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Do the Human Ventricles Eject Simultaneously?*

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The lack of an accurate measure of the transmission time of the pulse from the left ventricle to the carotid artery has been a critical deficiency in a study of the forces which give rise to the deflections of the ballistocardiogram. For the I-wave on the ballistocardiogram which, from all theoretical constructions, should mark the beginning of the cardiac ejection, does not start, on the average, until 5 msec. before the upstroke of a carotid surface pulse.[1] This short interval would indicate that the ballistocardiograph is insensitive to the first part of the ejection. How large a part depends upon whether the estimate of 60 msec. for the transmission time from apex beat to subclavian artery,[2] or the estimate of 30 msec. from heart to carotid, based on stretch measurements made upon isolated aortic rings,[1] is nearer the correct figure.

In a series of patients in whom the right ventricles were catheterized, we have recorded simultaneously the right ventricular pressure, carotid surface pulse and ballistocardiogram, to determine directly this transmission interval from heart to carotid. Unexpectedly, the data do not give evidence on this point, for they indicate that the ejection does not start from the 2 ventricles simultaneously.

Method. A silk X-ray opaque catheter was passed through an antecubital vein into the right ventricle, using the technic of Cournand *et al.*[3] Whenever possible, the catheter was also passed into the pulmonary artery to record pulmonary diastolic pressure levels. The catheter was connected to an optical manometer of adequate frequency for pressure recording. The carotid surface pulse was recorded by funnel connected, with air transmission, to a rubber diaphragm bearing a mirror. The ballistocardiograph was of the high frequency type. All recording light beams were passed into the same camera, and all were cut by a single timer clock, so that parallax was measurable on the records themselves.

For an estimate of the time lags inherent in the recording systems, a rubber bag filled with air was placed on the ballistocardiograph. The catheter was passed through a stopper into the bag to record pressure change. The funnel connected to the surface pulse recorder was placed on the surface of the bag, and rapid pressure oscillations within the bag were generated by gentle taps. In a series of 10 trials, the interval between the start of the ballistocardiographic recoil and the start of the pressure change as recorded by catheter was 0.8 msec., and that between ballistocardiogram and surface pulse recorded 3.6 msec.

Results. The timing of the records taken from 10 individuals are given in Table I, with an example in Fig. 1. All events were dated from the beginning of ejection in the right ventricle, as determined by the point on the ventricular pressure rise when the pulmonary diastolic pressure level was reached. In 2 cases (marked by asterisk), pulmonary pressure tracings were not available, and the beginning of ejection was placed by inspection. In only 2 of the 10 cases is the time interval reasonable for pulse transmission from heart to carotid. In 4, the surface pulse upstroke actually precedes the beginning of ejection. Since we have no evidence that

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1 Hamilton, W. F., Dow, P., and Remington, J. W., *Am. J. Physiol.*, 1945, **144**, 557.

2 Bazett, H. C., Cotton, F. S., LaPlace, L. B., and Scott, J. C., *Am. J. Physiol.*, 1935, **113**, 312.

3 Cournand, A., Ranges, H. A., and Riley, R. L., *J. Clin. Invest.*, 1942, **21**, 287.

TABLE I.
Timing of Events from Start of Right Ventricle Ejection.

Subject	Symptomology	Brachial pressure, mm Hg	Start of carotid surface pulse, msec.	Ballistocardiogram: Start of H wave msec.	Ballistocardiogram: Start of I wave, msec.
1	Congestive failure	146/54	— 5		
2*	Malignant hypertension	290/190	+30	—40	+10
3*	Compensated congestive failure	138/75	—25	—75	—25
4	Congestive failure	128/70	+10	—70	— 5
5	,, ,,	125/80	+45	?	+ 5
6	,, ,,	101/73	0	—30	+ 5
7	Normal	110/80	—50	—50	—30
8	,,	90/60	+ 5	—40	— 5
9	,,	140/100	+15	—30	+10
10	,,	152/100	—10	—25	0
Mean			+ 1	—45	— 4

an artefact in the recording can account for this discrepancy, we are faced with the conclusion that the left ventricle begins its ejection earlier than the right. That asynchronism of the beginning of isometric contraction may be present in the exposed dog heart was pointed out by Katz.[4] In his records, either ventricle might precede, and the average time difference was of the order of 13 msec. The time differences recorded here are considerably larger than this.

The human tracings of Bloomfield *et al.*[5] indicate a lag of the order of 80 msec. from the first part of the R wave of the electrocardiogram, to the beginning of the pressure rise in the right ventricle, whereas the ventricular contraction should start during the last part of the R wave.[6] This is seemingly further evidence in favor of an asynchronization of the 2 ventricles.

The start of the I-wave of the ballistocardiogram does not differ greatly in time from the upstroke of the carotid pulse, as noted before.[1] In fact, the start of the H-wave seems roughly related to the start of left ventricle ejection, and the I-wave usually does not develop until right heart outflow has begun.

That the right ventricle may play a larger role in determining the initial deflections of the ballistocardiogram than any proposed theoretical construction of the forces would allow is suggested by the recent evidence of Starr and Friedland.[7] They found that in inspiration, the ballistocardiographic recoil was increased, and in expiration, decreased, as might be expected if the forces generated were related to changes in right heart output as opposed to left heart output. Our records show the same changes they have reported. In addition, however, we[8] find that in a straining with closed glottis (Valsalva's experiment), the ballistocardiographic recoil is also increased, which seemingly cannot be correlated with output changes from either ventricle.

Summary. On the basis of simultaneously recorded right ventricular pressures, carotid surface pulses and ballistocardiographic recoils, evidence is presented that ejection from the right and left ventricles may not start simultaneously in the human. The I-wave of the ballistocardiographic record seemingly dates to the right heart ejection, and is not initiated by left ventricle ejection which must have started earlier.

Since this paper was submitted, an abstract appeared in the *Federation Proceed-*

4 Katz, L. N., *Am. J. Physiol.*, 1925, **72**, 655.

5 Bloomfield, R. A., Lauson, H. D., Cournand, A., Breed, E. S., and Richards, D. W., Jr., *J. Clin. Invest.*, 1946, **25**, 639.

6 Wiggers, C. F., *Circulation in Health and Disease*, 267, Lea and Febiger, Philadelphia, 1923.

7 Starr, I., and Friedland, C. K., *J. Clin. Invest.*, 1946, **25**, 53.

8 Hamilton, W. F., and Dow, P., unpublished observations.

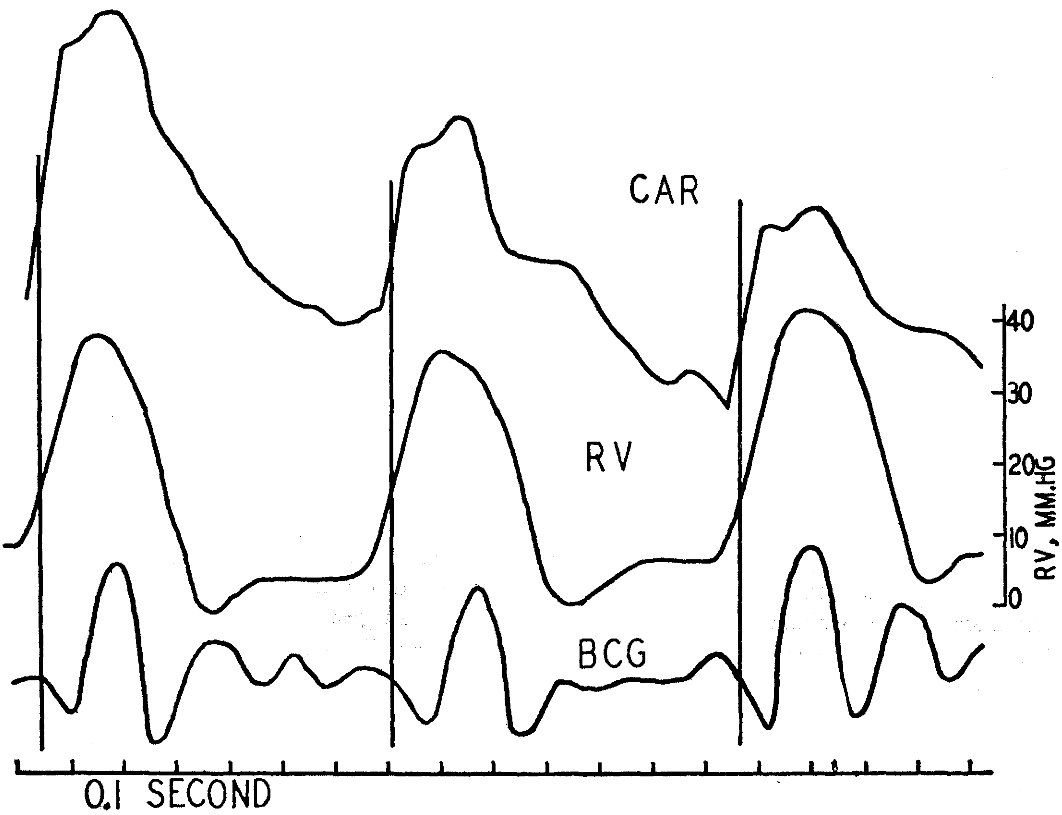

FIG. 1.
Reconstruction of a simultaneous record of carotid surface pulse, right ventricle pressure, and ballistocardiogram.

ings[9] stating that, in the human, a time discrepancy between the start of ejection from the 2 ventricles exists in almost all cases. The measurements were taken from electrokymograph recordings. In this series, either ventricle might precede, whereas in our series, the left ventricle usually precedes the right. The time discrepancies are somewhat larger in our series. Whether these differences are attributable to the small number of cases reported here remains to be determined.

9 Chamberlain, W. E., Boone, B. R., Ellinger, G. F., Henny, G. C., and Oppenheimer, M. J., *Fed. Proc.*, 1947, **6**, 88.