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# EFFECT OF INTRATHORACIC PRESSURE ON LEFT VENTRICULAR PERFORMANCE

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**Abstract** Left ventricular dysfunction is common in respiratory-distress syndrome, asthma and obstructive lung disease. To understand the contribution of intrathoracic pressure to this problem, we studied the effects of Valsalva and Müller maneuvers on left ventricular function in eight patients. Implantation of intramyocardial markers permitted beat-by-beat measurement of the velocity of fiber shortening ($V_{CF}$) and left ventricular volume. During the Müller maneuver, $V_{CF}$ and ejection fraction decreased despite an increase in left ventricular volume and a decline in arterial pressure. In addition, when arterial pressure was corrected for changes in intrapleural pressure during either maneuver it correlated better with left ventricular end-systolic volumes than did uncorrected arterial pressures. These findings suggest that negative intrathoracic pressure affects left ventricular function by increasing left ventricular transmural pressures and thus afterload. We conclude that large intrathoracic-pressure changes, such as those that occur in acute pulmonary disease, can influence cardiac performance. (N Engl J Med 301:453-459, 1979)

PREVIOUS investigators[1-5] have noted that respiration and respiratory maneuvers may affect cardiac function. The exact mechanisms by which left ventricular function is depressed during exacerbation of chronic obstructive lung disease, asthma, adult respiratory-distress syndrome and restrictive lung disease have been a subject of continuing controversy.[6-11] Franklin et al.[1] and Hoffman et al.[4] measured instantaneous flows in the aorta and pulmonary artery and observed that, during inspiration, right ventricular stroke volume increased but left ventricular stroke volume decreased. These changes were attributed to alterations in ventricular filling produced by changes in intrathoracic pressure during normal inspiration. Best and Taylor[12] have stated that, during inspiration, the capacity of the pulmonary vessels is increased, blood is pulled into the lungs and the venous return to the left heart is decreased. The resulting decrease in aortic flow is reflected by the fall in aortic pressure. After a delay that lasts for a few beats during expiration, the volume of pulmonary blood returns to its pre-inspiratory value. The pooled blood in the lungs is added to the venous return to the left side of the heart and increases aortic flow. Alterations in the flow and hemodynamics of the left heart during normal respiration have thus been considered to result from changes in left ventricular filling produced by changes in intrathoracic pressure.

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Although this hypothesis predicts a decline in left ventricular volume during inspiration, Goldblatt et al.[3] have observed a marked increase in left ventricular volume during deep inspiration but no appreciable change in this volume during normal respiration. Similarly, Morgan et al.[5] have noted an increase in pulmonary venous flow in dogs during normal inspiration. From these observations one would predict, according to the Frank–Starling principle, that left ventricular stroke volume would increase during deep inspiration unless another factor was affecting left ventricular performance. Recently, Permutt and his colleagues[13-16] suggested that changes in intrathoracic pressure can affect left ventricular performance by altering left ventricular transmural pressure.

To study the effect of intrathoracic pressure on left ventricular function, we implanted intramyocardial markers in eight patients and studied them during normal respiration and during periods of negative intrathoracic pressure. Five of these patients were also studied with positive intrathoracic pressure.

## METHODS

### Patient Characteristics

The patients had received tantalum intramyocardial markers at the time of coronary-artery-bypass grafting or cardiac transplantation. All were functionally asymptomatic and clinically free of congestive heart failure. No dyssynergy had been detected on left ventriculography, and none had more than mild obstruction on pulmonary-function studies (forced expiratory volume [one second] >72 per cent of forced vital capacity). No patients were taking propranolol before this study. All gave informed consent for insertion of myocardial markers and for completion of the physiologic studies. No complications occurred as a result of this investigation.

### Measurements of Myocardial Dynamics

The use of intramyocardial markers to assess myocardial dynamics has been described previously.[17] During the operation, tiny tantalum coils (1.5 mm × 0.85 mm) were inserted into the mid-left ventricular wall in seven locations (at the apex and at approximately equidistant points between the apex and the base along the anterolateral and the inferior margins), thereby outlining the left ventricular cavity as seen in the 30° right-anterior oblique projection. Two silver-tantalum clips were placed in the aortic adventitia above the aortic valve, and from these reference points, the anterior and posterior aspects of the aortic valve in the 30° right-anterior oblique projection were delineated. The markers were visualized by single-plane (30° right-anterior oblique projection) cardiac fluoroscopy with a cesium iodide intensifier and recorded at 30 frames per second on a video disk recorder. The instantaneous amplitude of the electrocardiogram (Lead II) was recorded as a horizontal bar superimposed on the video image so that the peak of the R-wave could be identified.

At the conclusion of each fluoroscopic study, the video recordings were replayed frame by frame (stop motion). The (X,Y) co-ordinates of the marker images were digitized with a light-pen coupled to a small digital computer and corrected for magnification of the radiographic system.[18] Calculations of the volumes and velocities of fiber shortening were made with a CDC 6400 computer. Left ventricular volumes were calculated from corrected marker co-ordinates by the single-plane, area-length method of Sandler and Dodge.[19] Computations from the intramyocardial marker co-ordinates included the volume of myocardium between the markers and endocardial surface and were corrected with a regression equation obtained from a previous comparison of marker dynamics and left ventriculograms.[20] The end-diastolic volume was derived from the maximum of the instantaneous volume curve, and the end-systolic volume from the minimum. The velocity of circumferential fiber shortening was calculated from the average ventricular diameter (calculated for each frame as one third the sum of the six minor radii) as the mean rate of change from the maximum-volume frame within 50 msec of the R wave to 167 msec (five frames) later, and normalized for the maximum average ventricular diameter. This method for measurement of velocity of fiber shortening is a modification of previous methods used in unanesthetized man.[21-23]

### Experimental Protocol

Before the study, all patients were carefully instructed about the manner of performing a Valsalva and a Müller maneuver at constant pressure with an open glottis. Changes in intrathoracic pressure were inferred from changes in airway-opening pressure during a no-flow, open-glottis strain maneuver of either positive intrathoracic pressure (Valsalva maneuver) or negative intrathoracic pressure (Müller maneuver). Changes in airway-opening pressure were measured with a Boehringer inspiratory meter calibrated to a water manometer to within ±0.5 cm $H_2O$ (0.049 kPa), or directly to a P23 DB Statham transducer. Arterial pressure was measured directly from the radial artery with a 20-gauge catheter attached to a P23 DB Statham transducer and recorded on a multichannel strip-chart recorder. The electrocardiogram, arterial pressure and airway-opening pressure were recorded simultaneously with the fluoroscopic recording of intramyocardial markers during each respiratory maneuver.

Base-line recordings were made in quiet surroundings while the patient was supine; respirations were synchronized with a metronome to 20 per minute, and the tidal volume was approximately 400 ml. At least two complete respiratory cycles were recorded.

#### *Valsalva Maneuver: +20 cm $H_2O$ (+1.96 kPa)*

At the completion of an end-tidal inspiration, the mouthpiece exit valve was occluded, and the patient was asked to "bear down" to an amount deflecting the force meter to a level of 20 cm $H_2O$ (1.96 kPa). After seven seconds of sustained positive pressure, the occlusion was released, and the subject allowed to breathe spontaneously. Fluoroscopic recordings were made during the entire seven-second strain phase.

#### *Müller Maneuver: −30 cm $H_2O$ (−2.94 kPa)*

At the end of a normal end-tidal expiration, the exit valve was occluded, and the patient was asked to "pull" to an amount deflecting the force meter −30 cm $H_2O$ (−2.94 kPa). After seven seconds of sustained negative inspiratory pressure, the occlusion was released, and the subject breathed spontaneously. Fluoroscopic recordings were made during the entire seven-second strain phase. At the completion of this maneuver, the patient rested for five minutes.

#### *Müller Maneuver: −60 cm $H_2O$ (−5.88 kPa)*

In this Müller maneuver, the patient was asked to "pull" to an amount deflecting the inspiratory force meter −60 cm $H_2O$ (−5.88 kPa). Fluoroscopic recordings were made during the seven seconds of strain and for five to seven seconds during the recovery phase after release from the maneuver.

### Data Analysis

Data from each cardiac cycle were recorded during each respiratory maneuver and correlated with continuously recorded arterial-pressure tracings during the maneuver. Cardiac cycles during inspiratory and expiratory phases of quiet respiration were identified by the fluoroscopic position and motion of the diaphragm. During each of the three strain maneuvers, the first three beats after airway-opening pressure had stabilized (approximately 0.5 second into each strain phase) were designated as "early" beats, and the last two or more consecutive beats after four seconds of strain as "late" beats. The recovery phase after the −60 cm $H_2O$ (−5.88 kPa) Müller maneuver was recorded; the initial three beats after release were designated as "early recovery" beats, and the consecutive beats four seconds after release were designated as "late recovery" beats. Paired t-test statistics were used for comparison of results obtained from cardiac cycles during different respiratory maneuvers in the same subject.

## Results

The averaged data for all patients are presented in Table 1. Each data point in Table 1 is the mean of measurements of two or three consecutive cardiac cycles in each patient. Data from all eight patients (after coronary operation and after cardiac transplantation) were combined because comparison of data from the two groups showed differences only in the end-diastolic volume during the late Valsalva maneuver ($P<0.02$) and in heart rate during the late recovery after the Müller maneuver ($P<0.05$).

Mean ventricular volumes during base-line respirations did not vary significantly between inspiration and expiration. The difference in ventricular volumes, either end-diastolic or end-systolic, did not exceed 4 ml in any patient. Velocity of circumferential fiber shortening, systolic blood pressure, heart rate and stroke volume did not differ between inspiration and expiration. For these reasons, all values for each index were averaged and used as a base-line value with which changes occurring during the other respiratory maneuvers were compared.

Figure 1 summarizes the results obtained in the five patients who performed Valsalva maneuvers. Base-line measurements were obtained by pooling inspiratory and expiratory measurements of all quiet, spontaneous respirations (Table 1), and the percentage changes from these averaged base-line respiratory measurements are listed. Both end-diastolic volume and end-systolic volume fell precipitously during the

strain phase of the maneuver, and there was a concomitant decline in cardiac output. The systolic arterial pressure rose early in the strain phase but fell later as stroke volume progressively fell. During the early strain phase, velocity of circumferential fiber shortening rose in three of five patients when their ventricular volumes were falling and their heart rates were relatively constant.

Table 1 and Figure 2 summarize the results of the −60 cm $H_2O$ (−5.88 kPa) Müller maneuver. End-diastolic volume rose 9 per cent during the early strain phase of the maneuver and 11 per cent by the late strain phase ($P<0.05$) (Fig. 2). At the same time, blood pressure fell by 6 per cent ($P<0.05$), although heart rate remained unchanged. End-systolic volume rose 18 per cent during the early Müller maneuver and 25 per cent during the late Müller maneuver, as compared with base-line measurements ($P<0.01$ for both values). Ejection fraction decreased significantly during the maneuver ($P<0.001$), and the decrease reflected a greater decline in end-systolic volume than in end-diastolic volume ($P<0.001$). Velocity of circumferential fiber shortening decreased more than other indexes — by 26 per cent of base-line values late in the Müller maneuver ($P<0.001$). These changes in the indexes of ejection phase are contrary to responses anticipated on the basis of the moderate decline in systolic blood pressure, stable heart rate and increase in end-diastolic volume. There was no change in cardiac output. As shown in Table 1, the results of the −30 cm $H_2O$ (−2.94 kPa) Müller maneuver were qualitatively similar to those obtained with the −60 cm $H_2O$ (−5.88 kPa) Müller maneuver; however, the results were quantitatively less marked.

Systolic arterial pressure was taken as a measure of left ventricular afterload and correlated with changes in indexes of end-systolic volume. Systolic arterial pressure, when arithmetically corrected for intrapleural pressure (only during the strain phase of the respiratory maneuvers), yields a measure of left ventricular transmural pressure. Figure 3 shows the results of plotting both systolic arterial pressure and left ventricular transmural pressure (arterial pressure minus intrapleural pressure during strain phases) against the end-systolic-volume index in one patient. The slope of the regression line relating end-systolic volume to transmural pressure is more consistent with known myocardial-function curves than the slope obtained if systolic pressure is used without correcting for positive or negative intrapleural pressure (transmural pressure: slope = 7.9, r = 0.98, versus systolic pressure: slope = −0.9, r = 0.38). Similarly, for all the patients the average slope and fit of the lines relating end-systolic volume and pressure were more consistent with available data if transmural pressure was used instead of systolic blood pressure (systolic pressure: slope = −0.17, r = 4.40, versus transmural pressure: slope = 4.01, r = 0.80). The individual responses for all subjects, including slopes and r values, are shown in Figure 4. Immediately upon release from the −60 cm $H_2O$ (−5.88 kPa) Müller maneuver, the end-systolic-volume index falls back to base-line levels as the left ventricular transmural pressure approaches systolic blood pressure.

## Discussion

Our results suggest that changes in intrathoracic pressure markedly affect cardiac performance. This relation can best be appreciated if one examines the effects of the −60 cm $H_2O$ (−5.88 kPa) Müller maneuver. Previous hypotheses suggested that, during

Table 1. Respiratory Effects on Left Ventricular Function (Mean ± S.E.M.).*

| | Base-Line | | | Valsalva Maneuver† | | Müller Maneuver†‡ | | Müller Maneuver† | | −60 Müller Recovery† | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Expiration | vs | Inspiration§ | Early | Late | Early | Late | Early | Late | Early | Late |
| | | | | +20 cm $H_2O$ | | −30 cm $H_2O$ | | −60 cm $H_2O$ | | | |
| No. of subjects | 8 | | 8 | 5 | 5 | 5 | 5 | 8 | 8 | 8 | 7¶ |
| EDV (ml) | 146.5±16.7 | | 147.6±17 | 112.2±12.7 | 93.6±11.1 | 129.9±16 | 123.4±13.5 | 160.4±18.4 | 162.6±18.3 | 151.8±17.1 | 138.1±15.3 |
| P value | | NS | | NS | <0.01 | NS | NS | NS | <0.05 | <0.05 | |
| ESV (ml) | 84.5±12.1 | | 84.6±11.8 | 66.0±8.9 | 58±7.5 | 76.4±11.2 | 75.8±10.1 | 99.4±13.9 | 105±14.6 | 85.8±11 | 76.1±10 |
| P value | | NS | | <0.05 | <0.01 | NS | NS | <0.01 | <0.01 | NS | NS |
| $V_{CF}$ (circ/sec) | 0.68±0.07 | | 0.68±0.06 | 0.72±0.09 | 0.67±0.07 | 0.58±0.12 | 0.55±0.08 | 0.56±0.08 | 0.50±0.06 | 0.71±0.08 | 0.77±0.07 |
| P value | | NS | | NS | NS | NS | <0.05 | <0.01 | <0.001 | NS | NS |
| BP (mm Hg) | 144±5 | | 144±5 | 151±11 | 134±11 | 139±8 | 139±9 | 139±5 | 136±5 | 129±5 | 129±8 |
| P value | | NS | | <0.05 | NS | <0.05 | NS | <0.05 | <0.05 | <0.05 | <0.05 |
| HR | 86±4 | | 87±4 | 85±5 | 87±5 | 83±6 | 81±6 | 87±6 | 87±6 | 90±4 | 94±3 |
| P value | | NS | | NS | NS | NS | NS | NS | NS | NS | NS |
| EF | 43.3±2.7 | | 43.4±2.8 | 41.1±2.3 | 38.2±2.2 | 41.4±3.5 | 39.0±2.6 | 38.6±3.2 | 36.1±3.1 | 43.8±2.7 | 45.4±2.9 |
| P value | | NS | | NS | <0.05 | NS | <0.01 | <0.001 | <0.001 | NS | NS |
| CO (liters/min) | 5.3±0.5 | | 5.4±0.5 | 3.9±0.4 | 3.1±0.4 | 4.3±0.5 | 3.8±0.5 | 5.3±0.7 | 4.9±0.7 | 5.8±0.7 | 5.9±0.8 |
| P value | | NS | | NS | <0.01 | NS | NS | NS | NS | NS | NS |

*To convert to kilopascals (kPa), multiply values by 0.098.

†P values compare results of interventions with mean base-line values (base-line expiration and inspiration were average).

‡All subjects did not perform the −30 cm $H_2O$ Müller maneuver. In the 5 who did, the average base-line values for this maneuver were end-diastolic volume (EDV) 128 ml, end-systolic volume (ESV) 73 ml, velocity of circumferential fiber shortening ($V_{CF}$) 0.68 circ/sec, peak systolic blood pressure (BP sys) 145 mm Hg, heart rate (HR) 83, ejection fraction as % end-diastolic volume (EF) 0.42 and cardiac output (CO) 4.6 liters/min.

§Not significant when expiration is compared with inspiration.

¶Insufficient data were collected from 1 subject.

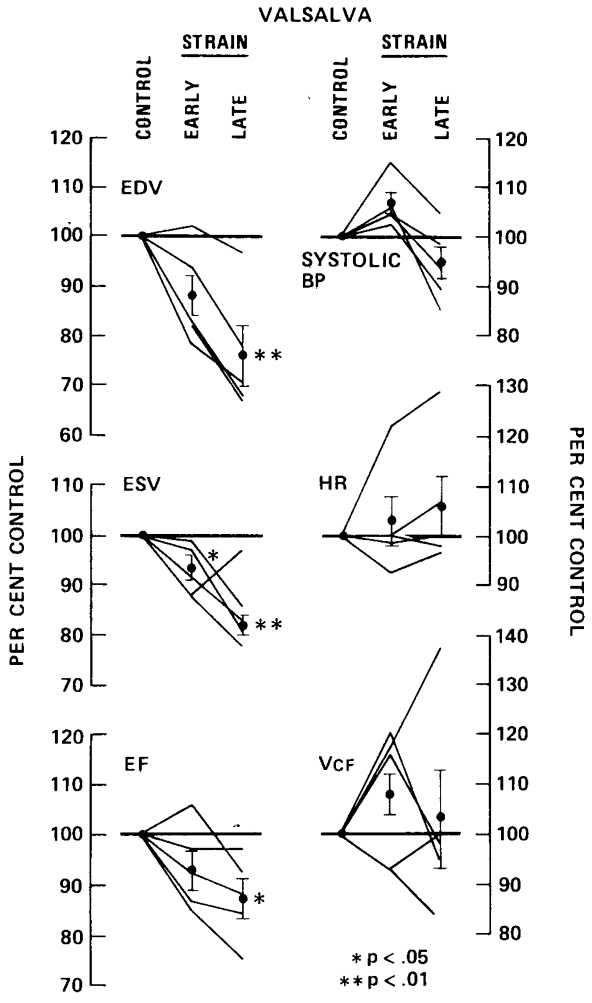


Figure 1. Valsalva Maneuver.

Each line represents the average of three beats for each subject as a per cent change from the respective base-line values for the measurements listed. The circles and I bars denote mean changes ± S.E.M. EDV denotes end-diastolic volume, ESV end-systolic volume, EF ejection fraction, BP blood pressure, HR heart rate and $V_{CF}$ velocity of circumferential fiber shortening.

negative intrathoracic-pressure maneuvers, right ventricular and pulmonary pooling would decrease left ventricular filling; however, we observed that left ventricular end-diastolic volume increased. Since end-diastolic volume increased at a time when arterial pressure was falling and heart rate was relatively constant, one would predict an increase in indexes of ventricular function, such as velocity of fiber shortening and ejection fraction. However, we observed consistent and statistically significant decreases in both these indexes. Our findings are supported by those of Schrijen et al.,[15] Sommer et al.[16] and Robotham et al.,[24] who demonstrated increases in left ventricular filling pressures, end-diastolic volumes and end-systolic volumes during deep inspiration and during the Müller maneuver in dogs. These seemingly paradoxical observations can best be explained by the suggestion of Permutt and his co-workers[13-16] that changes in transmural left ventricular pressure ($P_{TM}$) — i.e., left ventricular pressure ($P_{LV}$) relative to intrapleural pressure ($P_{PL}$), or $P_{LV}$ minus $P_{PL}$ — more accurately reflect left ventricular afterload than does systolic aortic pressure during situations of dynamic alterations in intrapleural pressure.

Thus, indexes of left ventricular function decline markedly at a time when heart rate, arterial pressure and preload would predict improved left ventricular performance.[25,26] A decline in left ventricular performance is indicated by the observation that during sustained negative intrathoracic pressure left ventricular end-systolic volume is also markedly increased. Recently, Grossman et al.[27] have used end-systolic

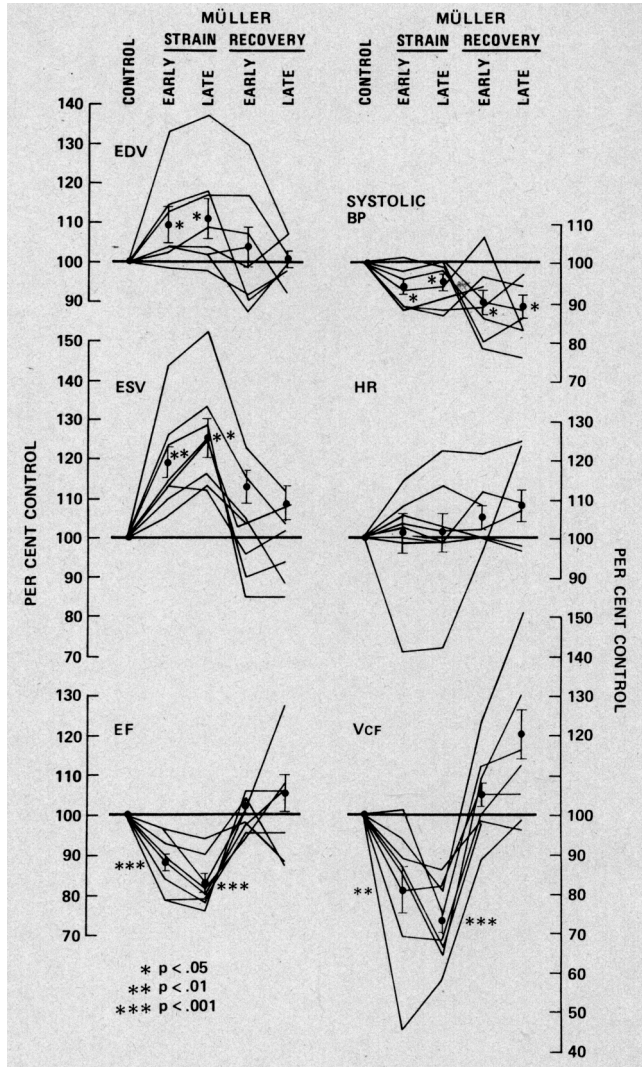


Figure 2. Müller Maneuver and Recovery.

Each line represents the average for each subject as a per cent change from the respective base-line values. The circles and bars denote mean changes ± S.E.M., and the abbreviations are the same as those in Figure 1. The values for early recovery were measured immediately after release from the −60 cm $H_2O$ (−5.88 kPa) Müller maneuver strain.

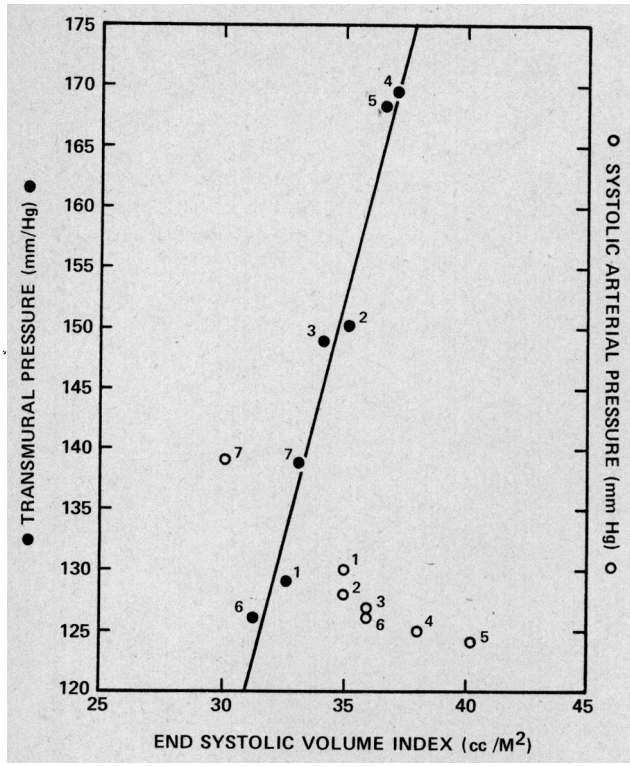


Figure 3. Average Values for Left Ventricular End-Systolic Volume and Systolic Arterial Pressure (Open Circles) or Left Ventricular Transmural Pressure (Solid Circles) in One Patient (Open Triangles in Figure 4).

(The number 1 denotes control values, 2 and 3 the early and late strain phases of the −30 cm $H_2O$ (−2.94 kPa) Müller maneuver, and 4, 5, 6 and 7 the early strain, late strain, early recovery and late recovery phases of the −60 cm $H_2O$ (−5.88 kPa) Müller maneuver. Volumes are normalized according to square meters of body-surface area.)

pressure-volume relations as a measure of left ventricular performance, and Marsh et al.[28] have established their linearity. The relation between end-systolic pressure and volume is thought to be independent of preload. When these workers increased afterload with pharmacologic pressor agents, left ventricular end-systolic volume also increased.

When similar comparisons are made between baseline values and values obtained during the Müller maneuvers in our subjects, end-systolic volume is increased significantly ($P<0.001$), but there is no significant change in systolic blood pressure. In some subjects there was simultaneous decrease in systolic blood pressure and increase in end-systolic volume — an observation that is in disagreement with known curves for left ventricular function.[27] If the calculated left ventricular transmural pressure ($P_{TM} = P_{LV} - P_{PL}$) is substituted for the observed systolic blood pressure, the relation parallels that observed when systolic blood pressure is elevated by pressor agents. The changes in left ventricular function observed in our subjects are consistent with rapid, marked changes in afterload (Fig. 3 and 4). Thus, it is inappropriate to regard systolic blood pressure as the only determinant of afterload when intrathoracic pressure is changing markedly. Both a fall in intrathoracic pressure and an increase in aortic (or left ventricular) pressure can increase transmural left ventricular pressure (and afterload) in the same manner (Fig. 5).

The observation in denervated human hearts[29] of declines in velocity of fiber shortening and increases in end-systolic volume that were similar to those of innervated hearts suggests that these changes in myocardial function are independent of heart rate and autonomic tone. Although sudden changes in left ventricular myocardial contractility cannot be entirely excluded as an explanation for these changes, it is unlikely that a sudden negative intrathoracic pressure would affect left ventricular contractility directly.

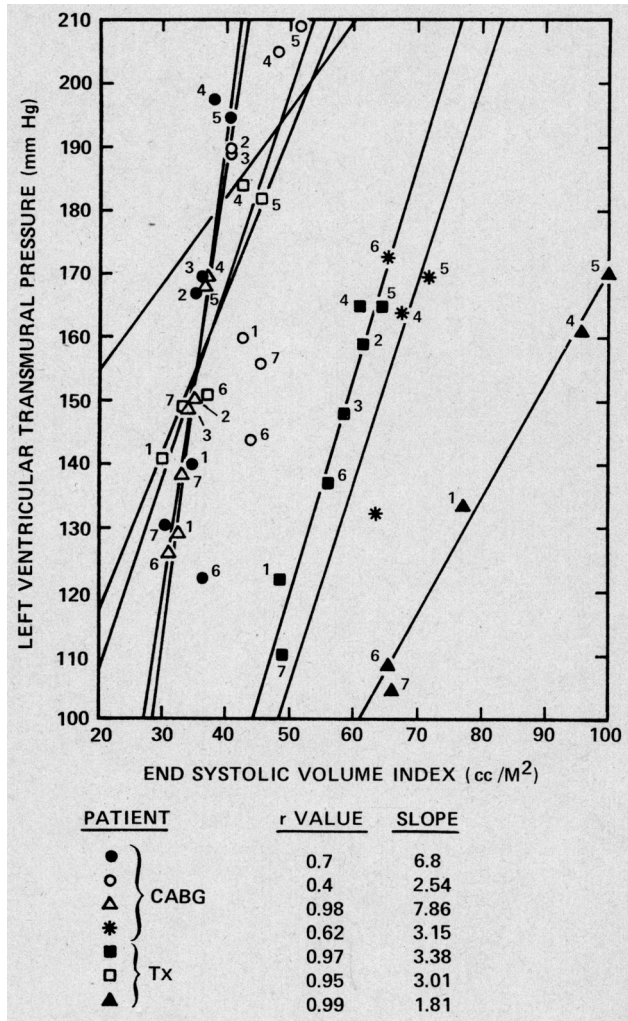


Figure 4. Average Values for Left Ventricular End-Systolic Volume and Left Ventricular Transmural Pressure Plotted for Each Subject.

The reference points are explained in the legend to Figure 3. Volumes are normalized according to square meters of body surface area. CABG denotes coronary-artery-bypass graft, and Tx transplantation. Data points for one Tx patient are not shown. The r value was 0.34 and the slope 2.20.

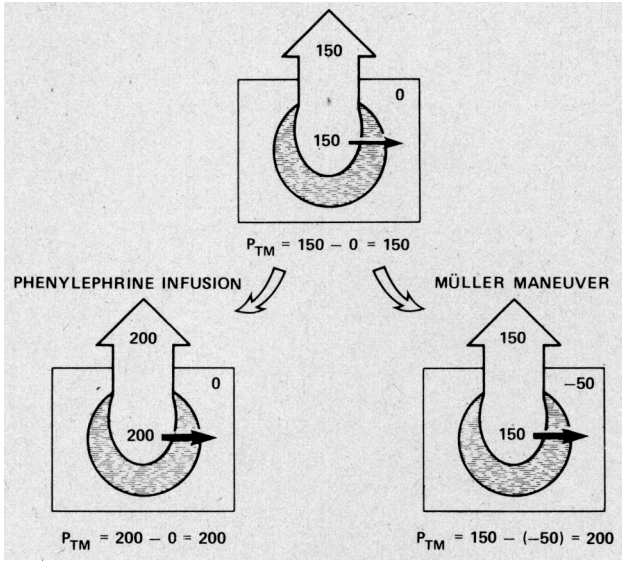


Figure 5. Schematic Representation of the Left Ventricular Wall, Thoracic Cavity and Aorta, Showing That Similar Changes in Left Ventricular Transmural Pressure ($P_{TM}$) Can Be Induced by Elevating Aortic Pressure (Phenylephrine Infusion) or Lowering Intrathoracic Pressure (Müller Maneuver).

The absolute effect of negative intrathoracic pressure occurred throughout the Müller maneuver. Upon release the velocity of fiber shortening, ejection fraction, end-systolic volume and end-diastolic volume rapidly returned to control values. These observations are again consistent with the sudden release of sustained afterload.

Our findings of statistically significant decreases in left ventricular end-diastolic volume, stroke volume and cardiac output during the Valsalva maneuver agree with those of Brooker et al.[30] One would predict from these changes a fall in velocity of fiber shortening according to the Frank–Starling mechanism. However, we observed no significant change in velocity of fiber shortening throughout the Valsalva maneuver. Since left ventricular transmural pressure ($P_{LV} - P_{PL}$) decreases during the Valsalva maneuver, it is possible that positive intrathoracic pressure unloads the left ventricle at a time when the preload is decreasing and thus maintains velocity of fiber shortening by decreasing its relative afterload.

Our observations during quiet respiration are in accord with those of Goldblatt et al.,[3] who showed that left ventricular end-diastolic volume, end-systolic volume and velocity of fiber shortening do not change between inspiration and expiration — suggesting that small changes in intrathoracic pressure (less than ±5 cm of $H_2O$ [±0.049 kPa]) affect left ventricular function minimally.

It should be recognized that operations on the heart had been performed in our patients, and that the anterior pericardium had been opened widely and not reopposed. The filling characteristics of both left and right ventricles may have been modified to some extent because, in the absence of a pericardium, the absolute volume of blood in one ventricle would not be as limiting a factor on the other.[31] Although the amount of ventricular filling could thus be affected, directional changes in volume are unlikely.

A possible limitation of this study is that respiratory increases in right ventricular volumes could alter septal position and curvature and cause a reduction in left ventricular volume that might not be detected by the distribution of right-anterior-oblique myocardial markers. However, the proportion of left ventricular wall potentially affected by this interaction is relatively small, and it is unlikely that flattening of the left ventricle would be so marked that the observed 18 to 25 per cent increase in right-anterior-oblique volumes during the Müller maneuver would be negated by septal incursion.

Changes in left ventricular performance were most evident with the −60 cm $H_2O$ (−5.88 kPa) Müller maneuver but less prominent with lesser degrees of inspiratory effort. It is therefore likely that this mechanism has a physiologic role only in situations of marked swings in pleural pressure or of previously compromised left ventricular function, which could make cardiac performance more sensitive to smaller changes in afterload.

The fact that large changes in intrathoracic pressure can markedly alter left ventricular performance has important clinical implications. Recently, Stalcup and Mellins[6] have demonstrated that patients with asthma have negative intrathoracic pressures during acute episodes. Pulmonary edema may subsequently develop in these patients even though the myocardial contractile state is normal.[7] Our observations of impaired cardiac function during sustained negative intrathoracic pressure may help to explain this phenomenon. In asthma, abnormal airway narrowing produces additional negative pleural pressure, which increases right and left ventricular afterload. The resulting elevation in pulmonary and bronchiolar microvascular pressures can lead to interstitial edema.[6] Stalcup and Mellins suggest that fluid administration should be limited in the management of acute asthmatic attacks.

Several investigators[8-10] have emphasized the prevalence of left ventricular hypertrophy and subsequent congestive heart failure in patients with chronic bronchitis and emphysema. Although additional disorders have explained these cardiac changes in many of these patients, the explanation in many others has been unknown. With the knowledge that negative intrathoracic pressure can cause a functional afterload of the left ventricle, one might speculate that the large changes in negative intrathoracic pressure that occur in these patients throughout life may be a factor in

altered myocardial function. Similarly, our observations would have important implications in patients maintained on artificial respirators. Large increases in positive ventricular pressure with positive end-expiratory pressure and continuous positive airway pressure may be a factor in improvement in pulmonary compliance and left ventricular function in these patients.[32] Recent studies have demonstrated that sustained negative intrathoracic pressure can abolish left-ventricular-outflow-tract gradients when they are present in patients with idiopathic hypertrophic subaortic stenosis.[33,34]

We have demonstrated that large, sustained changes in intrathoracic pressure may affect left ventricular function not only by altering ventricular filling but also by changing afterload. When left ventricular transmural pressure falls, afterload decreases; when left ventricular transmural pressure increases, afterload increases. In the presence of large changes in intrathoracic pressure in man, one must consider their influence on left ventricular transmural pressure and the resulting effects on cardiac performance.

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