HÆMODYNAMIC EFFECTS OF OXYGEN IN PATIENTS WITH ACUTE MYOCARDIAL INFARCTION

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Oxygen is frequently given in the treatment of patients with acute myocardial infarction. The hæmodynamic changes associated with its administration in this condition have not been defined.

The purpose of this study has been to investigate the effect of breathing oxygen on the cardiac output and systemic arterial pressure of patients in the early stages of acute myocardial infarction.

SUBJECTS AND METHODS

Six male patients aged 47 to 72 years were studied on the first and second day of myocardial infarction. In two of these there were additional studies on the sixth and seventh days. In one patient there was only one study on the tenth day. All had unequivocal evidence of acute myocardial infarction as judged by the clinical history and electrocardiograph. The clinical data are given in Table I.

All patients were investigated in a special intensive care unit permanently equipped with apparatus for observation, investigation, and treatment of patients with acute myocardial infarction (Shillingford and Thomas, 1964). Facilities were available for the measurement of cardiac output and intravascular pressures.

After clinical assessment, electrocardiography, and chest radiography were completed, polythene catheters (Intramedic U.S.A. PE60) were inserted percutaneously into the brachial artery and an antecubital vein. The venous catheter was advanced so that the tip lay in the superior vena cava. Heart rates were measured from an electrocardiographic tracing over half-minute periods throughout the study and when cardiac output determinations were made. Cardiac output was measured by a dye dilution technique using Coomassie Blue (I.C.I.) as indicator and recording the curve with a photoelectric earpiece (Cambridge Instrument Co.). The first curve was calibrated by equating the height of the tail of the curve three minutes after injection with the amount of indicator in a central venous or arterial blood sample taken at the same time. Dye was extracted from the plasma and measured by spectrophotometry. Subsequent cardiac outputs were calculated according to the areas of the curves (Gabe, Tuckman, and Shillingford, 1962).

Brachial arterial pressures were measured by strain gauge manometers (P23Gb Statham Transducers Inc.) and recorded on a direct writing system (Devices Ltd). The pressures were measured with reference to a point 5 cm. below the sternal angle. Measurements were made throughout the periods of study and immediately before each cardiac output determination. Pressure flow ratio (peripheral resistance) was calculated as the mean pressure in the brachial artery expressed in mm. Hg divided by the cardiac output expressed in l./min.

The patients breathed oxygen delivered at 10 l./min. into a lightweight plastic face mask (Polymask 330216—British Oxygen Co. Ltd.). Approximately 40 per cent oxygen was inhaled by the patient. Before hæmodynamic measurements were made the patients had rested, breathing oxygen, for at least 20 minutes after the catheters had been inserted. Some had received oxygen from the time of admission to hospital. Duplicate determinations of cardiac output and repeated measurements of heart rate and blood pressure were made, a tap was then turned to allow compressed air from a cylinder to enter the mask at the same

TABLE I
CLINICAL DATA

Patient No.	Age (yr.)	Weight (kg.)	Height (cm.)	Past history	Presenting symptom	General condition on admission	Highest enzyme	E.C.G.	X-ray appearance of lung fields
1	64	72	169	Diabetes mellitus 15 years	Sudden pain across chest; felt weak and faint; vomited	Pale and sweating; heart rate 100; JVP not raised; BP 115/70 mm. Hg; normal heart sounds	S-GOT* 102 I.U.	Sinus rhythm, S-T segment elevation in aVF and III	Normal
2	72	65	162	Myocardial infarction 4 years previously	Sudden loss of consciousness; recovered; vomited; no pain	Pale; heart rate 80; JVP not raised; BP 145/75 mm. Hg; apex beat displaced laterally; normal heart sounds; râles at lung bases	S-GOT 6 I.U.	Sinus rhythm, S-T segment elevation in V2 to V7	Slight congestive changes at bases
3	73	64	160	Effort angina	Awoke in morning with severe chest pain extending down both arms; weak and nauseated	Pale and in pain; heart rate 50; JVP +3 cm.; BP 140/80 mm. Hg; apex beat displaced laterally; presystolic heart sound	S-GOT 22 I.U.	Sinus rhythm, S-T segment elevation in aVF and III	Slightly full hilar shadows
4	47	76	176.5	Hypertension many years; effort angina 1 month	Sudden severe chest pain in night; vomited	Good general appearance; heart rate 60; JVP not raised; BP 150/105 mm. Hg; presystolic heart sound	S-GOT 27 I.U.	Sinus rhythm, slight S-T elevation in V4	Normal
5	51	65	163	Angina 3 mth.	Collapsed while bicycling; severe pain; ventricular fibrillation in hospital; resuscitated	Pale, sweating; no pain after resuscitation; heart rate 80; BP 55/0 rising to 100/60 mm. Hg after 2 hours	LDH† 1230 I.U.	Sinus rhythm, S-T elevation in V1-V4, QT inversion V4R-V4	Marked pulmonary oedema
6	56	78	177	Myocardial infarction 2 weeks previously; acute ventricular fibrillation; resuscitated	Cardiac arrest; resuscitated	Very pale, sweating; peripherally cyanosed; heart rate 60; BP 95/60 mm. Hg	LDH 1500 I.U.	Q V2-V4; S-T elevation V2-V5; T inversion V2-V7	Marked pulmonary oedema

* Serum glutamic oxalacetate transaminase.

† Serum lactic dehydrogenase.

rate as, and instead of, the oxygen. The change was made without the patient's knowledge. Measurements were made for 30 minutes after the change of gas. The exact times are given in Table II. On six occasions another set of measurements was made after a further change back to oxygen.

RESULTS

Table II gives hæmodynamic data recorded simultaneously with or just before each cardiac output determination. The percentage change given is based on average values of all measurements made while the patient was breathing air or oxygen respectively. The mean values given are restricted to the percentage change at the first investigation in each patient. The diagrams represent the measurements made immediately before the change of gas and the first measurement after the change. Given in the results are additional measurements of cardiac output and brachial arterial

FIG. 1.—Measurements of heart rate made before and after changing the inspired gas from oxygen to air and from air to oxygen.

FIG. 2.—Measurements of cardiac output made before and after changing the inspired gas from oxygen to air and from air to oxygen.

FIG. 3.—Stroke volume calculated from measurements of cardiac output and heart rate before and after changing the inspired gas from oxygen to air and from air to oxygen.

pressure made separately. These are not included in the detailed analysis as no evaluation of change in peripheral resistance was possible.

Heart Rate. When the patients were breathing air the heart rate ranged from 56 to 102 a minute in the 12 instances where the patients were in sinus rhythm. In one patient with atrial fibrillation the rate was 134 a minute. When the patients were breathing oxygen, the heart rate was lower in 16 of 19 comparisons (Table II). The mean of the differences in heart rate in the first comparison in each patient was 4 per cent.

In 9 additional instances in these patients and in one instance in another, comparisons were made. In 8 of these the heart rate was lower when the patients were breathing oxygen. Fig. 1 shows the last measurement before the change and the first measurement afterwards in 19 comparisons.

Cardiac Output. When patients were breathing air, cardiac output ranged from 2.2 to 7.7 l./min.; breathing oxygen, the cardiac output was lower in 15 of 19 comparisons. The mean of the differences in the first comparison in each patient was 17 per cent ($p < 0.01$). Cardiac output change was measured on 9 additional occasions in these patients and in one instance in another patient with acute myocardial infarction. In all of these comparisons the cardiac output was lower when the patients were breathing oxygen. Fig. 2 shows the last measurement before the change and the first measurement after in 29 comparisons.

Stroke Volume. When patients were breathing air, the stroke volume ranged from 23 to 104 ml.; breathing oxygen, the stroke volume was lower in 14 of 19 instances. The mean of the differences in the first comparison in each patient was 14 per cent ($p < 0.05$). Stroke volume change was measured on 9 additional occasions in these patients and in one instance in another patient. In these comparisons stroke volume was lower when the patients were breathing oxygen in all but one instance. Fig. 3 shows the last measurement before the change and the first measurement after in 29 comparisons.

Brachial Artery Pressure. Systolic arterial pressure when patients were breathing oxygen ranged from 85 to 167 mm. Hg, diastolic pressure from 48 to 92 mm. Hg, and mean pressure from 61 to 122 mm. Hg. When patients were breathing oxygen, systolic, diastolic, and mean pressures were higher in 14 of 19 comparisons. Fig. 4 shows an example of the pressure change recorded. The means of

TABLE II
HEMODYNAMIC DATA OF PATIENTS WITH ACUTE MYOCARDIAL INFARCTION

Patient No.	Day of infarction	Po ₂ (mm. Hg)			Heart rate (beats/min.)			Cardiac output (l./min.)			Stroke volume (ml.)		
		O ₂	Air	O ₂	O ₂	Air	O ₂	O ₂	Air	O ₂	O ₂	Air	O ₂
1	1				78 70	73 74		4.2 4.5	4.8 5.0		54 64	66 67	
	2				68 66	70 72		3.6 3.3	3.4 3.3		52 50	48 46	
2	1	234	60		78 76	78 84		4.8 5.0	6.2 6.1		61 66	80 78	
	2	155	60		66 66	70 67 65	64	4.1 4.3	5.1 4.8 5.1	5.1	62 65	73 72 78	80
	6				116 117	134		2.9 2.9	3.6		25 25	27	
3	1	350	74		50 52	58 56		3.6 3.3	5.0 5.5		73 63	86 98	
	2	253	64	280	57 58	62 62	58 56	4.4 3.9	4.9 4.7	5.0 5.0	78 67	80 76	87 90
4	1				51 50	57 57	52 55	5.0 4.5	4.9 5.9	4.5 6.2	97 91	85 104	86 113
	2				55 59	62 62	62 68	4.8 5.1	6.2 6.4	5.9 5.8	88 86	99 104	95 85
	2	395	79		59 62	63 62		5.1 5.5	4.1 5.6		87 89	65 90	
5	2				96	93	87	6.1	7.7	6.3	64	83	73
6	1				96	99		2.1	2.2		22	23	
	2	270	59	202	100	102 100	98 99	2.5	2.9 3.1	2.8 2.8	25	28 31	29 28

* These figures represent the time between changing the gas and making the measurements.

the differences in the first comparison were systolic 5 per cent, diastolic 3 per cent, and mean pressure 2 per cent. Additional measurements were made in four instances in one of the patients. On every occasion, systolic, diastolic, and mean pressures were higher when the patient was breathing oxygen. Fig. 5 shows the last measurement of the systolic and diastolic pressure before the change and the first measurement after in 23 comparisons. Fig. 6 shows the change in mean arterial pressure in these comparisons.

Peripheral Resistance. When patients were breathing air the peripheral resistance ranged from 9 to 33 units. When patients were breathing oxygen it was higher in 16 of 19 comparisons. The mean difference in the first comparisons was 25 per cent ($p < 0.02$). Fig. 7 gives the peripheral resistance calculated from measurements made before the change and from the first ones made after the change in 19 comparisons.

WHEN BREATHING OXYGEN AND WHEN BREATHING AIR

Brachial arterial pressure (mm. Hg)									Resistance units			Minutes after change to air*	Minutes after change to O ₂ *
Systolic			Diastolic			Mean							
O ₂	Air	O ₂	O ₂	Air	O ₂	O ₂	Air	O ₂	O ₂	Air	O ₂		
142 144	137 134		73 74	73 64		100 100	95 94		24 22	20 19		10 19	
105 109	103 101		57 58	56 57		73 75	72 71		21 23	21 21		10 21	
127 134	137 130		70 74	73 72		90 96	95 94		19 19	15 16		14 27	
138 138	142 140 135	143	70 73	72 72 68	73	88 93	96 96 92	98	22 22	19 20 18	19	16 27 34	23
94 100	87 96		60 59	56 57		72 69	69		25 24	19		14	
153 160	141 147		66 70	65 65		96 101	92 97		27 31	19 18		16 30	
143 143	130 126	141 155	65 65	59 60	64 67	95 95	86 88	92 99	22 24	17 19	18 20	23 31	18 26
129 132	135 134	137 143	72 72	77 78	77 80	94 95	100 102	103 104	19 21	21 17	23 17	16 34	17 28
151 158	167 162	180 180	84 92	92 91	98 98	110 118	122 120	130 130	24 23	20 19	22 23	18 31	20 24
154 155	152 150		83 83	83 83		112 111	110 109		22 20	27 20		18 26	
107	99	100	53	48	50	70	68	69	12	9	11	9	10
100	92		68	65		80	74		38	33		12	
78	86 85	98 107	48	55 52	57 66	57	64 61	66 78	23	22 20	23 28	9 13	6 10

DISCUSSION

Previous work on normal subjects (Barratt-Boyes and Wood, 1958; Daly and Bondurant, 1962), patients with pulmonary disease (Howarth, McMichael, and Sharpey-Schafer, 1947; Aber, Harris, and Bishop, 1964), with mitral stenosis (McGregor, Bothwell, Zion, and Bradlow, 1953), and with patent ductus arteriosus (Burchell, Swan, and Wood, 1953) has shown that the administration of oxygen has marked haemodynamic effects. Circulatory changes following its administration in acute myocardial infarction had not been investigated. In this disease the basis for the use of oxygen as therapy is ill defined though heart muscle with borderline blood supply may benefit. Experimental work by Sayen *et al.* (1951) in dogs demonstrated improved oxygenation in the peripheral zones of myocardial infarction when 100 per cent oxygen was delivered to the lungs. In addition to an effect

FIG. 4.—Brachial arterial pressure recorded while a patient was breathing oxygen, air, and after returning to oxygen. Arterial PO_2 on each occasion shown below the appropriate trace.

been shown to reduce the calibre of retinal arteries and veins (Dollery *et al.*, 1964). If the essential haemodynamic response to oxygen administered to patients with acute myocardial infarction is vasoconstriction associated with an increase in blood pressure, the fall in cardiac output may be due to the rise in peripheral resistance.

The therapeutic implications of this work are not clear. The circulatory changes in acute myocardial infarction are complex; ideal therapeutic principles await definition and may be different in different patients. It is known that cardiac output can be within a wide range at a given low blood

on damaged heart muscle, it might be anticipated that the somewhat increased oxygen saturation of haemoglobin and the greatly increased oxygen tension in the blood might be of benefit if the circulation became inadequate for tissue metabolism as a whole.

We have shown that the administration of oxygen to patients with acute myocardial infarction results in a rise in arterial blood pressure and a fall in cardiac output. The component mechanisms involved in this response are not clear. It is probable that a rise of blood pressure in the presence of a lowered cardiac output is due to arterial vasoconstriction—either as a result of reflex activity or as a direct effect of oxygen. Direct vasoconstrictor effects of oxygen have been demonstrated by experimental work on animal preparations (Carrier and Guyton, 1963; Sobol *et al.*, 1962).

In man, breathing oxygen at high pressure has

FIG. 5.—Measurements of brachial arterial systolic and diastolic pressure made before and after changing the inspired gas from oxygen to air and from air to oxygen.

FIG. 6.—Measurements of brachial arterial mean pressure made before and after changing the inspired gas from oxygen to air and from air to oxygen.

FIG. 7.—Peripheral resistance calculated from measurements of cardiac output and brachial arterial mean pressure made before and after changing the inspired gas from oxygen to air and from air to oxygen.

pressure (Thomas, Malmcrona, and Shillingford, 1965) and a fall in cardiac output induced by oxygen administration could be of different significance in different patients. An analysis of potential benefit is made more difficult by ignorance of regional blood flow. Measurements in other conditions have shown that oxygen reduces cerebral flow in normal man (Kety and Schmidt, 1948) and reduces renal flow in patients with pulmonary disease (Aber *et al.*, 1964). Oxygen has also been shown to lower pulmonary artery pressure in normal subjects (Barratt-Boyes and Wood, 1958) and in patients with mitral stenosis (McGregor *et al.*, 1953). Further work including a study of the effects of oxygen on regional blood flow is necessary to define its place in therapy.

SUMMARY

The hæmodynamic changes following the administration of oxygen to patients with acute myocardial infarction have been studied. Measurements of cardiac output and brachial arterial pressure were made. Breathing 40 per cent oxygen usually results in a rise of systemic blood pressure and a fall in cardiac output. The possible mechanisms and clinical implications are discussed.

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