Effect of acute alterations in afterload on left ventricular function in patients with combined coronary artery and peripheral vascular disease

Michael Y Henein, Saroj K Das, Christine O'Sullivan, Vijay V Kakkar, Charles E Gillbe, Derek G Gibson

Abstract

Objective—To assess the effect of acute alterations in afterload by aortoiliac clamping, during peripheral vascular surgery, on left ventricular function.

Design—Prospective examination of the left ventricular long axis and transmitral Doppler flow preoperatively and intraoperatively; before aortic clamping, during clamping and 5 min, 15 min, and 5 days after unclamping.

Setting—A tertiary referral centre for cardiac and vascular disease equipped with invasive and non-invasive facilities.

Patients—20 patients (11 men; mean (SD) age 61 (8) years) with significant aortoiliac disease and documented coronary artery disease and 21 normal controls of similar age.

Results—Preoperatively: long axis function was abnormal compared with that in normal controls. In systole total long axis excursion and peak shortening rate were reduced, onset of shortening delayed, and there was pre-ejection lengthening ($P < 0.001$). In diastole there was abnormal shortening during isovolumic relaxation, delaying the onset of long axis lengthening ($P < 0.001$). Peak lengthening rate was also reduced and A wave excursion increased ($P < 0.001$). Transmitral Doppler showed increased A wave velocity and reduced peak E/A diastolic flow velocities ratio ($P < 0.001$). Intraoperatively: preclamping results did not differ from those before operation. With clamping the extent of systolic and diastolic abnormalities promptly increased as to a lesser extent did those of transmitral flow velocity, although heart rate and blood pressure did not change significantly. Total long axis excursion and A wave amplitude were more reduced by aortic than iliac clamping, whereas the onset of lengthening was more delayed and the lengthening velocity more reduced with iliac clamping. Some 5 min after unclamping systolic long axis function had already returned towards normal; total excursion increased, as did the peak shortening rate, and the onset of shortening became less delayed ($P < 0.001$). In diastole the delayed onset of lengthening regressed, its lengthening velocity increased, and A wave excursion fell ($P < 0.001$). Early diastolic transmitral flow velocity also increased. This improvement in systolic and diastolic

long axis function had progressed 15 min after unclamping but showed no further change at 5 days. At 5 days after operation, however, systolic and diastolic measurements had improved compared with those preoperatively.

Conclusion—Resting left ventricular long axis function is abnormal in patients with combined coronary artery disease and peripheral vascular disease. It is unaffected by anaesthesia but deteriorates with aortic or iliac clamping, although blood pressure remains unchanged. It promptly improves with unclamping after successful peripheral arterial reconstruction. Thus, even in apparently stable coronary artery disease, resting subendocardial function is labile, showing pronounced alterations with changing after-load, even when arterial pressure itself does not change.

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It is generally agreed that the heart cannot be considered in isolation from the circulation. The velocity, extent, and time course of shortening and tension development of isolated muscle fibres are all greatly influenced by afterload.¹ The exact equivalent of afterload in the intact heart is not certain. If the circulation were non-pulsatile, it would simply be wall stress or blood pressure. However, with a pulsatile circulation, the picture becomes more complex, and other variables must be included. At least two important factors have been identified: aortic compliance² and pressure waves reflected from branch points in the peripheral circulation, probably the aortic bifurcation.³ Although there is much information about the response of the heart to an increase in arterial pressure, there is little on the independent effects of changes in these other two entities on left ventricular contraction pattern, and still less on any additional effects that they might have on its diastolic function. In patients with peripheral vascular disease, the properties of the aorta or its major branches are abnormal under control conditions.⁴ At the time of vascular surgery, the aorta or a major branch is clamped, and finally unclamped once structural continuity has been restored peripherally. It is standard anaesthetic practice to keep arterial pressure

Department of
Cardiology, Royal
Brompton Hospital,
London
M Y Henein
C O'Sullivan
D G Gibson

Department of
Anaesthesia, Royal
Brompton Hospital,
London
C E Gillbe

Thrombosis Research
Institute, Royal
Brompton Hospital,
London
S K Das
V V Kakkar

Correspondence to:
Dr D G Gibson, Department
of Cardiology, Royal
Brompton Hospital, Sydney
Street, London SW3 6NP.

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constant throughout the procedure. We therefore took advantage of the opportunity offered by such surgery to study the effects of these different states on the pattern of left ventricular shortening. At the same time, we also examined the possibility that diastolic function of the left ventricle might also change. In view of the frequent coexistence of coronary with peripheral arterial disease,⁵ we elected to study a group of patients with both. Not only would this increase the clinical relevance of our results, but it also seemed likely that basal impairment of ventricular function would make it more likely that we would detect any additional effects of acute changes in loading.

Patients and methods

PATIENTS

We studied 20 patients (11 men) with significant peripheral vascular disease, in whom the ratio of ankle to brachial systolic pressure measured by Doppler was below 0.6 (normal ≥ 1), during intraoperative arterial reconstructive surgery. The mean (SD) age was 61 (8) years and coronary artery disease had been confirmed by coronary arteriography in all patients. Ten had had myocardial infarction, five had had previous coronary artery bypass grafting, and five had stable angina pectoris. At operation, two patients had aortoiliac grafts, three had aortobifemoral grafts, two had right aortofemoral grafts, 11 had femoropopliteal grafts, and two had repair of an abdominal aortic aneurysm. In addition, 14 had systemic hypertension, five had diabetes mellitus, and nine smoked. Intermittent claudication was the main exercise limiting complaint in 16 patients and lower limb rest pain in four. No patient had had any documented ischaemic cardiac event for at least 6 months before surgery. Cardiac medications were not altered during the hospital stay, apart from standard postoperative analgesia and antibiotics. Some 21 normal individuals of similar age were taken as a control group. None had any previous history of coronary artery or peripheral vascular disease, hypertension, or diabetes mellitus.

METHODS

All patients were operated on under general anaesthesia after premedication with temazepam. They were induced with fentanyl 10 $\mu\text{g/kg}$ and etomidate 0.1–0.2 mg/kg, paralysed with pancuronium 0.1 mg/kg, and maintained on isoflurane oxygen and nitrous oxide. Dopamine was used as necessary to maintain blood pressure and urine output during and 48 h after anaesthesia. If necessary excessive blood pressure was controlled with glyceryl trinitrate and sodium nitroprusside infusion during surgery and in the early postoperative period.

A full preoperative transthoracic Doppler echocardiographic examination was performed 1 day before surgery. This included standard minor axis and long axis M modes and pulsed Doppler recordings of transmitral and aortic blood flow velocities. Intraoperative

echocardiography was performed in the operating theatre with the patient lying flat and attached to a single lead electrocardiac monitor using a Hewlett-Packard Sonos 500 echocardiograph with a 2.5 MHz phased array transducer interfaced to it. The echocardiograph was placed by the head of the operating table and to the right of the patient across a sterilised screen from the surgeons; therefore, the only accessible echocardiographic window was from the apex. Baseline echocardiographic examination was performed, with the patient fully anaesthetised and the artery exposed, 5–15 mins before aortic clamping. It was repeated during the first 15 min of aortic clamping, 5 min and 15 min after unclamping, and finally 5 days after surgery. The site of clamping, proximal to the site of arterial reconstruction, was in the upper abdominal aorta in two patients, the lower abdominal aorta in seven, and at the iliac artery in eleven. Mean (SD) clamping time was 60 (15) min. By placing the echocardiographic transducer on the chest wall at the apex of the heart, in the fifth left intercostal space, clear four and two chamber views were obtained and a standard cross sectionally guided M mode of the left ventricular long axis function was recorded.⁶ This was achieved by positioning the M mode cursor at the left, septal, and posterior angles of the mitral ring which by expanding the depth axis gave a clear display representing segmental longitudinal motion of the base of the ventricle at each site. We also recorded transmitral pulsed Doppler flow velocities from the apical four chamber view, with the sample volume at the level of the tips of the mitral valve leaflets. An electrocardiogram and precordial phonocardiogram were also recorded showing A2, the first high frequency component of the second heart sound, on all traces. All M modes and Doppler traces were recorded at a paper speed of 100 mm/s and M mode traces were later digitised.⁷ A digital record of clock time was superimposed on all cross sectional echocardiograms. Arterial blood pressure was measured by sphygmomanometer before and after operation, automatically during operation, and by a transducer connected to a radial artery cannula in the early postoperative period.

MEASUREMENTS

Heart rate and systemic (brachial) arterial blood pressure were monitored continuously during surgery and stored (Care Vue computer system; Hewlett Packard, Andover, MA, USA) so that values corresponding exactly in time to the echocardiographic recordings were subsequently identified. To assess systolic long axis function we measured the total mitral ring excursion from end systole (at A2) to end diastole (at the nadir of the A wave). The time interval from the Q wave of the electrocardiogram to the onset of long axis shortening was measured from the original traces and the extent of any lengthening during it. We also measured the peak rate of long axis shortening and the time interval from the Q wave to peak shortening rate from the digitised long axis

Figure 1 Long axis recordings from the left, septal, and posterior sites of the mitral ring in a normal control (left) and a patient with coronary and peripheral vascular disease (right). Note the generalised reduction in total long axis excursion, delayed onset of lengthening with respect to A2, and reduced lengthening velocity. There is also abnormal lengthening after the Q wave at the left site (arrow). ECG, electrocardiogram; PCG, phonocardiogram; A2, aortic closure component of the second heart sound.

traces. Diastolic long axis function was assessed from the amplitude of the A wave, taken as the backward displacement of the mitral ring (that is, towards the atrium, in late diastole, after the P wave of the electrocardiogram was determined. The time interval from A2, the first high frequency component of the second heart sound of the phonocardiogram, to the onset of lengthening was measured and also the extent of any further shortening occurring during it. The peak rate of long axis lengthening and the time interval from A2, aortic component of the second heart sound, to peak lengthening rate were derived from the digitised traces. Finally, from the transmitral Doppler forward flow trace we measured the time interval from A2, the second heart sound, to the onset of early diastolic transmitral forward flow representing “Doppler isovolumic relaxation time”. Peak early (E) and late diastolic flow velocities (A) were also measured and hence the E/A ratio calculated.

STATISTICAL ANALYSIS
Preoperative, preclamping, and 5 days postoperative results were compared with those of normal controls using the unpaired Student’s *t* test. Consecutive results, namely, baseline, during clamping, 5 min, 15 min, and 5 days after aortic declamping, were compared using a one way analysis of variance. When the analysis of variance was significant individual stages during the study were compared using a paired *t* test.

Results
Table 1 gives left ventricular haemodynamic, heart rate, and arterial blood pressure values preoperatively, before clamping, during clamping, and at 5 min, 15 min, and 5 days after declamping of the aorta, while tables 2 and 3 and figs 1–3 give corresponding results. Table 4 gives transmitral Doppler values.

BASELINE VERSUS NORMAL
Left ventricular long axis function was abnormal before surgery (fig 1). During systole (table 2) total long axis excursion was reduced at all three left ventricular sites and the onset of shortening delayed with respect to the Q wave of the electrocardiogram. Peak rate of shortening was reduced at all sites and there

Table 1 Haemodynamic variables

Variables	Preop	Preclamp	Clamp	Unclamping		
				5 min	15 min	5 days
Heart rate (beat/min)	65 (15)	62 (13)	61 (13)	63 (15)	66 (14)	67 (12)
Systolic BP (mm Hg)	140 (15)	130 (11)	131 (13)	129 (13)	141 (20)	143 (16)
Diastolic BP (mm Hg)	75 (16)	68 (10)	68 (7)	64 (5)	73 (9)	72 (10)
Mean (SD) blood pressure (mm Hg)	100 (15)	90 (10)	89 (8)	86 (7)	96 (12)	92 (11)

Values are means (SD) and were not significant (ANOVA). BP, blood pressure.

Table 2 Systolic long axis function

Variables	Normal	Preop	Preclamp	Clamp	Unclamping		
					5 min	15 min	5 days
Total excursion (cm)							
Left	1.5 (0.3)	1.1 (0.3)†	1.1 (0.3)	0.8 (0.2)‡	1.2 (0.3)‡	1.3 (0.3)†	1.4 (0.4)§
Septal	1.5 (0.3)	1.0 (0.3)†	1.0 (0.3)	0.9 (0.2)‡	1.0 (0.3)‡	1.1 (0.3)†	1.2 (0.3)§
Posterior	1.5 (0.3)	1.2 (0.4)†	1.2 (0.5)	0.9 (0.2)‡	1.1 (0.2)‡	1.3 (0.3)*	1.4 (0.4)
Q onset of shortening (ms)							
Left	90 (20)	135 (30)‡	135 (30)	142 (30)	125 (30)†	115 (25)‡	120 (30)
Septal	80 (10)	120 (25)‡	120 (25)	135 (20)‡	115 (17)‡	105 (15)†	105 (20)
Posterior	100 (15)	130 (30)‡	130 (30)	145 (45)	140 (40)	130 (30)†	115 (35)
Peak shortening rate (cm/s)							
Left	8 (1.5)	5.2 (2.0)‡	5.2 (2.3)	3.9 (1.5)†	4.5 (1.6)	4.9 (1.8)	6.8 (2.7)§
Septal	7.5 (1.2)	3.8 (1.5)‡	3.8 (1.7)	3.1 (0.1)*	3.9 (1.1)‡	4.5 (1.4)	5.7 (2.8)
Posterior	8.5 (1.5)	5.0 (1.8)‡	5.0 (1.8)	3.7 (1.5)†	4.0 (0.7)†	4.7 (1.7)	5.2 (1.2)
Q-peak shortening (ms)							
Left	205 (50)	220 (70)	218 (70)	220 (70)	220 (50)	190 (35)	140 (15)
Septal	210 (50)	190 (50)	190 (50)	210 (55)	200 (55)	195 (30)	150 (10)
Posterior	205 (40)	220 (45)	220 (45)	205 (25)	215 (30)	190 (40)	150 (70)
IVC motion (mm)							
Left	— #	1.0 (1.4)‡	1.0 (1.4)	2.8 (0.5)	2.5 (0.5)	2.0 (1.0)	1.0 (0.8)
Septal	— #	0.5 (1.0)‡	0.5 (1.0)	1.3 (1.0)	1.0 (0.8)	0.3 (0.5)	0.3 (0.5)
Posterior	— #	0.9 (1.2)‡	0.9 (1.2)	3.7 (1.5)†	2.7 (1.6)	2.0 (1.0)	0.6 (0.5)

Values are means (SD). *P < 0.05; †P < 0.01; ‡P < 0.001 comparison between each stage and the preceding one. §P < 0.05 versus preoperative results. #Absence of long axis lengthening during isovolumic contraction (IVC). ANOVA and Student's *t* test.

Table 3 Diastolic long axis function

Variables	Normal	Preop	Preclamp	Clamp	Unclamping		
					5 min	15 min	5 days
IVR shortening (mm)							
Left	—	1.8 (1.2)‡	1.8 (1.3)	3.5 (2.0)	3.5 (2.0)	2.5 (2.0)	1.5 (1.3)
Septal	—	1.0 (1.0)‡	1.0 (1.0)	2.7 (0.5)	1.5 (0.5)	1.0 (0.5)	0.7 (0.6)
Posterior	—	1.3 (1.2)‡	1.3 (1.2)	4.0 (3.0)*	3.0 (2.0)	2.0 (2.0)*	0.9 (1.0)
A2 to onset of lengthening (ms)							
Left	58 (11)	90 (15)‡	90 (15)	105 (20)‡	92 (20)‡	85 (15)†	90 (15)
Septal	60 (9)	90 (20)‡	92 (15)	110 (25)‡	95 (20)‡	87 (20)*	87 (17)§
Posterior	60 (10)	92 (10)‡	92 (13)	105 (25)*	96 (25)‡	90 (25)†	85 (16)§
A2 peak lengthening (ms)							
Left	115 (25)	135 (25)	135 (25)	160 (25)	150 (25)	150 (20)	100 (10)
Septal	120 (25)	135 (30)	135 (35)	160 (35)	160 (35)	150 (45)	150 (10)
Posterior	120 (20)	140 (35)	135 (40)	165 (40)	145 (25)	135 (25)	100 (50)
Peak length rate (cm/s)							
Left	10 (2.5)	4.6 (2.0)‡	4.6 (2.0)	3.9 (1.5)*	5.4 (2.1)‡	5.7 (1.6)	6.1 (2.1)#
Septal	8.5 (2)	4.0 (1.6)‡	4.0 (1.6)	2.9 (1.3)‡	4.4 (1.4)‡	5.0 (1.5)	5.4 (1.5)
Posterior	10 (2)	4.9 (2.0)‡	4.9 (2.0)	3.1 (1.3)†	4.3 (1.0)†	5.2 (1.9)	4.9 (1.4)
A wave excursion (%)							
Left	29 (6)	47 (10)‡	47 (12)	44 (15)	43 (9)	37 (8)	40 (8)
Septal	33 (8)	49 (15)‡	49 (14)	52 (13)	45 (6)†	46 (6)	44 (9)
Posterior	30 (7)	47 (10)‡	46 (10)	43 (7)	40 (4)	37 (8)	37 (4)

Values are means (SD). *P < 0.05; †P < 0.01; ‡P < 0.001 comparison between each stage and the preceding one. §P < 0.05; #P < 0.01 versus preoperative results. —, Absence of abnormal shortening during isovolumic relaxation time (IVR). A2, aortic component of the second heart sound. ANOVA and Student's *t* test.

was also an abnormal reversed long axis motion (lengthening) during isovolumic contraction time. In diastole (table 3) there was an abnormal shortening during isovolumic relaxation period which resulted in delayed onset of lengthening with respect to A2, the second heart sound of the phonocardiogram. Peak lengthening rate was reduced followed by an exaggerated A wave excursion in late diastole. These diastolic long axis disturbances were associated with abnormally prolonged Doppler isovolumic relaxation time as well as with increased late diastolic

filling velocity and hence reduced E/A ratio (table 4).

BASELINE VERSUS PRECLAMPING
There was no significant difference between the mean value of any measurement made preoperatively and the corresponding value immediately before clamping (tables 1–4).

PRECLAMPING VERSUS CLAMPING
Heart rate and blood pressure did not change significantly (table 1) but long axis observations became strikingly more abnormal (figs 2

Table 4 Transmitral Doppler

Variables	Normal	Preop	Preclamp	Clamp	Unclamping		
					5 min	15 min	5 days
A2 to onset of E wave (ms)	80 (10)	105 (25)†	105 (25)	120 (30)‡	110 (25)†	95 (25)†	90 (20)
E wave velocity (m/s)	0.7 (0.1)	0.6 (0.2)	0.6 (0.2)	0.5 (0.2)*	0.6 (0.2)*	0.7 (0.2)	0.6 (0.2)
A wave velocity (m/s)	0.5 (0.1)	0.8 (0.2)‡	0.8 (0.2)	0.6 (0.2)‡	0.6 (0.2)	0.6 (0.2)	0.6 (0.18)
E/A ratio	1.4 (0.4)	1.0 (0.9)‡	1.0 (0.9)	1.1 (1.0)	1.2 (0.7)	1.3 (0.9)	1.15 (0.8)

Values are means (SD). *P < 0.05; †P < 0.01; ‡P < 0.001 comparison of each stage and the preceding one. A2, aortic component of the second heart sound; E, early diastolic; A, late diastolic mitral flow velocity. ANOVA and Student's *t* test.

Figure 2 Example of long axis recording from the posterior site of the mitral ring in a single patient before clamping, during clamping, and 5 min, 15 min, and 5 days after unclamping. Note the effect of clamping manifested by a reduction in total long axis excursion, the appearance of abnormal lengthening after the Q wave (arrow), and a decrease in lengthening velocity. There is progressive disappearance of these disturbances after unclamping. Abbreviations as given in fig 1.

contraction. In diastole (table 3) abnormal posterior wall shortening after A2 was exaggerated and the onset of long axis lengthening delayed, while peak lengthening rate fell even lower. These diastolic abnormalities also affected left ventricular filling by delaying the onset of E wave and reducing peak early and late diastolic filling velocities.

Clamping site

When patients in whom the abdominal aorta was clamped (n = 9) were compared with those in whom the iliac artery was clamped (n = 11) significant differences appeared. In systole, total long axis excursion decreased more in patients with aortic clamping ($P < 0.001$) as did peak rate of shortening ($P < 0.01$); however, the onset of shortening was more delayed in patients in whom the iliac artery was clamped. In diastole, A wave amplitude was reduced more in patients who had aortic clamping ($P < 0.01$); however, peak lengthening rate was reduced ($P < 0.01$) and onset of lengthening delayed more ($P < 0.001$) with iliac artery clamping. Transmitral blood flow velocities were reduced in early ($P < 0.02$) and late ($P < 0.001$) diastole, and Doppler isovolumic relaxation time more prolonged ($P < 0.01$) in patients in whom the iliac artery was clamped.

Segmental analysis

In all but one patient, baseline systolic function was abnormal in at least one of the three left ventricular segments, namely, left, septal, and posterior, defined as an abnormal systolic long axis parameter outside the 95% confidence limit of normal. Seventeen patients had one or more baseline diastolic abnormalities outside the normal range. The consistent effect of aortic clamping on long axis systolic function was to reduce the total excursion of these initially depressed segments by 10–15% compared with 35–45% in normal segments ($P < 0.01$). Whenever the onset of shortening was delayed at baseline, abnormal lengthening during isovolumic contraction always appeared with clamping regardless of whether or not it had been present before. In diastole,

and 3). In systole (table 2) there was further reduction of total long axis excursion at the three sites, delayed onset of septal shortening from the Q wave of the electrocardiogram, and reduction of peak rate of shortening of the septal and posterior sites. There was also abnormal lengthening during isovolumic

Figure 3 Plots (means (SD)) of changes in (A) systolic total long axis excursion and (B) diastolic peak lengthening rate. Note the pronounced reduction in both variables during clamping and the gradual recovery after unclamping.

eight of 15 patients with delay in the onset of lengthening developed abnormal shortening during isovolumic relaxation during clamping. The overall delay of 15 ms in the onset of lengthening from A2 with clamping was equal to that in the onset of shortening from the Q wave of the electrocardiogram.

5 MIN AFTER AORTIC UNCLAMPING VERSUS CLAMPING

Heart rate and arterial blood pressure were unchanged (table 1), but by 5 min after unclamping long axis disturbances were already returning towards normal. In systole total long excursion increased at the three sites and its onset of shortening became less delayed (table 2). Peak shortening rate also increased. In diastole the delayed onset of lengthening regressed at the three long axis sites, peak lengthening rate increased, and relative A wave excursion decreased in late diastole (table 3). This was associated with shortening of isovolumic relaxation time and an increase in early diastolic left ventricular filling velocity (table 4).

15 MIN VERSUS 5 MIN AFTER UNCLAMPING

Long axis abnormalities continued to return towards normal again with no change in blood pressure and heart rate. In systole total excursion increased, its onset of shortening became less delayed, and peak shortening rate increased (table 2). In diastole the abnormal shortening during isovolumic relaxation period regressed, as did the delayed onset of lengthening (table 3). This diastolic improvement in function was associated with further shortening of Doppler isovolumic relaxation time (table 4).

5 DAYS VERSUS 15 MIN AFTER UNCLAMPING

Long axis abnormalities at 5 days were not significantly different from those at 15 min after unclamping (table 2).

PREOPERATIVE VERSUS 5 DAYS POSTOPERATIVE

Values 5 days postoperatively were significantly different from those preoperatively. During systole, total long axis excursion at two sites and peak shortening rate at one increased (table 2). During diastole the delay in the onset of lengthening was less at two sites and peak lengthening rate increased at one (table 3). In all cases these changes were in the direction of normality in values that had been significantly abnormal preoperatively, and they also occurred in the absence of any change in heart rate or blood pressure.

Discussion

Aortic clamping alters the characteristics of the arterial system, as seen from the left ventricle, in a clearly defined way.⁸ The physical properties of the aorta and great arteries do not, themselves, change but the volume accessible to ejected blood is reduced. Compliance, defined as the ratio of volume increased to pressure increase, thus falls. At the same time, the amplitude of the reflected wave is

increased, not only as the result of reduced compliance, but also because when the clamp is placed proximal to the arterial disease, the site of reflection is nearer to the heart. On removal of the clamp, it is likely that these changes will be reversed. Superimposed on them, for a short period, will be those associated with reactive hyperaemia in the distal circulation. The latter will, of course, have completely regressed by 5 days. In the present study, therefore, we were able to observe the effects on left ventricular function—independent of any alteration in blood pressure or heart rate—of major changes in arterial properties induced by clamping and repair acutely as well as at a more chronic time scale, when values before and 5 days after operation were compared.

The baseline preoperative values for the patients were consistently abnormal in a way which we have shown to be common in coronary artery disease.⁹ Premedication, anaesthesia, reflex changes associated with surgery, positive pressure respiration, or the recumbent position might all have been expected to alter long axis function, yet there was no change in any of the 30 variables studied between baseline and preclamping values. Within 5 min of clamping, though, major long axis abnormalities occurred accentuating those present at baseline. During ejection, as might be expected, the extent and peak velocity of long axis shortening at all three left ventricular sites fell strikingly. The time to peak shortening, however, was unaltered, suggesting that left ventricular inotropic state did not change. The onset of shortening was delayed, compatible with prolongation of the pre-ejection period, and the extent of early dimension lengthening during this period increased. Not only systolic but also exaggerated diastolic disturbances occurred with further delay in the onset of lengthening, reduction of its lengthening velocity, and a compensatory increase in the extent of long axis excursion component occurring during atrial systole. At the same time, the pattern of transmitral flow also changed, with prolongation of Doppler isovolumic relaxation time and a minor increase in peak A wave during clamping. These abnormalities are similar to those occurring acutely during coronary balloon angioplasty¹⁰ and as severe as those in unstable angina.¹¹ They are the opposite of those after successful coronary angioplasty.¹² We believe, therefore, that they represent the effects of increasingly severe myocardial ischaemia affecting longitudinally directed, mainly subendocardial, muscle fibres of the left ventricle.

Reversal of these disturbances could already be seen within 5 min of releasing the aortic clamp, and this process was complete within 15 min. Recovery occurred while the patients were still under general anaesthesia and before skin closure, providing further evidence that deterioration in the long axis function was not related to anaesthesia, patient position, positive pressure respiration, or surgery itself. We do not believe that this recovery was directly caused by distal reactive hyperaemia, which would have been more severe at 5 than at 15

min, but attribute reversal of the long axis changes specifically to unclamping of the aorta. Furthermore, when values 5 days after the operation were compared with those pre-operatively there was significant improvement in systolic and diastolic functions. Thus the recovery process of long axis function was primarily and acutely initiated by removal of the clamp and continued on a long-term basis after successful peripheral revascularisation.

The main limitations of this study arise from the necessity of making observations during surgery. Access to the patient was thus restricted and it proved impossible to use the parasternal window and hence to record the transverse axis of the left ventricle. We therefore recorded changes in long axis and transmitral Doppler flow velocity. Our study was thus complementary to many others based on recordings of only left ventricular transverse axis.¹³ A single electrocardiogram monitoring lead was used, so it is possible that ischaemic ST changes might have occurred which would have been recognised had 12 leads been recorded throughout.

It was not the aim of our study to determine the exact basis of the change in aortic properties caused by clamping. We did not have a tip manometer in the aortic root so we therefore did not measure its compliance. Similarly, it would have been desirable to have calculated proximal aortic wave intensity,¹⁴ which would have given valuable information about the timing and extent of reflected waves. In the absence of definite information, we prefer not to speculate on the underlying mechanisms. Arterial pressure was measured from a peripheral artery, so that values would not have been identical with those in the ascending aorta. However, we were concerned more with changes in arterial pressure than in its absolute value, and even with the small doses of vasoactive drugs administered to maintain constant pressure, we consider it unlikely that the difference between central and peripheral levels varied by more than a few mm Hg. The possibility clearly arises that the vasoactive drugs themselves may have altered left ventricular wall motion directly. This seems unlikely, as it was necessary to raise or lower the pressure using agents with contrasting pharmacological effects in individual patients whereas the changes in wall motion were consistent.

Although coronary artery disease had been confirmed by coronary arteriography at some time in all patients, there was no clinical reason to repeat the investigation and therefore we did not have precise details for most patients immediately before surgery. We did not attempt to relate angiographic findings to the severity of wall motion changes.

Our results clearly demonstrate that the pattern of left ventricular wall motion varies with changes in the peripheral arterial bed even in the absence of significant change in blood pressure. In general terms, the nature and direction of those results during systole are explicable on the basis of an increase in left ventricular afterload. Thus the onset of shortening was delayed, and its extent and in par-

ticular its peak velocity were all reduced, though the time to peak shortening remained unaltered suggesting that the inotropic state was unchanged. One reason for this sensitivity was that our patients had associated coronary artery disease, in common with many of those with peripheral artery disease severe enough to require surgery, which might have jeopardised longitudinal function under resting condition. More surprising, perhaps, was the effect of clamping on ventricular diastolic function. This cannot have been directly caused by a change in afterload as there is no direct continuity between the left ventricle and the peripheral circulation in diastole when the aortic valve is closed. A number of possibilities exist. An acute change in systolic function may have engendered or intensified subendocardial myocardial ischaemia, as has been seen to occur experimentally with acute changes in aortic compliance.¹⁵ The pronounced changes in diastolic function caused by aortic cross clamping along with a significant column of blood moving from the depressurised lower circulation may well have been accompanied by changes in left ventricular filling pressure which we did not document. In addition, it is possible that changes in aortic impedance cause secondary alterations in the pattern of coronary flow.¹⁶ Finally, diastolic changes might be a direct consequence of those occurring during systole. Such interrelations are common in disturbances of activation; however, none of our patients developed any conduction abnormality during or after surgery. Our results do not allow us to distinguish between these various possibilities, though it seems likely that the overall effect of cross clamping is complex.^{17,18} Whatever the individual contribution of each of these possible mechanisms their overall effect was to aggravate disturbances which we have shown to correlate closely with thallium perfusion abnormalities,¹⁹ and thus might be expected to cause or intensify local myocardial ischaemia.

Our results also have clinical significance. A high incidence of myocardial ischaemic complications associated with peripheral vascular surgery^{20,21} is well recognised. Our observations further confirm that this deterioration was not the effect of general anaesthesia or even of dissection of the affected vessel, but specifically the result of cross clamping the aorta or iliac artery. Of potential significance was that ischaemia associated disturbances, present under control conditions, consistently regressed within 15 min of clamp removal and within 5 days of successful surgery had actually improved with respect to baseline. This suggests that myocardial perfusion in patients with coronary artery disease might be improved by dealing with peripheral as much as with coronary arterial stenoses. Our results also raise the possibility that manipulating the properties of the systemic vascular tree might be therapeutically useful. If the changes in aortic pressure flow relations could be successfully neutralised or even reversed during surgery, it might reduce the tendency of aortic clamping to aggravate myocardial ischaemia.

It could even have a chronic antianginal effect. While many vasoactive drugs affect the systemic circulation, changes in blood pressure or peripheral resistance rather than any other properties of the peripheral circulation are normally used as primary haemodynamic end points. Implementation of the ideas explored in the present study might thus allow new approaches to the medical treatment of patients with coronary artery disease.

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