Haemodynamic effects of angiographic contrast material in man

*A beat-by-beat analysis*¹

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Information concerning the circulatory effects of angiographic contrast material during the early beats after injection in man is critical to the validity of angiographic methods for evaluating left ventricular performance. Accordingly, we assessed the haemodynamic effect of contrast medium during the first 10 beats after left atrial injection in 5 subjects without left ventricular disease and in 8 patients with left ventricular myocardial disease, and after aortic root injection in 8 patients with aortic insufficiency.

Mean maximum left ventricular dp/dt , measured by catheter-tip micromanometer, showed no significant decline in the normal subjects until the fifth beat after injection (mean $\Delta -7\%$, $P < 0.05$) while in the patients with myocardial disease, mean maximum dp/dt did not decrease significantly even after 10 beats. After aortic root injection, mean maximum dp/dt declined by the fourth beat (mean $\Delta -6.8\%$, $P < 0.02$). No significant changes in heart rate and left ventricular end-diastolic pressure occurred in the first two groups, while in the patients with aortic insufficiency a significant decrease in heart rate and a rise in left ventricular end-diastolic pressure occurred during the first 2 beats, perhaps as a result of a higher concentration of contrast material in the coronary arterial bed. Only minor changes in systemic arterial pressure occurred in all three groups throughout the time of study.

Since myocardial performance was little affected in the first few beats after injection of contrast material and not at all in patients with reduced left ventricular function, it is concluded that angiographic methods of assessing left ventricular function allow valid comparisons of one patient with another, provided a contraction before the fifth opacified beat is analysed.

Studies in experimental animals have shown that significant haemodynamic alterations occur after injection of contrast material into the left heart chambers (Austen, Wilcox, and Bender, 1964; Krovetz, Mitchell, and Neumaster, 1967; Carleton and Clark, 1969; Krovetz *et al.*, 1970). Though the late haemodynamic effects of angiocardiology have been evaluated (Friesinger *et al.*, 1965; Brown *et al.*, 1965, 1969; Rahimtoola, Duffy, and Swan, 1966, 1967; Kloster *et al.*, 1966), there is little information available concerning the immediate effects of angiographic contrast material on left ventricular function in man.

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Since angiographic techniques have become the principal method for evaluating left ventricular performance in patients, it is of considerable importance to define the magnitude and time course of the circulatory effects of contrast material in the human subject. In the present study, left ventricular performance was examined on a beat-by-beat basis in patients with and without left ventricular disease after left atrial or aortic root injection of contrast medium.

Methods

Twenty-one patients were studied during diagnostic left heart catheterization. All had sinus rhythm. On the basis of clinical findings and standard haemodynamic measurements, 5 patients had normal left ventricular dynamics. This group included 1 patient with mitral stenosis and mild aortic stenosis (left ventricular-aortic peak systolic pressure difference, 10 mmHg) and 4 patients

TABLE I

Case No.	Diagnosis	Heart rate	Arterial pressure (mmHg)		Left ventricular end-diastolic pressure (mmHg)	Cardiac index (l./min/m ²)	Maximum left ventricular dp/dt (mmHg/sec)
			Systolic	Diastolic			
Without left ventricular disease							
1	Atrial septal defect	91	120	80	11	2.60	1155
2	Mitral stenosis	56	112	50	9	3.23	1701
3	Atrial septal defect	98	151	101	11	3.88	1785
4	Atrial septal defect	95	123	85	10	2.33	1937
5	Atrial septal defect	83	151	77	9	3.09	1900
With left ventricular disease							
6	Myocardial disease	66	126	74	12	2.50	1586
7	Arteriosclerosis heart disease + mild mitral stenosis	92	98	64	5	2.93	1067
8	Myocardial disease	80	149	98	31	2.36	1234
9	Myocardial disease	86	114	91	28	1.49	352
10	Arteriosclerosis heart disease/old myocardial infarction	94	112	64	27	3.03	1505
11	Arteriosclerosis heart disease/old myocardial infarction	98	120	82	16	2.87	863
12	Myocardial disease	69	105	58	10	2.44	1325
13	Myocardial disease	98	145	95	23	2.13	701
With aortic insufficiency							
14	Aortic insufficiency	107	181	64	7	3.38	2327
15	Aortic stenosis; aortic insufficiency	91	145	74	11	—	2249
16	Aortic insufficiency	73	154	55	16	—	1396
17	Aortic insufficiency	108	139	60	44	1.94	687
18	Aortic insufficiency	102	192	62	19	1.89	1052
19	Aortic insufficiency	106	180	76	5	2.56	1691
20	Aortic insufficiency	88	213	66	25	2.67	1500
21	Aortic insufficiency	66	181	52	12	2.30	1242

Maximum left ventricular dp/dt = maximum rate of change of left ventricular pressure.

with atrial septal defect. Their haemodynamic findings before angiography are summarized in Table 1. Maximum dp/dt, recorded immediately before left atrial injection of contrast material from a catheter-tip micromanometer placed in the left ventricle, ranged from 1155 to 1937 mmHg/sec (average 1696).

Eight patients had left ventricular myocardial disease of varying aetiology (Table 1). Six of the 8 patients had abnormal left ventricular haemodynamics at rest. The left ventricular end-diastolic pressure at rest was raised in 6 patients (> 12 mmHg) and normal in 2, and the cardiac index was below normal in 5 (< 2.50 l./min/m²) (Table 1). In the remaining 2 patients, both of whom reported symptoms of congestive heart failure, left ventricular dynamics at rest were normal, but the haemodynamic response to exercise was abnormal (Ross *et al.*, 1966). Four patients were receiving a digitalis preparation. Maximum left ventricular dp/dt, recorded immediately before left atrial injection of contrast medium, ranged from 352 to 1580 mmHg/sec (average 1079).

The third group was composed of 8 patients with free aortic regurgitation, 1 of whom had associated mild aortic stenosis (maximum transvalvular aortic pressure difference of 20 mmHg). Five of the 8 patients had abnormal haemo-

dynamics at rest (Table 1). The left ventricular end-diastolic pressure was raised in 4 patients (> 12 mmHg) and was normal in 4. Maximum left ventricular dp/dt, recorded immediately before aortic root injection of contrast material ranged from 687 to 2327 mmHg/sec (average 1517).

The haemodynamic study was performed in the postabsorptive state after giving pentobarbitone sodium, 100 mg, intramuscularly. A Courmand needle was placed in the left brachial or left radial artery. Left heart catheterization was performed by the retrograde arterial technique, by transseptal puncture (Ross, 1966), or by introducing a catheter into the left heart via an atrial septal defect. A catheter-tip micromanometer was introduced into the left ventricle to permit the recording of high-fidelity left ventricular pulses (Yanof *et al.*, 1963). To avoid ventricular premature beats, the left ventricle was visualized by injection of contrast material proximal to the left ventricle in the patients with normal left ventricular function and in those with left ventricular myocardial disease, either through a catheter introduced into the left atrium by transseptal puncture or via an atrial septal defect. In the patients with aortic regurgitation, ventricular premature beats were avoided by injection of contrast material into the aortic root immediately distal to the aortic valve plane.

The patient was positioned in the right anterior oblique projection, and in mid-inspiration 1 ml/kg contrast material (diatrizoic acid, 90%, or Renovist, 69%) was injected over 2 to 3 seconds with a power syringe. Before and during the cineangiogram lead II of the electrocardiogram, left ventricular pressure and its first derivative, and the brachial arterial pressure were recorded simultaneously at 200 mm/sec on a photographic recorder.

Results

Measurements made on the two cardiac cycles immediately before injection comprise the control observations (Table 1), and the effects of contrast material on the heart during the first ten cycles after injection are tabulated in Tables 2-4. The percentage change in mean left ventricular dp/dt with time for each of the three groups is depicted in Fig. 1.

In the 5 patients with normal left ventricular function (Table 2), mean left ventricular dp/dt initially rose to a maximum of 3.3 per cent above control values (range -2.3 to +19.6%, $P > 0.3$), and then fell to control levels at the fourth beat. Beginning with the fifth beat a statistically significant decline in left ventricular dp/dt occurred, reaching its nadir by the eighth beat (mean decrease at beat eight of 15.3%, range -31.5 to -1.1%, $P < 0.05$) (Fig. 1). Though heart rate tended to diminish, this effect was not significant until after the seventh beat (mean decrease at beat 8 of 10.8%, range -19 to (+)15%, $P < 0.01$).

FIG. 1 The mean percentage change in maximum left ventricular dp/dt during the first ten beats after left atrial or aortic root injection of contrast material is shown. Despite different injection sites, the slope of the decline in left ventricular dp/dt is similar in normals and in patients with aortic insufficiency. The modest changes in mean left ventricular dp/dt in the patients with left ventricular myocardial disease are not statistically significant.

Left ventricular end-diastolic pressure tended to rise slightly (maximum mean increase of 3.4 mmHg at the eighth beat), but this rise was at no time statistically significant. The average systemic systolic blood pressure rose slightly after the injection of contrast, and a slight drop did not occur until after the sixth beat, while mean diastolic blood pressure tended to fall slightly.

In the 8 patients with left ventricular myocardial disease (Table 3) mean left ventricular dp/dt never fell by a statistically significant amount, the maximum decline occurring at beat 10 (mean decrease of 6%, range -24 to (+)9%, $P > 0.05$). Similarly, the small decrease in the mean heart rate and the slight rise in average left ventricular end-diastolic and systolic pressures seen in these patients were not significant.

In the 8 patients with aortic insufficiency (Table 4), on the other hand, all of whom had aortic root injections of contrast material, a statistically significant decrease in the mean left ventricular dp/dt occurred by the fourth beat (mean change of -6.8% <, range 0 to -13.5% <, $P < 0.02$), and continued through beat 10 (Fig. 1). Heart rate declined significantly by beat 2, and returned to control levels by beat 9. The increment in left ventricular end-diastolic pressure was significant by the first beat. Though the mean left ventricular end-diastolic pressure remained raised throughout the period of measurement, the increase was no longer statistically significant by the sixth beat.

The relation between left ventricular end-diastolic pressure and left ventricular dp/dt in beats 1, 3, 5, and 7 after injection of contrast material is depicted in Fig. 2. In the first beat after injection both left ventricular end-diastolic pressure and left ventricular dp/dt tended to rise (Fig. 2A). By the third beat after injection, left ventricular dp/dt remained raised in some patients, but in others it had returned to baseline or declined minimally, despite a persistent increase in left ventricular end-diastolic pressure (Fig. 2B). During beat 5 and thereafter, for example beat 7, left ventricular end-diastolic pressure tended to remain raised, while left ventricular dp/dt showed a considerable decline, except in patients with myocardial disease (Fig. 2C and D).

Discussion

Injection of radiographic contrast material into left heart chambers produces complex alterations in ventricular function. Infusion of 1 ml/kg over a period of 2-3 seconds is the

TABLE 2 Normal patients (left atrial injection)

Beat No.	1	2	3	4
Mean Δ heart rate	-1.8	-6.5	-2	-5
Range	-3 to +2	-37 to +12	-13 to +1	-9 to +1
P value	P>0.4	P>0.7	P>0.3	P<0.05
Mean Δ brachial arterial systolic/diastolic pressure	+2.5/-0.3	+8.8/-2.8	+4.8/-0.8	+6/-2.4
Mean Δ left ventricular end-diastolic pressure	+0.5	+2.1	+1.5	+1.5
Range	0 to +1.5	+0.7 to +3.5	-1 to +3.5	0 to +3.5
P value	P>0.7	P<0.1	P>0.1	P>0.5
Mean Δ maximum dp/dt	+45	+38	-52	-50
Range	-8 to +117	-45 to +143	-117 to 0	-146 to +178
P value	P>0.1	P>0.3	P>0.05	P>0.4
Mean % Δ maximum dp/dt	+3.0	+3.3	-2.9	-0.9
Range	-0.4 to +10	-2.3 to +19.6	-10 to 0	-9 to +9.2

Maximum dp/dt = maximum rate of rise of left ventricular pressure.

TABLE 3 Patients with left ventricular myocardial disease (left atrial injection)

Beat No.	1	2	3	4
Mean Δ heart rate	+0.9	-3	+0.4	-2.3
Range	-1 to +6	-7 to +1	-3 to +9	-13 to +5
P value	P>0.3	P<0.05	P>0.8	P>0.2
Mean Δ brachial arterial systolic/diastolic pressure	+0.9/+2.9	+2/+3.6	+1.9/+0.9	+3/-0.4
Mean Δ left ventricular end-diastolic pressure	+0.5	+0.7	+1.7	+2.3
Range	-1.3 to +3.5	-0.5 to +3.5	0 to +6.5	-3 to +7.5
P value	P>0.5	P>0.4	P>0.05	P>0.1
Mean Δ maximum dp/dt	+15.6	+2.4	+5.4	+28.6
Range	-14 to +75	-26 to +75	-35 to +59	-39 to +131
P value	P>0.2	P>0.8	P>0.6	P>0.2
Mean % Δ maximum dp/dt	+1.2	-0.6	0	+2
Range	-4 to +5	-9.4 to +5.7	-6.8 to +8.4	-6.8 to +10.6

Maximum dp/dt = maximum rate of rise of left ventricular pressure.

TABLE 4 Patients with aortic insufficiency (aortic root injection)

Beat No.	1	2	3	4
Mean Δ heart rate	-6.3	-5	-6.1	-7.1
Range	-29 to 0	-12 to -1	-1 to -18	-1 to -20
P value	P>0.1	P<0.02	P<0.05	P<0.02
Mean Δ brachial arterial systolic/diastolic pressure	+6.9/+3.1	+4.6/+1.1	+4.4/-1.5	+1.1/+1.3
Mean Δ left ventricular end-diastolic pressure	+2.6	+4.9	+4.4	+5.8
Range	-1 to +4.5	0 to +10.5	-7 to +13.5	-2 to +12
P value	P<0.05	P<0.02	P<0.1	P<0.02
Mean Δ maximum dp/dt	+28.3	-14	-9.6	-86.8
Range	-58 to +90	-84 to +98	-238 to +209	0 to -193
P value	P>0.1	P>0.5	P>0.8	P<0.02
Mean % Δ maximum dp/dt	+2.3	-1.4	-1.2	-6.8
Range	-3.9 to +7.2	-6.8 to +4.2	-14.1 to +9.3	0 to -13.5

Maximum dp/dt = maximum rate of rise of left ventricular pressure.

5	6	7	8	9	10
-5.8 -18 to +2 P>0.1	-10.4 -31 to +3 P>0.1	-6.4 -22 to +9 P>0.2	-10.8 -19 to -5 P<0.01	-6.6 -15 to +3 P<0.05	-4.8 -9 to +3 P<0.1
+2.8/-4.2	0/-6.6	+3.4/-6	+2/-4.8	+5.9/-6.6	-6.2/-6.2
+1.4 -1 to +4 P>0.05	+3.1 -1 to +6.5 P>0.1	+3 -1 to +6.5 P>0.5	+2.6 -1 to +7.5 P>0.2	+1.8 -2 to +7 P>0.3	+1.4 -2 to +6 P>0.3
-111 -266 to +144 P<0.05	-142 -389 to -13 P>0.05	-207 -462 to +9 P<0.05	-273 -680 to +39 P<0.05	-297 -680 to +39 P>0.05	-251 -534 to +143 P>0.05
-7.0 -16 to -2	-8.1 -22.9 to -1.1	-13.4 -15.7 to +0.8	-15.3 -31.5 to -1.1	-16.3 -40 to +3.4	-13.0 -31 to +12

5	6	7	8	9	10
-1 -2 to +4 P>0.2	-1.8 -4 to +3 P<0.05	-0.9 -3 to +3 P>0.2	-2.1 -7 to +2 P<0.02	-1.1 -4 to +2 P>0.2	-2 -5 to +2 P>0.05
+1/+1	+1.4/-0.4	0/+1.4	-0.9/+0.1	-0.4/+1.1	-2/-1.5
+1.5 -6 to +5 P>0.2	-1.3 -7 to +7.5 P>0.4	+1 -8 to +6 P>0.5	+1.2 -8 to +6 P>0.4	+1.2 -9 to +6 P>0.5	0 -11 to +6 P>0.9
-32 -151 to +75 P>0.2	-28.9 -158 to +103 P>0.3	-27.5 -210 to +80 P>0.4	-48 -210 to +103 P>0.4	-52.9 -263 to +59 P>0.3	-91 -292 to +80 P>0.05
-2 -12 to +9	-2.2 -12.8 to +11.9	-1.0 -17 to +11.8	-2.7 -17 to +11.9	-3.9 -10.4 to +6.6	-6 -24 to +9

5	6	7	8	9	10
-6.5 -19 to -2 P<0.05	-3.9 -11 to +4 P>0.05	-6 -18 to -1 P<0.02	-4.1 -12 to +3 P>0.05	-0.7 -8 to +8 P>0.7	-1.5 -5 to +9 P>0.4
-1/+1	-3.9/-2.7	-6.1/-4.3	-14/-2.6	-17.9/-4.3	-18.5/+4
+4.5 -5 to +18 P<0.1	+4.4 -2 to +18 P>0.1	+4.1 -2 to +20 P>0.1	+3.1 -3 to +15 P>0.1	+2.6 -3 to +13 P>0.2	+1 -3 to +11 P>0.5
-89 -193 to +58 P<0.05	-142.3 -268 to -62 P<0.01	-149.5 -240 to -41 P<0.001	-158 -353 to +41 P<0.01	-160.9 -438 to +41 P<0.05	-140 -325 to +90 P<0.01
-7 -15 to +4	-9.8 -12.2 to -4.7	-10.2 -13.5 to -3.3	-10.5 -17.6 to +3.3	-10.9 -20.5 to +3.3	-9 -22 to +7

approximate equivalent of a single stroke volume, and this increase in end-diastolic volume produces an immediate augmentation of myocardial performance by the Frank-Starling mechanism. A volume increase of 5–15 per cent may persist for as long as 8 beats after injection of contrast medium (Sanmarco *et al.*, 1966). A depressant effect on the myocardium occurs several beats after initial opacification and correlates both with the sodium content of the agent (Gensini and Di Giorgi, 1964; Banks, Raftery, and Oram, 1969; Gootman, Rudolph, and Buckley, 1970), and the time of its arrival in the coronary arterial bed (Banks *et al.*, 1969; Krovetz *et al.*, 1970). Studies in experimental animals have shown that rises in cardiac output, detected by an electromagnetic flow meter, occur as early as 3 seconds after injection of a

volume load (Hallermann, Rastelli, and Swan, 1964), while by 10 seconds there is a reduction in systemic arterial pressure (Krovetz *et al.*, 1967), as well as a decline in myocardial contractile force (Austen *et al.*, 1964). Despite persistent enlargement of canine ventricular diameters after injection of contrast, Carleton and Clark (1969) reported that ventricular contractility fell progressively between 1.8 and 4.1 seconds after injection. In dogs, Krovetz *et al.* (1970) found the effect of contrast to be instantaneous and extremely variable, with the most common type of response being an early positive inotropic effect, followed by a period of declining contractility. Both Carleton and Clark (1969) and Krovetz *et al.* (1970) urge caution in interpreting data on left ventricular performance, which are derived from angiographic contrast studies.

Δ LEFT VENTRICULAR END DIASTOLIC PRESSURE – mmHg

FIG. 2 (A) In the first beat after injection of contrast material, the change in left ventricular end-diastolic pressure is plotted against the corresponding change in maximum left ventricular dp/dt . Most of the points fall in the upper right quadrant of the graph, suggesting that the enhanced ventricular performance resulted from an increase in resting fibre length (Frank-Starling effect). (B) The plot of the change in left ventricular end-diastolic pressure against the corresponding change in maximum left ventricular dp/dt in the third beat after injection shows no consistent relation. (C) The relation between the change in left ventricular end-diastolic pressure and the corresponding change in maximum left ventricular dp/dt is depicted in the fifth beat after injection of contrast medium. The majority of the points fall in the right lower quadrant of the graph. Thus, despite an increase in resting fibre length in these patients, left ventricular performance is depressed, suggesting that a true decline in left ventricular contractility has occurred. (D) By the seventh beat after the injection of contrast medium, the plot of the change in left ventricular end-diastolic pressure v. the change in left ventricular dp/dt continues to show a decline in left ventricular contractility in most of the patients. A persistent enhancement of cardiac performance due to the Frank-Starling mechanism is still evident in 3 patients with left ventricular myocardial disease.

Previous evaluations in man of haemodynamic changes after angiocardigraphy have provided little information concerning the immediate effects of contrast medium on ventricular contractility. Studies in the human subject have been limited to serial measurements of left atrial, left ventricular end-diastolic, and systemic arterial pressures, and of cardiac output. Kloster *et al.* (1966) found that systemic arterial pressure remained unchanged or rose slightly for 10 to 15 seconds after injection and then fell, while the average increase in left ventricular end-diastolic pressure within the first 10 seconds was 4.6 mmHg. The earliest reported cardiac output determinations were two measurements performed 10 seconds after injection (Kloster *et al.*, 1966), while most have been taken one minute or longer after injection (Brown *et al.*, 1965; Friesinger *et al.*, 1965; Rahimtoola *et al.*, 1966; Brown *et al.*, 1969). In 11 patients who had either left atrial or left ventricular injection of contrast medium, Hammermeister and Warbasse (1970) reported that peak aortic root velocity, measured by a catheter electromagnetic velocity probe, was unchanged from control observations 4 to 5 seconds after injection of angiographic dye. Since angiographic assessment of left ventricular performance requires the evaluation of early beats, the acquisition of data concerning the magnitude and timing of the haemodynamic effects of contrast material in man immediately after injection is of considerable importance in assessing the validity of such methods.

In the present study left ventricular performance in man was evaluated on a beat-by-beat basis after the injection of angiographic contrast material. The data indicate that in patients with normal cardiac function, left ventricular dp/dt increased slightly in the first two beats after injection, then declined until significant depression occurred by the fifth beat (Fig. 1). Concurrent changes in heart rate and systemic and left ventricular end-diastolic pressures appeared to be relatively minor. The small initial increase in left ventricular dp/dt, which was accompanied by a slight rise in left ventricular end-diastolic pressure (Fig. 2A), probably represented a Frank-Starling effect due to the increase in end-diastolic volume which occurs after injection of contrast medium (Sanmarco *et al.*, 1966). In the experimental animal, this volume load tends to persist (Sanmarco *et al.*, 1966). In our patients, the continued rise of the left ventricular end-diastolic pressure presumably reflects a similar phenomenon. Despite persistence of this volume load, however, left

ventricular dp/dt subsequently declined, an effect which has been correlated in dogs with the time of coronary artery visualization (Krovetz *et al.*, 1970).

Patients with left ventricular myocardial disease who have impaired cardiac function showed no significant changes in left ventricular dp/dt, heart rate, or systemic arterial pressure during and after injection of contrast material. The absence of important haemodynamic effects in the subject with left ventricular myocardial disease suggests that in patients with compromised left ventricular function, not enough contrast material is ejected to produce a significant myocardial concentration via the coronary circulation. Thus, in patients with compromised left ventricular performance, in whom angiographic evaluation is most pertinent, it is also most accurate.

Aortic root injection of contrast medium produced qualitatively similar, but earlier and more profound haemodynamic changes (Fig. 1). These alterations in cardiac performance are probably the result of a direct myocardial toxic effect of contrast material (Gensini and Di Giorgi, 1964), which reaches the coronary circulation sooner and perhaps in higher concentration after aortic root injection than after left atrial or left ventricular injection. The bradycardia seen in most of the patients is probably in part the result of the Valsalva manoeuvre, which is commonly employed during angiographic filming, but in later beats may also be related to the reflex bradycardia which occurs after contrast material reaches the coronary arteries (Deyrup and Walcott, 1948; Carson and Lazzara, 1970).

Though most laboratories utilize catheters placed directly in the left ventricle for performing cineangiograms, the left atrial and aortic root injection sites used in the present study permitted the accurate measurement of dp/dt from another catheter in the left ventricle. Also ventricular irritability during angiography was not a problem with these injection sites. It might be argued that more profound haemodynamic alterations might have been observed had left ventricular injection sites been used. That this was probably not the case is evidenced by the results in the patients with left ventricular myocardial disease, in whom a statistically significant decline in left ventricular performance could not be shown even by the tenth beat after injection of contrast medium.

Hyperosmolarity is probably the major determinant of the systemic hypotension which begins during the 10 to 20 seconds after injection of contrast material (Kloster *et*

al., 1967), while direct myocardial toxicity is probably the result of the sodium content of the contrast agent (Gensini and Di Giorgi, 1964). Since the two agents used in the present study do not differ appreciably in either sodium concentration or viscosity, and since they were used interchangeably during the study, differences in haemodynamic effects among the three groups of patients cannot be ascribed to the contrast agent.

The use of maximum left ventricular dp/dt relative to left ventricular diastolic pressure as an index of myocardial contractility appears to be an acceptable approach in this setting since each patient is used as his own control (Ross, 1969). We have already alluded to the probable initial movement upward along the ventricular function curve produced by a large volume of injectate. Though such a Frank-Starling effect may improve cardiac performance and dp/dt (Wallace, Skinner, and Mitchell, 1963), an increase in myocardial contractility is not implied. An increase in systemic arterial pressure tends to increase maximum left ventricular dp/dt, while a decline in systemic arterial diastolic pressure and in heart rate tends to decrease it (Wallace *et al.*, 1963). However, inspection of Tables 1-3 reveals that changes in these parameters were generally small except for the early bradycardia seen in the patients who had aortic root injections. The association of a persistently raised left ventricular end-diastolic pressure (suggesting an increased end-diastolic volume or resting fibre length) with a declining left ventricular dp/dt, implies that left ventricular contractility decreased in later beats (Fig. 2C and D).

Since maximum left ventricular dp/dt is little affected in the first few beats after injection of contrast material, especially in patients with reduced left ventricular performance, we conclude that angiographic methods of assessing left ventricular function, such as ejection fraction (Dodge, 1968) and external fibre shortening rate (Gault, Ross, and Braunwald, 1968; Karliner *et al.*, 1971) allow valid comparison of one patient with another, provided a contraction before the fifth opacified beat is used.

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