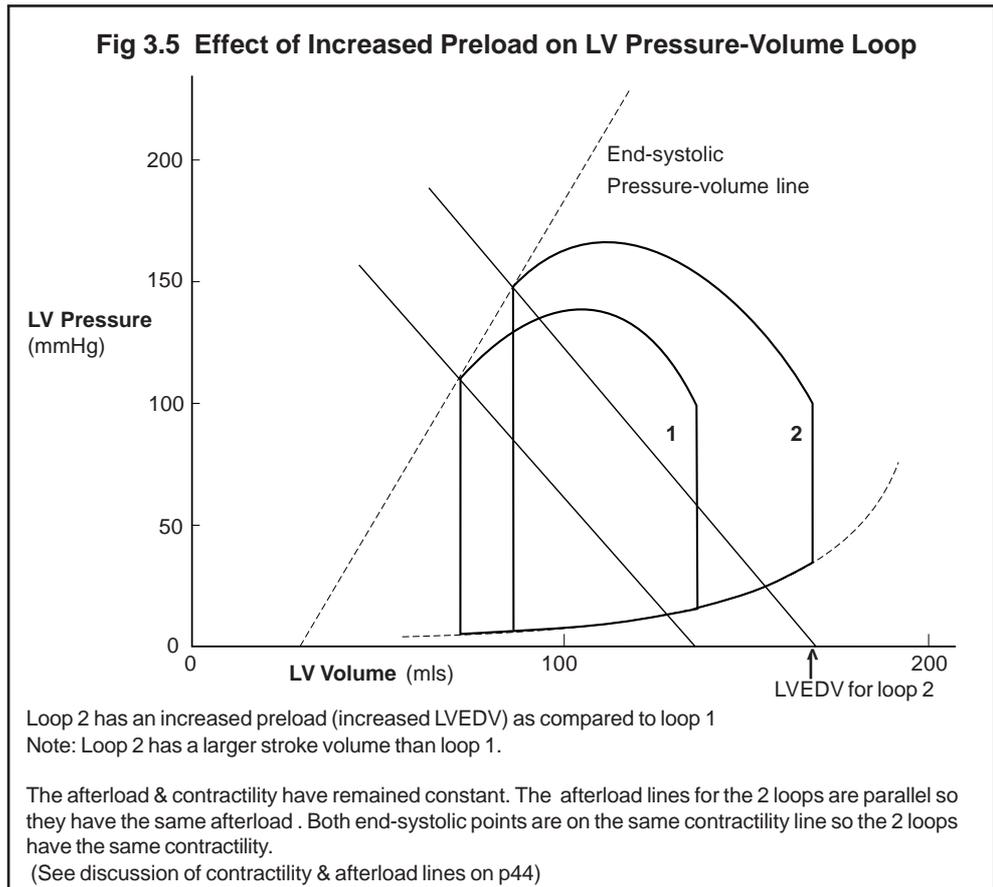
Over the typical physiological range the curve is fairly flat and only slowly curves upward. The LV volume increases without much increase in LV pressure. **The ventricle is easy to fill.** The curve begins to rise steeply outside the typical value for left ventricular end-diastolic volume (LVEDV) ie above about 140 ml. The significance here is that **the heart is difficult to 'overflow'** as the increase in pressure tends to impede excess increases in LVEDV (ie the stiffer heart is obviously harder to fill). The sarcomere length does not increase much above its optimal value of 2.2  $\mu\text{m}$  so the force of the ventricular contraction tends not to be adversely affected.

Can you draw a pressure-volume loop for the left ventricle?

Could you indicate where the mitral and aortic valves open and close?  
 Can you indicate what represents the stroke volume on this curve?



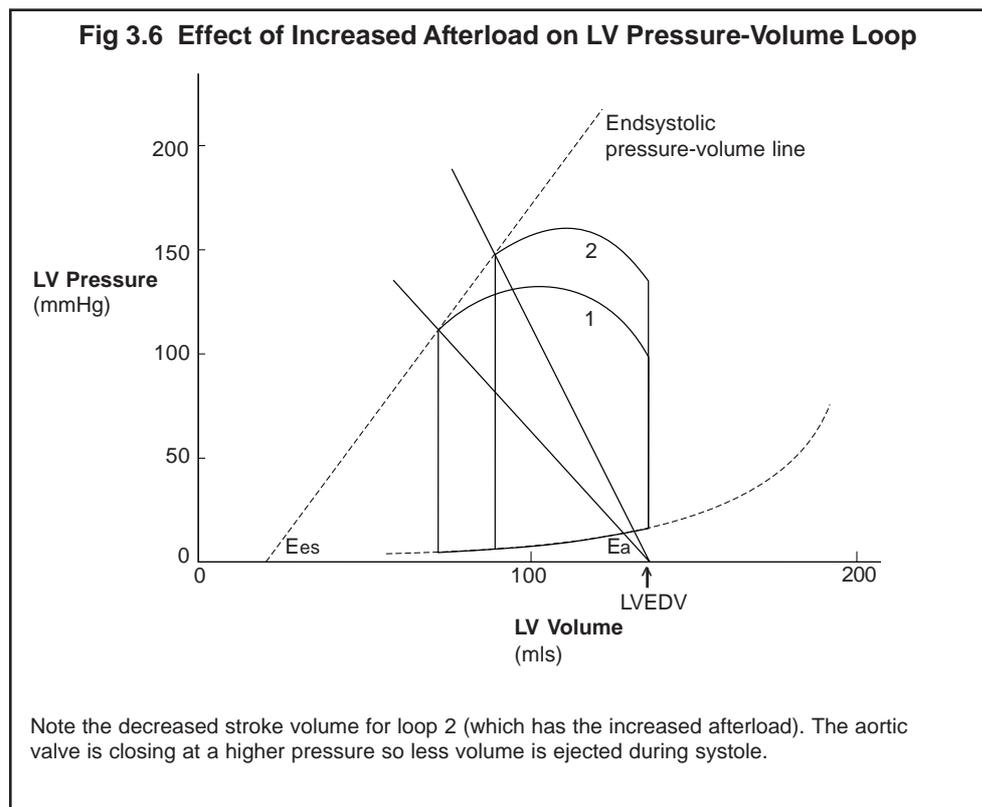
Could you superimpose another loop representing the situation where the preload has been increased but the afterload and contractility remain constant?



**What is the best index of preload on these curves?**

The point on the x-axis (volume axis) which represents end-diastole is the left ventricular end-diastolic volume (LVEDV). This point is the best index of preload on the curve (and indeed, the LVEDV is the best index in the intact heart as well). As mentioned previously, the end-diastolic pressure is less reliable as an index of preload because of changes in compliance, especially if the ventricle is particularly distended.

**Considering the original curve again: Could you superimpose a curve where afterload was increased but preload and contractility were unchanged?**



**What is the best index of afterload on a pressure-volume loop?**

The best index of afterload is the slope of the straight line connecting the LVEDV (on the x-axis) with the end-systolic point for the loop (or equivalently, the angle this line makes with the x-axis - labelled  $E_a$  in the figure). In Fig 3.6, the 'afterload lines' for loops 1 & 2 are both drawn. The 'afterload line' for loop 2 makes a larger angle with the x-axis than the line for loop 1 - thus the afterload for loop 2 is higher.

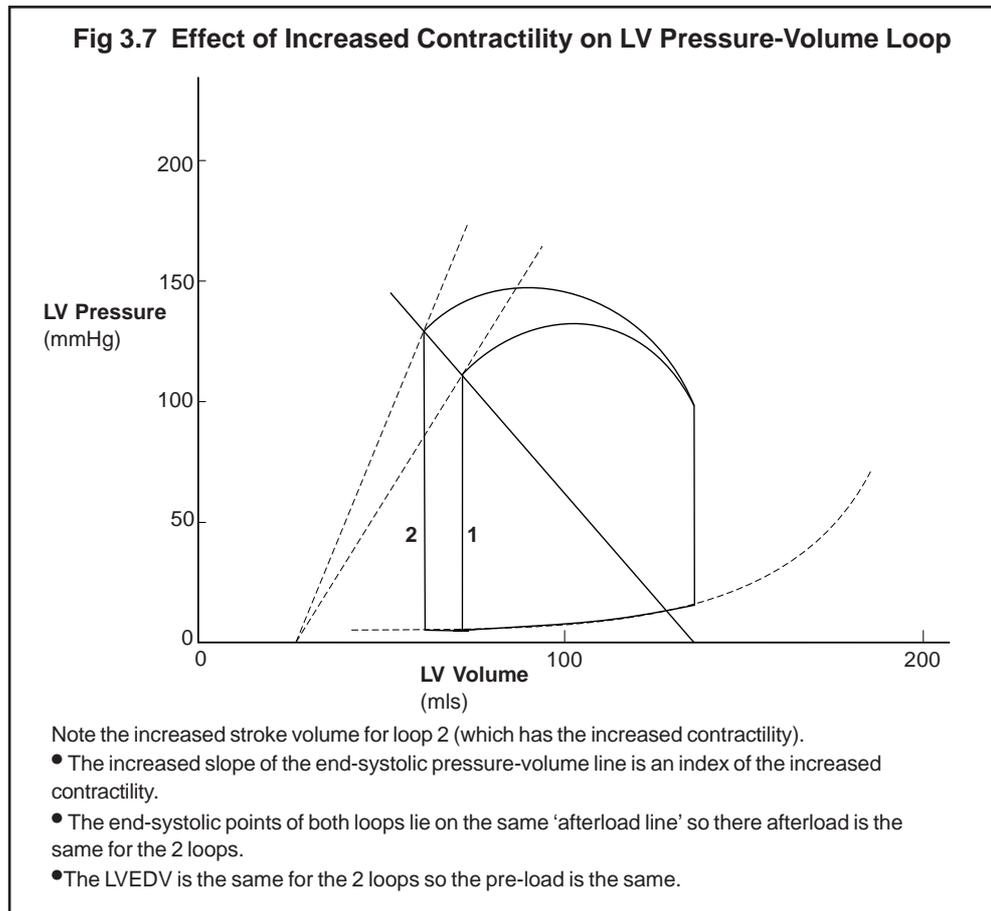
**How would you show that preload and contractility were the same for the two curves in the above diagram?**

The LVEDV is the same for both curves, so preload is constant.

The index of contractility is the *slope* of the end-systolic pressure-volume line (or equivalently the angle this line makes with the x-axis - this is labelled  $E_{es}$  in fig 3.6). The end-systolic points for loops 1 and 2 both lie on the same 'contractility line' so contractility is constant. (In practice, the end-systolic pressure-volume line would have to be established first and then the end-systolic points checked to see that they both lie on it - but for simplification here the line has just been given.)

If contractility was increased (eg by an adrenaline infusion), the pressure-volume line would have an increased slope and be rotated slightly up and to the left.

*Can you draw a curve showing the effect of an increase in contractility (while preload and afterload remain constant)?*



***What does the area within the LV pressure-volume loop represent?***

Pressure multiplied by volume is work. The area inside the loop represents the external work performed by the left ventricle for that cardiac cycle.

An increase in contractility in the diagram above (loop 2) is associated within an increased area representing the increased external work performed in ejecting an increased stroke volume.

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***Comment:*** The terms preload, afterload and contractility developed from isolated muscle experiments where it was relatively easy to define and look at the effect of changes in each separately. Converting these concepts to an equivalent and measurable quantity relevant to the intact cardiovascular system has proven to be a bit difficult.

More recently, the LV pressure-volume loop has been increasingly used to try to determine new indices to measure these quantities. The difficulty with contractility has been to obtain an index which is independent of the loading factors. Even the slope of the end-systolic pressure-volume line (known as end-systolic elastance -  $E_{es}$ ) is partly dependent on afterload.