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Research Article

HYPERVENTILATION IN ARTERIOLAR HYPERTENSION

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Raab (1), in a study dealing with the effect of hyperventilation on the blood pressure of patients with arteriolar hypertension, concluded that there is a direct and constant relationship between the level of the blood pressure in patients with essential hypertension and the extent to which the CO_2 tension of the arterial blood (alveolar CO_2 tension) is lowered. The assumption was that hyperventilation produced lowering of the blood pressure in people with essential hypertension because of lowering of the CO_2 content of the blood.[1]

Previous to this work many physiologists had studied the effect of hyperventilation on people with normal arterial tension and in animals. Their methods differed so much from those of Raab and those presented here that comparisons are perhaps unjustifiable. Their results, however, are significant. Vincent and Cameron (2) in 1915 showed that hyperventilation in the human subject with normal blood pressure was associated with a rapid and considerable fall in blood pressure. This work confirmed earlier observations by Hill and Flack (3) and by Boothby (4). Collier, Densham, and Wells (5) found no effects of hyperventilation on the blood pressure of most of their human subjects with normal blood pressures. They thought that the systolic blood pressure was maintained nearly constant by means of a compensating cutaneous vasoconstriction. Schneider (6) agreed with this view. Vincent and Thompson (7) found that 37 out of 41 normal subjects showed a fall in blood pressure during a short period of hyperpnea. They suggested that the falls in blood pressure are due to mechanical interference with the return of blood to the heart, and that the lowered CO_2 tension of the blood is only a subsidiary factor.

In this study, an attempt has been made further to evaluate the significance of the CO_2 factor in the blood in essential hypertension. Also in our subjects with hypertension, the effect of hyperventilation on the cardiac output, the pulse rate, and on the vital capacity of the lungs was observed.

[1] Recently Corbini has been unable entirely to confirm these views. (Corbini, G.: Effetti della iperventilazione polmonare sulla pressione sanguigna. Riforma med. 1932, 1167–1173).

Seven patients were studied. In each case, blood pressure readings had been taken on numerous visits to the clinic before these studies were undertaken, so that we were thoroughly familiar with the variations and fluctuations in the blood pressure levels to which these patients were subject. The experimental periods were repeated several times on separate days in each case, not only to obtain satisfactory checks, but also to note possible daily variations. The effect of hyperventilation on the blood pressure of three normal people was observed also.

The patients were all women between the ages of thirty-five and sixty. In each case the diagnosis was essential hypertension. There was no evidence of heart failure or pulmonary disease in any patient. The pertinent facts concerning the status of the cardiovascular system in the individual patients are given in Table I. In all patients the following special tests and examinations were made: Electrocardiogram, orthodiagram of the heart, careful examination of fundus oculi, dilution and concentration test and phenolsulphonphthalein excretion test for kidney function. Also the percentages of nonprotein nitrogen and urea nitrogen in the blood were determined.

METHOD

The patients sat in a chair in a comfortable position. They were allowed to sit quietly with mouthpiece, nose-clip, and blood pressure cuff attached until the blood pressure reached a resting level. A determination of the cardiac output was then made, using the acetylene method of Grollman (8). A sample of the alveolar CO_2 at rest was obtained at the same time, and the vital capacity was measured. It was possible to carry out all of these procedures without disturbing the patient. A three-way valve was used. The patient thus could breathe first into a spirometer (125 liters Tissot) where air could be collected for determinations of metabolism. Then the patient could expire through another opening of the valve into a tube in the middle of which (about 40 cm. from mouthpiece) was a one-way flap valve. From the beginning of this tube an alveolar sample was collected. Connected to this tube beyond the flap valve was a small spirometer for measuring vital capacity. On the third opening of the three-way valve was a balloon, to which the patient could be switched at will, containing the acetylene mixture which was used for the estimation of the arteriovenous oxygen difference.

Patients were constantly urged to breathe deeply in and out during the hyperventilation. The rate of breathing was the same in all cases, being timed by a metronome. The hyperventilation was continued four to twenty-five minutes. The rate of the pulse and the level of the blood pressure were observed every one to two minutes, and alveolar samples were collected every three to five minutes. Where the level of the blood pressure and the value of the alveolar CO_2 are recorded at the same time,

TABLE I

Blood pressure, alveolar CO_2 tension, and alveolar CO_2 content before, during, and after hyperventilation in seven patients with arteriolar (essential) hypertension and in one patient with normal blood pressure

Case number	Experiment number	Sex	Age	Range of blood pressure fluctuation before hyperventilation	Blood pressure taken just before hyperventilation	Duration of rest period before hyperventilation	Duration of hyperventilation	During hyperventilation		After hyperventilation		Simultaneous readings in resting state			Lowest alveolar CO_2 during hyperventilation			Readings after hyperventilation			Blood pressure during hyperventilation			Clinical findings
								Lowest blood pressure during hyperventilation	Duration of hyperventilation when it occurred	Blood pressure reading	Time after hyperventilation	Alveolar CO_2 tension	Alveolar CO_2 percentage	Blood pressure	Tension	Percentage	Blood pressure at the time	Alveolar CO_2 tension	Alveolar CO_2 percentage	Blood pressure	Five minutes	Ten minutes	Fifteen minutes	
			years	*mm. Hg*	*mm. Hg*	*minutes*	*minutes*	*mm. Hg*	*minutes*	*mm. Hg*	*minutes*	*mm. Hg*		*mm. Hg*	*mm. Hg*		*mm. Hg*	*mm. Hg*		*mm. Hg*	*mm. Hg*	*mm. Hg*	*mm. Hg*	
1	1	F	60	198/110 184/108	198/110	59	10	164/112	2	196/112	8										168/108	170/110		Height 5 feet 3 inches. Weight 110 pounds. Advanced retinal arteriosclerosis. No cardiac enlargement. Aorta tortuous. Electrocardiogram normal. Normal kidney function; slightest possible trace of albumin, no casts
	2			196/112 184/110	184/114	35	5	170/114	7			35.65	5.02	170/104	11.22	1.58	174/106				174/106	170/114		
	3			204/108 164/102	204/108	60	15	162/116	11	186/112	5										174/106	170/114	170/120	
	4			230/128 174/110	214/120	80	12	180/120	10	214/118	9	36.97	5.20	214/120	18.27	2.57	190/120	34.27	4.82	204/118	190/120	180/120		
	5			220/108 188/110	192/120	70	15	158/114	10	188/116	17	35.39	4.97	198/120	17.73	2.49	166/110	30.40	4.27	190/112	176/128	158/114	166/110	
	6			200/114 180/108	180/108	45	16	154/108	16	182/110	14	34.64	4.88	196/116	17.54	2.47	154/108	31.95	4.50	186/110	174/102	154/108	154/108	
	7			214/128 190/122	190/122	75	16	158/118	16	194/120	25	38.40	5.40	216/130	20.34	2.86	158/116	33.71	4.74	198/124	170/110	170/112	158/116	
	8			194/110 160/106	180/114	55	11	166/114	8	176/112	18	34.06	4.80	186/118	20.19	2.84	176/114	33.92	4.77	176/112	170/102	176/114		
	9			206/116 178/110	192/116	100	5	168/102	5	190/112	20	29.90	4.20	180/108	19.58	2.75	168/102	32.76	4.60	188/110	168/102			
2	1	F	35	204/110 180/116	190/118	46	5	178/100	1	186/112	7	32.11	4.51	192/118	22.22	3.12	190/120	26.70	3.75	186/112	190/120			Height 5 feet 4 inches. Weight 135 pounds. Slight retinal arteriosclerosis. Heart probably slightly enlarged to left. Electrocardiogram: Moderate left axis deviation, otherwise normal. Normal renal function; no albumin, no casts
	2			188/112 168/106	180/112	40	10	174/104	5	180/110	16	34.07	4.79	180/106	19.62	2.76	174/110	27.87	3.92	176/110	174/104	180/110		
	3			182/106 166/102	170/104	45	6	160/96	1	186/112	9	30.96	4.33	174/106	18.52	2.59	166/100				166/100			
	4			194/110 178/110	186/110	40	7	166/110	4	170/110	45	33.20	4.65	184/110	19.21	2.69	174/112	30.13	4.22	184/110	174/112			
	5*			186/110 170/110	186/110	55	4	146/98	1	194/114	3	30.16	4.23	182/110	16.26	2.28	168/104							
	6*				186/112	10	4	164/100	1	180/100	1													
	7*				180/110	10	4	164/90	1	192/114	3	30.13	4.22	180/110	17.14	2.40	170/110							
	8			166/98 158/98	158/98	10	18	144/88	1	158/96	4	31.47	4.44	158/100	14.95	2.10	152/98				150/100	154/100	162/96	
	9			178/108 176/108	178/108	30	10	160/100	3			33.33	4.70	178/110	17.59	2.48	180/110				170/110	180/110		
3	1	F	41	240/140 220/138	220/138	42	10	248/140	8	224/140	16	33.42	4.72	220/140	20.68	2.92	250/144	30.03	4.24	224/140	254/150	250/140		Height 5 feet 5½ inches. Weight 140 pounds. Slight retinal arteriosclerosis. Heart enlarged slightly to left. Electrocardiogram: Moderate left axis deviation. T_1 inverted, T_2 flat. Normal renal function
	2			234/128 218/132	230/134	60	5	240/136	1	234/140	2	32.21	4.53	220/126	21.26	2.99	250/140				250/140			
	3			258/146 238/142	258/146	39	7	258/144	4	244/154	2	37.12	5.22	256/140	21.62	3.04	258/144				258/144			
	4*			254/148	254/148	40	6	248/146	1			36.82	5.20	250/140	13.81	1.95	260/150				260/150			
	5			220/136 214/132	214/136	22	10	210/130	9	210/138	6	35.55	5.00	220/136	19.27	2.71	210/130				220/128	210/130		
	6			230/130 214/132	214/132	34	25	200/128	22	216/134	5	32 61	4.58	218/134	16.95	2.38	202/126				216/128	214/134	214/128	
4	1	F	53	256/138 234/120	256/138	90	9	254/140	9	240/136	11										254/140			Height 5 feet 2 inches. Weight 148 pounds. Slight retinal arteriosclerosis. Heart slightly enlarged to left. Electrocardiogram: Left axis deviation, otherwise negative. Normal renal function; no albumin, no casts
	2			256/142 256/142	240/136	100	4	238/132	3															
	3			238/130 228/118	238/130	11	7	224/126	2			33.35	4.69	228/126	19.70	2.77	234/136				234/124			
	4*			224/124 208/120	224/124	17	10	206/118	8	204/116	2	38.41	5.41	224/124	11.22	1.58	218/122				210/120	212/114		
5	1	F	59	170/102 150/98	150/98	24	10	152/98	1												158/102	164/100		Height 5 feet 3½ inches. Weight 136 pounds. Slight retinal arteriosclerosis. Slight cardiac enlargement. Electrocardiogram: Moderate left axis deviation, otherwise negative. Normal renal function; no albumin, no casts
	2			190/108 176/110	180/112	11	10	170/110	1			35.12	4.96	180/112	20.60	2.91	178/118				176/110	178/118		
	3			170/110 160/108	160/108	18	15	160/104	1			33.18	4.70	166/98	19.20	2.72	160/104				198/120	178/118	160/104	
6	1	F	50	210/90 188/96	188/96	10	16	180/90	1	194/94	5	31.29	4.42	188/96	17.06	2.41	184/90				182/92	184/94	184/90	Height 5 feet 5 inches. Weight 188 pounds. Slight retinal arteriosclerosis. Slight cardiac enlargement. Electrocardiogram: Negative. Normal renal function; no albumin, no casts
7	1	F	55	216/100 204/98	214/100	76	15	176/98	13	178/92	10	31.70	4.49	204/98	19.06	2.70	176/100				200/100	194/102	176/100	Height 5 feet 4½ inches. Weight 190 pounds. Moderate retinal arteriosclerosis. Slight cardiac enlargement. Electrocardiogram: PR interval =0.22 second. Moderate left axis deviation. Normal renal function. No casts. Slightest possible trace albumin
	2			196/98 182/102	182/102	24	15	156/100	15	188/100	6	36.41	5.12	188/102	19.98	2.81	156/100		4.92	188/100	170/100	164/98	156/100	
8	1	F	48	104/62 96/58	100/64	50	5	100/68	1	98/64	13	33.96	4.80	100/66	22.48	3.17	102/70	28.52	4.03	102/70	102/70			Height 5 feet 6½ inches. Weight 127 pounds. Heart and kidneys normal. Electrocardiogram normal
	2			100/62 96/60	96/60	41	9	100/66	1	96/62	7	33.98	4.80	96/60	17.17	2.51	106/70	32.07	4.53	98/64	102/70			
	3			98/62 96/60	96/62	22	10	100/62	2	98/62	15	29.40	4.14	96/64	19.32	2.72	102/70	30.32	4.27	98/62	100/68	102/70		
	4			108/66 98/62	108/66	15	5	104/66	1	100/66	50	30.32	4.27	104/70	22.72	3.20	106/70				106/70			
	5			96/60 84/56	96/60	42	8	102/62	1	96/64	21	35.88	5.04	94/60	20.78	2.92	108/70	28.48	4.00	100/62	102/62			

* Rate of respiration 28 (otherwise 18).

the reading of the blood pressure was always made immediately before the alveolar CO_2 samples were collected so that the exertion of the complete expiration did not influence the level of the blood pressure. Breathing of the three per cent CO_2 mixture was from the 125 liter Tissot spirometer.

RESULTS

Hyperventilation and blood pressure. There was no uniformity of results (Table I). There was a considerable drop in blood pressure in only 3 of the 7 patients studied; in 2 there was only a slight drop; in 1 patient there was no drop; and in the remaining patient the blood pressure usually rose with hyperventilation. The duration of the period of hyperventilation did not change these results significantly. Sometimes more rapid hyperpnea caused a greater drop in blood pressure. In the three normal persons no definite changes occurred in the blood pressure following hyperventilation. The result of hyperventilation in a person with normal blood pressure is shown in Table I. The other two people with normal blood pressure also showed no effect. The periods of hyperventilation ranged from 4 to 25 minutes. The respiratory rates were fixed at 18 or 28 per minute.

In all of the patients a considerable drop could have been recorded had the readings been taken only at the end of inspiration. The effect of a single inspiration or expiration on the blood pressure is well known and is probably to be attributed to the mechanical effect of sudden changes in intrathoracic pressure. Considerable fluctuation in the levels of the blood pressure was observed during the various phases of single respirations, and accurate readings were therefore difficult to obtain. Whenever possible, double values were recorded for the blood pressure at the various stages of a single respiration. When the fluctuations were not marked and single readings are recorded, these readings represent the first point at which the sounds came through. It is possible that in those cases in which little or no fall in blood pressure is recorded, a fall might have occurred which was obscured by a rise due to the excitement and exertion of the hyperventilation. In order to overcome the emotional reaction as a disturbing factor, the procedure was repeated several times until it appeared reasonably certain that little or no excitement attended the process of deep breathing. The physical exertion was so slight as not to be of considerable importance. The extent of the work is indicated by the fact that in three of the cases in which the oxygen consumption was measured before and during hyperventilation, there was an average rise only from 200 cc. of oxygen per minute to 260 cc. of oxygen per minute.

As can be seen from Table I, there was usually considerable spontaneous fluctuation in the blood pressures during the resting stage preceding the periods of hyperventilation. Hyperventilation was not always begun just when the blood pressure reached the lowest resting level. Thus in

some instances in which a drop is observed during hyperventilation, there was no drop from the lowest resting level. Since spontaneous variations occur so regularly in the resting periods, it is not unreasonable to assume that they occur also during the periods of hyperventilation. The lowest blood pressure reached during hyperventilation, then, may be in part due to a spontaneous fall in some instances. This assumption is borne out especially by the fact that the lowest blood pressure during hyperventilation usually persisted only one or two minutes.

It was not an uncommon occurrence for the blood pressure to reach its lowest level during the first one to three minutes of hyperventilation, and then gradually rise again. In some instances, on the other hand, it was only after several minutes of hyperventilation that a change was observed. There was considerable and irregular variation in the manner of reaction in this as in most studies dealing with people who have essential arteriolar hypertension.

Alveolar CO_2 and blood pressure. No definite relationship was observed between the lowering of the alveolar CO_2 tension, and the drop in blood pressure. For example, in Case 2 in which there was some drop with hyperventilation, the blood pressure was 180/106 during rest and the alveolar CO_2 tension was 34.07 mm. Hg (alveolar CO_2 content 4.79 per cent). After hyperventilation for five minutes, the blood pressure had dropped only to 174/104, although the alveolar CO_2 tension was now 22.25 mm. Hg (alveolar CO_2 content 3.13 per cent). With nine minutes hyperventilation, the blood pressure was still 174/110, while the alveolar CO_2 tension had dropped to 19.62 mm. Hg (alveolar CO_2 content 3.92 per cent). Ten minutes after the hyperventilation, the blood pressure was practically the same, 176/110, and yet the alveolar CO_2 tension had risen to 27.87 mm. Hg (alveolar CO_2 content 3.92 per cent).

The view might be held that possibly a delay occurs in the reaction of the blood pressure to the drop in alveolar CO_2 tension, and that if the alveolar CO_2 tension were kept low long enough, the blood pressure would drop. This was found not to be true. If the drop in blood pressure took place, it was almost simultaneous with the drop in the alveolar CO_2 tension; if it did not occur, a long continued hyperventilation with a subsequent lowering of the alveolar CO_2 tension did not produce it. Thus, in Case 6, the alveolar CO_2 tension at rest was 31.29 mm. Hg (alveolar CO_2 content 4.42 per cent), and the blood pressure at rest 188/96. After hyperventilation for three minutes the alveolar CO_2 tension was 21.88 mm. Hg (alveolar CO_2 content 3.09 per cent), and the blood pressure 180/92. At the end of seven minutes, alveolar CO_2 tension was 18.69 mm. Hg (alveolar CO_2 content 2.64 per cent), blood pressure 184/94. At the end of eleven minutes alveolar CO_2 tension was 17.70 mm. Hg (alveolar CO_2 content 2.5 per cent), blood pressure 184/94; and at the end of fifteen minutes alveolar CO_2 tension was 17.06 mm. Hg (alveolar CO_2 content

2.4 per cent), and blood pressure 184/90. In other words, while the alveolar CO_2 tension was quickly and considerably lowered by hyperventilation, and remained so for fifteen minutes, the blood pressure was never lowered. The same was true in the other case in which no effect was produced on the blood pressure by hyperventilation (Case 5), the blood pressure just before hyperventilation being 160/108, whereas after fifteen minutes hyperventilation it was 160/104, although several samples showed the alveolar CO_2 tension to be distinctly low throughout this period of hyperventilation.

This question naturally arose: Were the differences in the response of the blood pressure to lowering of alveolar CO_2 due to differences in sensitivity of the vasomotor centers to the CO_2 tension of the arterial blood? That is, was the vasomotor center in Case 1 (in which blood pressure dropped considerably) more sensitive to the CO_2 tension in the arteries than the vasomotor center in the cases in which the blood pressure did not fall with the drop in CO_2 tension? It was thought that these differences in sensitivity, if they occurred, could be observed simply by noting the response of the blood pressure when a mixture containing 5 per cent CO_2 was breathed quietly. During such a procedure the blood pressure rose in Case 1 from 174/104 in six minutes to 214/122; whereas in Case 6, in which a drop in alveolar CO_2 tension did not produce a drop in blood pressure, the blood pressure rose in six minutes from 220/120 to 264/138. In other words, each patient seemed equally sensitive to CO_2 as determined by the response of the blood pressure to quiet breathing of a constant mixture of five per cent CO_2, and yet a lowering of the CO_2 tension of the arterial blood produced quite different responses of the blood pressure in each case. It would seem, therefore, unjustifiable to assume that in those cases of essential hypertension in which hyperventilation with subsequent lowering of the tension of the arterial CO_2 produces a large drop in blood pressure, a greater sensitivity to CO_2 exists. The fact that more rapid hyperpnea without more marked drop in arterial CO_2 tension sometimes produced greater lowering of the blood pressure also militates against the idea that the drop is related simply to a sensitivity of the vasomotor center to CO_2.

The chief argument of those who favor the view that it is the lowering of the CO_2 tension alone which is responsible for the drop in blood pressure is that the blood pressure will not drop when the alveolar CO_2 tension is maintained at a normal level during hyperventilation by the use of a mixture containing an excess of CO_2. It is contended that if the drop in blood pressure were due to a mechanical factor, this drop would also be observed when the alveolar CO_2 was maintained at a normal level, the mechanical factors remaining unchanged. However, an air mixture containing enough CO_2 to maintain the alveolar CO_2 at a normal level (about 3 per cent in our studies) contains enough CO_2 to act in itself as an

abnormal stimulus to the vasomotor center and thus raise the blood pressure (Van Esveld (9)). In cases in which the blood pressure apparently does not drop with hyperventilation, using a 3 per cent CO_2 mixture, it may well be that the drop is obscured by a rise due to the stimulating effect of CO_2. What seems like no effect then is probably a double effect in which there is a drop balanced by a rise. The following results make this assumption seem indeed likely. In Case 1, in which simple hyperventilation with lowering of the alveolar CO_2 tension was accompanied by a definite drop in blood pressure, hyperventilation for five minutes with three per cent CO_2 mixture produced no drop. The blood pressure at rest was 184/108, and the alveolar CO_2 tension was 33.02 mm. Hg (alveolar CO_2 content 4.65 per cent); the blood pressure after the hyperventilation with three per cent CO_2 was 184/110, and the alveolar CO_2 tension remained at the high level of 29.39 mm. Hg (alveolar CO_2 content 4.14 per cent). If it were assumed that hyperventilation in this case caused a drop in blood pressure which was balanced by a rise due to the air mixture containing three per cent CO_2, then in a case where similar sensitivity to CO_2 existed and in which simple hyperventilation produced little or no drop, hyperventilation with a three per cent CO_2 mixture should cause the blood pressure to rise. Case 2 affords such an instance. Here, while there was on several occasions only a slight drop in blood pressure with simple hyperventilation at a respiratory rate of 18 per minute, the blood pressure rose from 170/108 to 194/120 after 4.25 minutes hyperventilation at the same rate with three per cent CO_2, and the alveolar CO_2 tension remained practically unchanged. In this case only the blood pressure raising effect of the CO_2 was present; so a rise was recorded. In the two cases just compared, quiet breathing of a five per cent CO_2 mixture produced similar rises in blood pressure indicating that the vasomotor centers were equally sensitive to CO_2. The chief argument in favor of the role of CO_2 in the lowering of the blood pressure in hyperventilation, namely, that when the alveolar CO_2 is maintained at a normal level, the hyperventilation does not produce a drop in blood pressure, would thus seem to be untenable, since the two cases above indicate that a drop does occur which is balanced by a rise due to the extraneous factor of breathing a mixture containing an excess of CO_2.

Hyperventilation and cardiac output. In three of the cases studied, estimations of cardiac output were made before and during hyperventilation. In one of these cases there was no change in blood pressure with hyperventilation; in one, a slight fall; and in one, a moderate fall. In the first of these cases the output of blood from the heart was practically unchanged during hyperventilation. In the other two there was somewhat of an increase (see Table II). The figures show in general what Grollman (10) found in normal people; namely, that the cardiac output increases to just about the extent which might be expected simply from

TABLE II

Hyperventilation and cardiac output

Case number	Duration of hyperventilation	Blood pressure before hyperventilation	Lowest blood pressure during hyperventilation	Oxygen consumption during rest	Arteriovenous oxygen difference at rest	Cardiac output at rest	Oxygen consumption during last minute of hyperventilation	Arteriovenous oxygen difference at end of hyperventilation	Cardiac output at end of hyperventilation
	minutes	*mm. Hg*	*mm. Hg*	*cc.*	*cc. per liter*	*liters*	*cc.*	*cc. per liter*	*liters*
3	10	214/140	210/130	194	77.34	2.5	242	105.2	2.3
2	7	186/110	174/112	181	53.37	3.4	278	62.32	4.5
7	7	182/98	164/96	227	53.11	4.3	260	50.85	5.1

TABLE III

Hyperventilation and vital capacity

Case number	Experiment number	Vital capacity at rest before hyperventilation	Vital capacity during hyperventilation	Time	Vital capacity at rest after hyperventilation	Time
		cc.	*cc.*	*minutes*	*cc.*	*minutes*
2	1	2700	3000	5		
		2800	2950	13		
	2	2850	2900	6	2825	11
			2950	12		
	3	3050	3050	4		
	4	3100	2950	7	3000	60
		3000	2925	4		
	5	3000	2850	4		
			2900	6		
			2800	8		
			2950	18		
3	1	2150	1700	6	2150	15
			1600	10		
	2	2300				
		2350	2350	5		
	3	2400	2450	5		
	4	1800	2050	3	2350	6
			1950	10		
	5	2350	2250	5		
			2200	10		
			2200	14		
			1750	18		
			2200	24		

the increase in work. The average increase in oxygen consumption was from 201 cc. per minute to 260 cc. per minute. In two of the cases, the arteriovenous oxygen difference increased, while in the third it remained almost unchanged.

Vital capacity. On the assumption that changes in blood volume within the lungs during hyperventilation, if present, might reflect themselves in changes in the vital capacities, the vital capacities were obtained before, during, and at the end of varying periods of hyperventilation. No definite changes in the vital capacities were observed. Two illustrative cases are presented in Table III.

Pulse rate. Hyperventilation was found to have no regular effect on the pulse rate. Sometimes there was no change in the pulse rate; sometimes there was slight slowing; more commonly there was a slight increase in the rate.

SUMMARY AND CONCLUSIONS

1. Hyperventilation produces a lowering of the blood pressure in some patients with essential hypertension. A significant drop does not regularly occur. There may even be a slight rise.

2. There appears to be no direct and constant relationship between the height of the blood pressure in patients with essential arteriolar hypertension and the alveolar CO_2 tension.

3. In those cases of essential hypertension in which lowering of the arterial CO_2 tension by hyperventilation is accompanied by a definite drop in blood pressure, no undue sensitivity to CO_2 exists (measured by response of blood pressure to breathing of a mixture containing an excess of CO_2) as compared with those cases in which hyperventilation has no effect.

4. In patients in whom a significant drop in blood pressure occurs with lowering of alveolar CO_2 tension by hyperventilation, there is no drop when the alveolar CO_2 tension is maintained at a normal level during hyperventilation with a mixture containing three per cent CO_2. Evidence is presented which suggests that the absence of a drop in blood pressure under such circumstances is due to the balancing of a fall in blood pressure from the mechanical effects of deep breathing and a rise from the vasoconstricting effect of the three per cent CO_2.

5. The cardiac output increases during hyperventilation in patients with essential hypertension to the extent which might be expected simply from the slight increase in work

6. The vital capacity appears not to be significantly altered after varying periods of hyperpnea. This is true also of the rate of the pulse.

BIBLIOGRAPHY

1. Raab, W., Ztschr. f. d. ges. exper. Med., 1929, lxviii, 337. Die Beziehung zwischen CO_2-Spannung und Blutdruck bei Normalen und Hypertonikern.
2. Vincent, S., and Cameron, A. T., Quart. J. Exper. Physiol., 1915, ix, 45. Observations upon the Vaso-motor Reflexes.
3. Hill, L., and Flack, M., J. Physiol., 1910, xl, 347. The Influence of Oxygen Inhalations on Muscular Work.
4. Boothby, W. M., J. Physiol., 1912, xlv, 328. Absence of Apnea after Forced Breathing.
5. Collier, R. J., Densham, H. B. A. R., and Wells, H. M., Quart. J. Exper. Physiol., 1927, xviii, 291. The Influence of Respiratory Movements on the Cutaneous Circulation.
6. Schneider, E. C., Am. J. Physiol., 1930, xci, 390. A Study of Respiratory and Circulatory Responses to a Voluntary Gradual Forcing of Respiration.
7. Vincent, S., and Thompson, J. H., J. Physiol., 1928, lxvi, 307. The Effect of Hyper-respiration on the Blood Pressure in Man.
8. Grollman, A., Am. J. Physiol., 1929, lxxxviii, 432. The Determination of the Cardiac Output of Man by the Use of Acetylene.
9. Van Esveld, L. W., Arch. f. exper. Path. u. Pharmakol., 1930, cxlvii, 317. Pharmakologie des Vasomotorenzentrums; II. Mitteilung: Der Anteil des Herzens und Vasomotorenzentrums an durch neidrige CO_2-Konzentrationen hervorgerufenen Blutdrucksteigerungen.
10. Grollman, A., Am. J. Physiol., 1930, xciv, 287. Physiological Variations in the Cardiac Output of Man. IX. The Effect of Breathing Carbon Dioxide, and of Voluntary Forced Ventilation on the Cardiac Output of Man.