The Effect of the Valsalva Maneuver on Echocardiographic Dimensions in Man

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SUMMARY Physiologic changes in the circulatory system caused by performing the Valsalva maneuver are blunted or absent in patients with congestive heart failure. Previously there has been no noninvasive method for examining cardiac chamber size during this maneuver. M-mode echocardiography was used to evaluate possible changes in cardiac chamber dimensions in 12 normal subjects (group I) and 15 patients with cardiovascular disease (group II). In group I, the left ventricular end-diastolic dimension decreased 11.2% (±1.5%) and the end-systolic dimension 9.5% (±1.32%), with a fall in stroke volume of 29%. The left atrial (LA) dimension decreased 30%.

The Valsalva Maneuver, raising intrathoracic pressure against a closed glottis ("forced expiration"), and the Mueller maneuver, reducing intrathoracic pressure behind a closed glottis ("forced inspiration"), have been used in the investigation of cardiovascular hemodynamics and autonomic nervous system function. Both produce marked hemodynamic changes, resulting in widespread alterations in the central and peripheral circulation. Disease states alter these responses.

The echocardiogram permits the noninvasive determination of an internal dimension of the left atrium, aorta, and left ventricle. We investigated the echocardiogram during the Valsalva and Mueller maneuvers in normal volunteers and in patients with heart disease to determine the change in cardiac chamber size that such maneuvers might produce and the correlation of this change with abnormalities of cardiovascular function.

Methods

Twenty men and seven women were studied. Group I was composed of 12 normal subjects (age range 21 to 58 years, mean = 32) who had no history of cardiovascular or other disease. These subjects were chosen from a group of 24 volunteers because they had satisfactory ventricular and atrial echograms throughout the Valsalva maneuver. Group II consisted of 15 patients (19 to 65 years, mean = 47) admitted to Vanderbilt University Hospital for cardiac evaluation and included patients with ischemic heart disease, aortic stenosis, mitral regurgitation, mitral stenosis and one with severe hypertension. These patients (excepting the hypertensive patient) underwent cardiac catheterization within one week of the study described below. Their clinical status and medications were stable between the two studies.

All echocardiograms were performed in the supine posture with patients in the postabsorptive state. Echocardiograms were done using an Ekoline 20A, Hoffrel 101C, or Unirad Series C ultrasonoscope, and recordings were made on a Honeywell 1858 or Cambridge strip chart recorder. A 2.25 MHz, 13 mm diameter, nonfocused transducer with a repetition rate of 1,000 cycles per second was used. Transducer position was maintained constant throughout control and experimental maneuvers after initial echocardiographic exploration for rotation of the left atrium did not suggest that lateral or cephalo-caudal motion of the atrium accounted for the alteration in dimension observed.

The Valsalva and Mueller maneuvers were calibrated using a standard mouthpiece connected in parallel to a graduated manometer and a Statham transducer. The manometer displayed the positive or negative pressure generated by the patient and was placed in view of the patient so that he could maintain the desired pressure. The pressure generated was recorded on the echocardiogram (via a pulse amplifier) or the time during which it was maintained was marked by a separate observer using a marker channel on the strip chart recorder. All subjects were thoroughly instructed and practiced each maneuver several times. Movement and tension of the thoracic and abdominal musculature were observed to ensure valid performance.

Left atrial diameter was measured as an internal dimension from the posterior aortic root echo to the atrial wall echo at both maximal and minimal points for each cardiac cycle. Measurements were made only from echocardiograms that demonstrated aortic valve leaflets within the root, so as to ensure stability of transducer position throughout the Valsalva maneuver. Also, the diameter of the aorta was monitored for alteration in size, since lateral motion of the heart at the level of the aorta would give an apparent decrease in aortic diameter as the ultrasonic beam traversed the aorta eccentrically. Significant changes in the aortic dimension did not occur.

Left ventricular end-diastolic dimensions were taken just below maximal mitral valve excursion, where septum and posterior endocardium were clearly defined, and were timed to coincide with the Q wave of the simultaneous electrocardiogram. End-systolic dimensions were taken at the point of most anterior movement of the posterior endocardium. All echocardiograms were measured by two observers with an average difference in dimension change measurement of 1.
mm. A representative normal response with dimensions indicated is illustrated in figure 1. Estimates of ventricular volume and stroke volume before and during the Valsalva maneuver were derived using the formulas of Pombo and associates, and others. The formula of Pombo was finally used for the absolute volumes reported here. In the patient group ventricular dimensions were not always obtainable during the Valsalva maneuver; because of the small number of cases in which data are available, these results are not presented.

Results were analyzed for significant change from control values using paired t-tests. Regression lines correlating atrial dimension change and changes in heart rate were derived.

Results

Normal Subjects

Normal subjects responded to a 40 mm Hg Valsalva maneuver with a reduction in cardiac chamber size. The left ventricular end-diastolic dimension ultimately decreased an average of 11.2% (±1.5%) while the end-systolic dimension was reduced 9.5% (±1.3%) and the echocardiographic estimate of stroke volume was reduced by 29% (fig. 2). The dimensions changed little during the first three seconds of the Valsalva maneuver, but then began to decline progressively over an average of 12 seconds, after which the dimensions remained stable until the positive intrathoracic pressure was released. A slight and statistically insignificant initial increase in left ventricular dimension was recorded in 8 of 12 subjects. During the "overshoot phase" (5–7 seconds after release of positive intrathoracic pressure), increased respiratory activity prevented recording of clear ventricular wall echos.

The left atrial chamber size was even more sensitive to changes in intrathoracic pressure. Atrial dimensions were reduced 30% and 28% respectively when measured at their maximal and minimal size during the cardiac cycle (fig. 3). Since there was little difference between the changes in maximal and minimal dimensions, we considered only the maximal dimension in further investigations. The decrease in
atrial size began at about 3 seconds into the maneuver and continued for about 9 seconds. While the atrial dimensions appeared to increase to greater than control values during the overshoot phase, accurate measurement was again hindered by respiration.

The heart rate increased an average of 20 beats/min during the Valsalva maneuver \( (P < 0.001) \). The acceleration in heart rate for the 12 normal subjects ranged from 8–34 beats per minute. The correlation coefficient between atrial size change and heart rate change was 0.76. In general, those whose atrial dimension changed the most also had the greatest changes in heart rate.

The unexpectedly large change in left atrial dimension with 40 mm Hg positive intrathoracic pressure prompted investigation of lower levels of pressure. On 14 occasions in four subjects, we determined left atrial dimension change with positive pressures of 40 mm Hg, 30 mm Hg, 20 mm Hg, and 10 mm Hg. Significant alterations in left atrial dimension were noted even at 10 mm Hg, with left atrial dimension decreasing by 13%. The other positive pressures affected the
atrial dimension in a linearly progressive fashion (fig. 4).

Compared to the Valsalva maneuver, the Mueller maneuver produced very modest alterations. Left atrial maximal dimension and the left ventricular dimension remained stable during the maneuver. The left atrial minimal dimension increased an average of 4% (statistically insignificant), with 11 of 12 subjects demonstrating this response.

The heart rate fell an average of 5 beats/min during the Mueller maneuver (P < 0.01), but no overshoot phenomenon was observed.

Patients

Because of the difficulty in recording a clear left ventricular echo throughout the Valsalva maneuver, and because the left atrial dimension was far more sensitive to the maneuver, this latter parameter was examined in patients with various forms of heart disease (table 1). Patients receiving sublingual nitroglycerin, sublingual isosorbide dinitrate, or propranolol were studied at the end of a dose interval, no less than six hours after the last dose of either of these medications. (Patient L. C. was receiving propranolol for otherwise intractable angina despite the coexistence of severe congestive failure. This latter condition predated the use of propranolol and was not clinically worsened by this medication.)

In contrast to the 30% reduction in left atrial dimension induced by the Valsalva maneuver in normal subjects, nine patients in NYHA functional class III or IV reduced their left atrial dimension by an average of only 3.8% (P < 0.001 compared with group I response). All these patients had diminutions in left atrial size of 6% or less except patient R. H. who was receiving α-methyldopa. Two representative responses of patients in failure are shown in figure 5. The four asymptomatic patients, those in NYHA functional Class I, did not differ from normal subjects in their response to the Valsalva maneuver. In general, subjects with little change in atrial dimension with Valsalva also had little or no increase in heart rate during the maneuver.

Because the Mueller maneuver produced no significant change in normal subjects, it was not investigated in patients.

Discussion

The Valsalva maneuver is best understood in terms of its four phases. At the onset of the maneuver, when intra-

![Figure 4](image_url)
These unretouched echocardiograms show two abnormal left atrial responses to the Valsalva maneuver in patients with NYHA class IV (top strip) and class III (bottom strip) congestive heart failure. The wavering line in each strip represents the beginning and duration of the Valsalva maneuver as marked by an observer; its direction of movement is arbitrary — in both cases a 40 mm Hg Valsalva was performed. Note that the bottom strip demonstrates an abnormal response despite normal left atrial size and normal aortic root amplitude of motion. AR = aortic root; AV = aortic valve; LA max = maximal left atrial dimension; LA min = minimal left atrial dimension; AVC = closure line of the aortic valve.

While cardiac chamber pressures and systemic blood pressures during the Valsalva maneuver have been investigated, changes in cardiac chamber size have been more difficult to assess. It was noted early that the cardiac silhouette on chest X-ray became smaller during the Valsalva maneuver, and during the overshoot phenomenon, sometimes became slightly overdistended in patients with mitral stenosis. This was thought to be due to the temporary dilatation of the left atrial appendage and was proposed as a radiographic sign of this valvular abnormality.

The technique of suturing metal markers to the surface of the ventricles during cardiac surgery and subsequently analyzing cineradiographic studies of such patients during various physiological and pharmacological interventions has been shown to correlate with but not estimate chamber volumes. By this method a right ventricular dimension decreased sharply during the Valsalva maneuver while the left ventricular dimension initially remained constant or increased slightly but then diminished. During overshoot, the ventricular end-diastolic dimension increased an average of...
5% above control. Angiographic studies revealed a 50% decrease in stroke volume during the Valsalva maneuver, with shortening of the duration of ejection and reduction in aortic cross-sectional area by 17%. Angiographically estimated ventricular size decreased to 50% of control in five patients performing the Valsalva maneuver during left ventriculography. Release of pressure was attended by a sharp rebound of left ventricular volume to control levels with transient increase in cardiac output to 42% above that of the resting state. A problem in the interpretation of the angiographic data has been the necessity of using contrast medium which may itself alter myocardial function and cardiac output. Echocardiography provides an easily repeated, noninvasive method which itself has no effect on cardiac function.

The echocardiographic observations reported here are consistent with the angiographic data. However, since the view of the heart is limited to a single axis, one must eliminate artifactual causes of the phenomena observed. Possible alternative explanations for the apparent diminution in atrial echocardiographic dimension included certain potential technical difficulties: 1) rotation of the atrium during the maneuver altering the dimension through which the ultrasound beam traveled and 2) conformation change in the atrium induced by movement of the esophagus. As mentioned above, echocardiographic exploration during the Valsalva maneuver did not reveal a larger atrial dimension in any direction. To observe the behavior of the esophagus during positive intrathoracic pressure one subject performed the Valsalva maneuver in the course of an upper gastrointestinal survey. The barium-lined esophagus was observed radiographically and found to remain collapsed during the maneuver without any impingement on the left atrium.

Because the echocardiogram permits noninvasive study of cardiac chamber size on a beat-to-beat basis, we applied this technique to patients with heart disease. Patients with most severe congestive heart failure had the least decrease in left atrial size with positive intrathoracic pressure. In several patients, the left atrial size did not change at all, and in one patient it increased slightly. It is conceivable that with greater intrathoracic pressures there would be a more "normal" response of left atrial size. The standard Valsalva maneuver, however, required considerable effort, and higher levels of pressure were not attempted in this study.

The findings in this study may explain the so-called "square-wave" phenomenon previously noted in patients with congestive heart failure. Instead of the diminution in systolic pressure and pulse pressure seen in normal subjects, in patients with heart failure the pulse pressure often does not decrease, and the systemic blood pressure may be raised for the duration of the positive intrathoracic pressure. If it is possible to generalize from the response of the left atrium, our data suggest that the failure of the pulse pressure to diminish in these subjects may relate to the fact that their heart chambers do not change in size with the maneuver, and heart volume remains near control levels.

Other physiological maneuvers have been used to differentiate normal subjects from patients with cardiovascular dysfunction. Lower body negative pressure (30 mm Hg) reduced cardiac output and stroke volume by 20% in normal subjects but these parameters were unchanged in two patients with advanced heart failure. Upright tilting reduced left ventricular end-diastolic volume index as estimated from echocardiographic dimensions in normal subjects, and this parameter also remained unchanged in subjects with left ventricular failure. These physiological maneuvers and the Valsalva maneuver are similar in at least one respect: all are associated with a peripheral pooling of blood in normal subjects, and this is accompanied by an increased heart rate and often a demonstrable fall in blood pressure.

Possible explanations of the insensitivity of patients with heart failure to these maneuvers include: 1) alterations in blood volume; 2) functional and/or structural changes in the heart or vascular system; and 3) altered activity of the sympathetic nervous system.

Increases in blood volume are known to occur in heart failure. This could interfere with the ability to pool blood efficiently in response to postural or pressure stimuli. Structural and functional changes in the cardiovascular system are also known to accompany heart failure. Increased arteriolar vascular stiffness that is unrelated to sympathetic nervous function has been described; should structural changes also occur in peripheral veins, alterations in venous capacitance might result and impede peripheral pooling. In patients with valvular heart disease, it might be supposed that simple obstruction to outflow could diminish the response to Valsalva. While this may indeed play a role, it does not account for those patients with the most abnormal responses, more than half of whom had no obstructive valvular lesions. It is, however, of interest that one patient with mitral stenosis had an abnormal left atrial and normal left ventricular response suggesting that outflow obstruction may in some cases account for a significant part of the abnormal response. It may be that in these cases both the severity of congestive failure and the abnormality of the response are related to the degree of obstruction to outflow.

The increased activity of the sympathetic nervous system in severe heart failure is suggested by an increased urinary norepinephrine excretion, a raised plasma norepinephrine level at rest, and such clinical evidence as tachycardia, diaphoresis, suppression of urine formation and peripheral vasoconstriction. The increased venous tone seen in heart failure is due, at least in part, to this increased sympathetic activity. The combination of increased peripheral venous tone and elevated blood volume would seem to be plausible explanations for the lack of decrease in heart size during positive intrathoracic pressure in patients with heart failure.

The echocardiographic atrial response to the Valsalva maneuver is an objective correlate of the severity of congestive failure. The sensitivity of this correlation needs further documentation; the observation, however, may provide an additional clinical tool for further evaluation of patients with cardiovascular disease.

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Intracardiac Pressure-Sound Correlates of Echographic Aortic Valve Closure

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SUMMARY Echographic aortic valve closure was compared to the diastolic notch of the aortic pressure and intracardiac A₂ to define the exact temporal relationship of the echographic, pressure, and sound parameters of aortic valve closure. Sixteen children, ages 3–20 years, were evaluated by simultaneous aortic valve echograms, micro-manometric aortic root pressure tracings, and intracardiac phonocardiograms recorded at paper speeds of 200 mm/sec. Our observations demonstrated that echographic coaptation of the aortic valve leaflets coincides with the slope of the aortic pressure incisura and the onset of A₂. The data suggest that A₂ is a result of valve closure.

ALTHOUGH considerable controversy exists regarding the genesis of the aortic component of the second heart sound (A₂), two major views prevail. One view contends that A₂ is a direct result of aortic valve closure (AVC). The other theory relates the genesis of A₂ to the vibrations that result from rapid acceleration and deceleration of blood within the cardiovascular system. The latter theory de-emphasizes the role of semilunar valve closure.

Cineangiographic studies in animals have demonstrated AVC to be coincident with the incisura of the aortic pressure curve but preceding A₂. Data from these studies supported the view that AVC does not generate A₂. Echocardiographic studies which allow clear, instantaneous delineation of aortic leaflet closure have been brought recently into the controversy.

Some investigators appeared to have demonstrated that echographic AVC preceded the surface recording of A₂, while data from Craig suggested that echographic AVC and the surface recorded A₂ were simultaneous.

Consequently, a study was undertaken of three simultaneously compared intracardiac events in order to delineate exact temporal relationships of echographic, pressure, and sound parameters of AVC. The three events were echo-
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