The Study of the Third Heart Sound in Relation to the Left Ventricular Filling and Wall Movement by Echocardiography

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SUMMARY

The left ventricular filling and wall movement were investigated in subjects with a third heart sound or ventricular gallop by echocardiography. Nine patients with ventricular gallop, who had left ventricular volume overload diseases, and 6 normal subjects with a third heart sound had higher normalized peak rate of increase of the left ventricular dimension (peak $dD/dT/D$) than 10 normal subjects without a third heart sound ($p < 0.01$). The normalized lengthening rate in the rapid filling phase was also higher in patients with ventricular gallop than in normal subjects without a third heart sound ($p < 0.05$). The time from the second heart sound to peak $dD/dT/D$ and rapid filling time did not show statistically significant values between subjects with ventricular gallop or a third heart sound and those without a third heart sound.

These results suggest that higher peak filling, larger filling volume in the rapid filling phase and more abrupt cessation of the outward movement of the left ventricular wall may be a cause of the production of ventricular gallop in patients with left ventricular volume overload and of the physiological third heart sound.

Additional Indexing Words:

Peak $dD/dT/D$ Rapid filling phase IIA-peak $dD/dT/D$ time
Rapid filling time

THE third heart sound has been related to blood flow in early diastole by many investigators. The augmentation of the third heart sound which accompanies elevated cardiac output is a well established clinical observation. However, the accentuated third heart sound in low output congestive heart failure is a disturbing and hardly less important clinical observation. Porter et al¹⁾ demonstrated that peak filling rates in early diastole were higher

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in patients with ventricular gallop than in normal subjects with the third heart sound. However, Prewitt et al²⁾ observed that peak rates of left ventricular wall movement in early diastole were similar in patients with and without the third heart sound.

Although previous studies on ventricular filling were performed with angiocardiology, the development of the echocardiographic method, which gives excellent resolution in time and allows rapid movements to be analysed, has made it possible to measure left ventricular volume.³⁾⁻⁵⁾ And also Sakamoto et al⁶⁾ suggested that the third heart sound occurs when the momentum of the moving mass of blood is abruptly arrested at the check point during rapid ventricular filling. The present study attempts to elucidate the genesis of the third heart sound in relation to the instantaneous changes in left ventricular filling and wall movement by echocardiography.

MATERIALS AND METHODS

Nine patients with ventricular gallop (3 males and 6 females, mean age: 34.5 ± 11.4), and 6 normal subjects with a third heart sound (4 males and 2 females, mean age: 23.3 ± 7.6) were studied. These selected cases clearly demonstrated this sound on the apical low-frequency phonocardiogram. Nine patients with ventricular gallop had left ventricular volume overload diseases. Five had mitral regurgitation, 3 had ventricular septal defect and 1 had patent ductus arteriosus. Ten normal subjects (7 males and 3 females, mean age: 30.1 ± 5.6) were also studied. They had no phonocardiographic evidence of a third heart sound.

Strip chart echocardiograms were recorded at a paper speed of 100 mm/sec using an Aloka SSD-90 (Japan Radiation and Medical Electronics Co) and 2.25 MHz transducer 1 cm diameter. All subjects were studied in the supine position. With the transducer in the third or fourth intercostal space, the characteristic echo from the anterior mitral valve was first identified. The transducer was then angled inferior and laterally, in order to make a record demonstrating the interventricular septum and the posterior wall. Left ventricular measurements were taken at the tip of the mitral leaflets as illustrated in Fig. 1. A lead II electrocardiogram and phonocardiogram from the mitral area with a piezoelectric microphone (Fukuda Electronics Co, MA 250) filtered to display medium (M: 160Hz/dB) and low (L: 50Hz/dB) frequencies were recorded simultaneously.

Measurements were made only on records showing clear continuous endocardial echoes from both structures throughout the cardiac cycle. The left ventricular internal dimensions (LVID) were taken as the distance from the posterior of the 2 septal echoes to the endocardial surface of the posterior wall, and one cardiac cycle was measured at every 20 msec interval. These dimensions and normalized rates of change of dimension ($dD/dT/D$), which were calculated to divide rates of change of dimension (dD/dT) by the instantaneous dimensions, were plotted against the time course (Fig. 1). These $dD/dT/D$, which were taken as an index of filling, were used to obtain their respective peak values and also to time events during diastole.

Fig. 1. Simultaneous recording of echocardiogram, electrocardiogram (ECG), and phonocardiogram (PCG, L & M) at a paper speed of 100 mm/sec (upper). Left ventricular internal dimensions (LVID) and normalized rates of dimensional change ($dD/dT/D$) are also shown (middle and lower), IVS: interventricular septum, LVPW: left ventricular posterior wall, IIIS: third heart sound, Dd: end-diastolic dimension, Ds: end-systolic dimension, Df: dimension at the end of rapid filling.

End-diastolic dimensions (Dd) and end-systolic dimensions (Ds) were measured at the R wave of electrocardiogram and at the onset of the second heart sound respectively. Dimensions at the end of rapid filling (Df) were determined when $dD/dT/D$ reached within 20% of its peak value (Fig. 1). Intervals from the second heart sound to peak $dD/dT/D$ and to the third heart sound were measured (IIA-peak $dD/dT/D$ and IIA-IIIS time). The time from the second heart sound to Df was taken as 'the rapid filling time' (IIA-Df time). Dimensional lengthening $[(Df-Ds)/Ds]$, divided by end-systolic dimension, and normalized lengthening rate $[(Df-Ds)/Ds/IIA-Df \text{ time}]$ in the rapid filling phase were also obtained. After the

above recording, echoes of the anterior mitral valve and the left atrium were recorded. From these echoes, the diastolic descent rates of the anterior valve (DDR) and the left atrial dimensions (LAD) were measured. Left ventricular posterior wall thickness (LVPWT) between the endocardium and epicardium of the posterior wall was also measured at the R wave of the electrocardiogram. Heart rate was determined by the RR interval and all subjects had sinus rhythm.

RESULTS

Normal subjects without a third heart sound

In this group, the mean heart rate was 69 beats/min. Dd, Ds, and Df were 4.48 ± 0.26 , 2.83 ± 0.21 , 3.98 ± 0.19 cm respectively. These values were not statistically significant when compared with the other 2 groups. The normalized peak rate of increase of left ventricular dimension (peak dD/dT/D) was $5.11 \pm 0.86 \text{ sec}^{-1}$. This was achieved in 104 msec after the second heart sound. Dimensional lengthening [(Df-Ds)/Ds] was 0.437 ± 0.062 and the normalized lengthening rate [(Df-Ds)/Ds/IIA-Df time] was $2.35 \pm 0.505 \text{ sec}^{-1}$ in the rapid filling phase. These results are given in detail in Tables I and II.

Normal subjects with a third heart sound

Peak dD/dT/D and DDR in this group were $7.54 \pm 1.05 \text{ sec}^{-1}$ and $9.00 \pm 0.68 \text{ cm/sec}$. These values were significantly raised with respect to normal subjects with no third heart sound ($p < 0.01$) (Figs. 2 & 3). IIA-peak dD/dT/D and IIA-Df time were 95.0 ± 7.6 and 181.7 ± 20.3 msec (Figs. 4 & 6). Dimensional lengthening, divided by end-systolic dimension, and normalized lengthening rate in the rapid filling phase were 0.428 ± 0.126 and 2.558

Table I. Echocardiographic Data (Mean $\pm$ Standard Deviation)

	III S	Dd (cm)	Ds (cm)	Df (cm)	DDR (cm/sec)	LAD (cm/M ²)	LVPWT (cm)	HR (beats/ min)
Normal	(-)	4.48 ± 0.26	2.83 ± 0.19	3.98 ± 0.19	6.81 ± 1.36	1.67 ± 0.20	0.85 ± 0.07	69.0 ± 11.3
Normal	(+)	4.35 ± 0.38	2.68 ± 0.22	3.86 ± 0.38	$9.00 \pm 0.68^{**}$	1.52 ± 0.33	0.85 ± 0.05	63.8 ± 4.7
LV Volume Overload	(+)	4.78 ± 0.72	2.78 ± 0.42	4.27 ± 0.82	8.40 ± 2.45	$2.24 \pm 0.49^{++*}$	$0.98 \pm 0.13^*$	71.1 ± 11.1

Note: III S; Third heart sound, Dd; End-diastolic dimension, Ds; End-systolic dimension, Df; Dimension at the end of rapid filling, DDR; Diastolic descent rate of anterior mitral valve, LAD; Left atrial dimension, LVPWT; Left ventricular posterior wall thickness, HR; Heart rate

*; statistically different from normal without a third heart sound ($p < 0.05$)

**; statistically different from normal without a third heart sound ($p > 0.01$)

++; statistically different from normal with a third heart sound ($p < 0.01$)

Table II. Analysis of Echocardiogram and Phonocardiogram
(Mean $\pm$ Standard Deviation)

	III S	Peak dD/dT/D (sec ⁻¹)	I/A-Peak dD/dT/D (msec)	I/A-III S (msec)	I/A-Df (msec)	(Df-Ds)/Ds	(Df-Ds)/Ds /I/A-Df (sec ⁻¹)
Normal	(-)	5.11 ± 0.86	104.0 ± 11.1		189.0 ± 16.4	0.437 ± 0.062	2.356 ± 0.505
Normal	(+)	7.54 $\pm 1.05^{**}$	95.0 ± 7.6	161.7 ± 6.9	181.7 ± 20.3	0.428 ± 0.126	2.558 ± 0.660
LV Volume Overload	(+)	7.55 $\pm 1.58^{**}$	92.2 ± 12.3	166.7 ± 24.5	175.6 ± 17.7	0.539 $\pm 0.106^*$	3.092 $\pm 0.758^*$

Note: III S; Third heart sound, I/A; Aortic component of the second heart sound, I/A-peak dD/dT/D; I/A-Peak dD/dT/D time, I/A-Df; I/A-Df time, I/A-III S; I/A-III S time

*: statistically different from normal without a third heart sound ($p < 0.05$)

**: statistically different from normal without a third heart sound ($p < 0.01$)

Fig. 2

Fig. 2. Diastolic descent rates of the anterior mitral valve (DDR) were significantly elevated in normal subjects with a third heart sound than in those without third heart sound ($p < 0.01$). Normal: Normal subjects, LV Vol.: left ventricular volume overload, III S: third heart sound.

Fig. 3

Fig. 3. Normalized peak rates of dimensional changes (peak dD/dT/D) were significantly higher in subjects with a third heart sound and with ventricular gallop than in those without a third heart sound ($p < 0.01$).

Fig. 4

Fig. 4. Time from second heart sound to peak $dD/dT/D$ (II A-peak $dD/dT/D$ time). This time appeared to decrease in subjects with a third heart sound and with ventricular gallop compared with subjects without a third heart sound. This was statistically insignificant.

Fig. 5

Fig. 5. Normalized lengthening rates $[(Df-Ds)/Ds/II A-Df \text{ time}]$ in the rapid filling phase was larger in subjects with ventricular gallop than in those without a third heart sound ($p < 0.05$). Normal subjects with a third heart sound with values between the other 2 groups.

$\pm 0.660 \text{ sec}^{-1}$ (Figs. 5 & 6). These values were located between the other 2 groups. IIA-IIIS time was $161.7 \pm 6.9 \text{ msec}$.

Patients with left ventricular volume overload diseases

Peak $dD/dT/D$ was $7.55 \pm 1.58 \text{ sec}^{-1}$ and higher than in normal subjects without a third heart sound ($p < 0.01$), but similar to those with a third heart sound (Fig. 3). IIA-peak $dD/dT/D$ and IIA-Df times were 92.2 ± 12.3 and $175.6 \pm 17.7 \text{ msec}$, and were slightly shortened compared with those without a third heart sound (Figs. 4 & 6). $[(Df-Ds)/Ds]$ and $[(Df-Ds)/Ds/II A-Df \text{ time}]$ were 0.539 ± 0.106 and $3.092 \pm 0.758 \text{ sec}^{-1}$ and were significantly higher than those without a third heart sound ($p < 0.05$) (Figs. 5 & 6). IIA-IIIS time was $166.7 \pm 24.5 \text{ msec}$. The left atrial dimension was $2.24 \pm 0.49 \text{ cm}/M^2$ and larger than normal subjects ($p < 0.01$) and the left ventricular posterior wall thickness was $0.98 \pm 0.13 \text{ cm}$, slightly thicker ($p < 0.05$).

Ventricular volume changes have long been considered important in the

production of a third heart sound. Although the mitral valve apparatus was once considered to play a fundamental role,⁹⁾⁻¹¹⁾ the demonstration of a third sound after homograft mitral and tricuspid valve replacement¹²⁾ has turned attention to the interplay of hemodynamic events and ventricular wall movement. Volume studies based on biplane angiograms, however, have not given unequivocal support to this idea, showing that low as well as high ventricular filling rates may be found in patients with ventricular gallop.¹⁾

Recently, with the development of the echocardiographic methods which gives excellent resolution in time, it has become possible to study the course of ventricular filling noninvasively. Gibson and Brown¹³⁾ showed a close correlation between echocardiographic and angiographic measurements of ventricular filling in patients with a variety of heart diseases. They also found that changes in the transverse diameter of the left ventricle may be taken as an index of ventricular filling. In this study, using this method, normalized peak rates of increase in the left ventricular dimension in early diastole were higher in subjects with a third heart sound and with ventricular gallop than in those without a third heart sound. Dimensional lengthening and normalized lengthening rate in the rapid filling phase were also high in patients with ventricular gallop than in normal subjects without a third heart sound. Sakamoto et al⁶⁾ also showed that normalized rates of rapid ventricular filling were higher in subjects with a third heart sound than in control subjects without a third heart sound. Otherwise, Prewitt et al²⁾ found that peak rates of wall movement were high in patients with non-rheumatic mitral regurgitation and low in those with left ventricular disease, although both patients had the third heart sound. These results and observations suggest that the sound occurs when there is an imbalance between rapid filling and the ventricle's ability to accommodate its increasing diastolic volume. Abnormal ventricular accommodation occurs in heart failure, in which myocardial distensibility may be poor. Grayzel⁸⁾ reported that the ventricular movements associated with a third heart sound and ventricular gallop were qualitatively similar, but differ quantitatively. In the present study, however, normalized peak rates of dimensional change in subjects with a third heart sound and with ventricular gallop were similar. Although reasons for this difference are not clear, many of our patients with ventricular gallop had mild mitral insufficiency and small cardiovascular shunts.

The time from the second heart sound to the normalized peak rate of dimensional change (IIA-peak $dD/dT/D$ time), and to the end of rapid filling (IIA-Df time) appeared to shorten, when subjects with ventricular gallop were compared with those with no third heart sound, but this was not statistically significant. Patients with ventricular gallop had a left ventricular

volume overload and may have elevated left atrial pressure. Since this would make the isovolumic relaxation time short, the peak filling and rapid filling phase will terminate earlier and more abruptly. This tendency was also recognized in subjects with a third heart sound, though to a lesser degree. These results may be cause of the production of ventricular gallop in patients with left ventricular volume overload and of the physiological third heart sound.

It is apparent that the echocardiographic method is a useful tool to study on the phase of ventricular filling. However, in order to do this, a continuous measurement of the distance between the interventricular septum and the posterior wall of the left ventricle is required, which is a laborious procedure to carry out manually. Some investigators,^{3),14),15)} therefore, have employed computer techniques to register the position of these 2 echoes throughout the cardiac cycle, and to obtain instantaneous left ventricular dimension and volume with their respective change.

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