RESPIRATORY MINUTE VOLUME DURING MODERATE EXERCISE

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The effect of blocking the vagi on respiratory minute volume both before and during exercise was studied in separate dogs without and after denervation of the carotid region. In all dogs the respiratory minute volume increased during exercise and further increased on blocking the vagi. Carotid denervation did not materially affect the respiratory minute volume, but exercise remarkably increased it in such dogs both before and after blocking the vagi. The possibility of a pulmonary chemoreceptor has been discussed, and it has been suggested that the afferents for such a reflex could travel in the vagus only if they escape block at 0°C., but if they do not travel in the vagi then sympathetic nerves could be an alternative pathway. Evidence has also been presented suggestive of production of certain metabolites that decrease the respiratory minute volume through the carotid chemoreceptors.

The increase in respiratory minute volume during moderate muscular exercise has been explained as due to nervous impulses arising from the exercising muscles, and to various humoral agents produced in such muscles and playing on the respiratory centre either directly or reflexly. Amongst the humoral agents Dill *et al.*, (1927), Bock *et al.*, (1928) and Lilienthal *et al.*, (1946) did not observe any change in the arterial pCo_2, po_2 or pH. These factors, therefore, could not act directly on the centre or reflexly through the chemoreceptors present in the arterial bed. Riley (1960) and Armstrong *et al.*, (1961) made an attempt to explain the mechanism of humoral regulation of breathing by postulating a new hypothesis of an existence of a separate chemoreceptor mechanism around the pulmonary artery, and suggested that afferents from such receptors travel along the vagus nerves. The present investigation was undertaken to study how the rate of pulmonary ventilation is affected by blocking the vagal afferents.

METHODS

The experiments were done on 24 healthy mongrel dogs of both sexes weighing from 8.0—17.75 kg. They were anaesthetised with chloralose (90 mg/kg) given intravenously. The respiration was recorded by introducing and inflating a toy balloon in the oesophagus and then connecting it to a recording tambour. The tracheal cannula was connected to a gas meter through a bivalved tube in such a way that all the expired air passed into the meter and was measured. The gas meter and an electromagnet were so incorporated in a circuit that every 1.25 litres of expired air was marked on the kymograph. The tidal volume was determined by dividing the respiratory minute volume with respiration rate. The vagi were cold blocked at 0°C by placing them in a groove on the flattened end of an insulated copper rod projecting for a short distance from the bottom of a receptacle containing ice and common salt mixture. Rewarming of the vagi was done by removing them from the copper rods and placing them within the neck. The cooling was done each time for five min, but reading of the last four min alone were taken into consideration. The hind limbs were first denervated by sectioning their sciatic, femoral and obturator nerves and then exercised by giving percutaneous square wave pulses of 25 m sec duration and 80 v intensity at 1/sec interval from a 'Seamax' electronic stimulator. Wide based electrodes were used on both the limbs to ensure stimulation of as large a number of muscles as possible. Carotid blood pressure and deep rectal temperature was recorded in each experiment.

In the first 12 dogs initial readings without exercise were taken before, during and after cooling the vagi. The hind limbs were then exercised and similar readings taken once again. In the second set of 12 dogs the carotid region of the two sides was denervated by dissecting out the adventitia of the internal and common carotid arteries for a distance of 2 cm on each side from the point of bifurcation of the artery and then painting the region with 80 percent phenol in water. The excess of phenol was neutralised with 70 per cent alcohol and then washed with excess of normal saline. In these dogs also similar readings before during and after cooling the vagi, both before and during exercise were taken.

RESULTS

The results are presented in the Table I, II and III.

DISCUSSION

On cold blocking the vagi, the respiration rate decreased and the amplitude increased over the resting value, with the result that the tidal volume increased to 294·2 ± 45·7 ml from a resting value of 145 6 ± 16·4 ml. This is due to blocking of the fibres for the Hering-Breuer reflex. In one dog, however, both the amplitude and the rate of respiration increased. Such

TABLE I

Respiratory minute volume etc. in dogs. Results without carotid denervation.

	Before exercise									During exercise								
	Respiration per minute			Respiratory minute volume in litters			Tidal volume in ml			Respiration per minute			Respiratory minute volume in litters			Tidal volume in ml		
Sr.No.	I	VC	V.Re	I	VC	V.Re	I	VC	V.Re	I	VC	V.Re	I	VC	V.Re	I	VC	V.Re
1	13	12	12	0.94	2.14	1.11	72	178	84	20	16	17	2.02	3.09	1.84	101	193	108
2	13	14	13	0.63	2.03	1.76	48	145	135	16	17	13	2.82	3.28	1.45	176	176	111
3	10	7	6	2.45	3.09	2.46	254	440	410	20	10	7	5.44	4.28	2.38	272	428	340
4	9	11	9	1.09	1.25	0.98	121	114	109	17	12	11	2.37	3.84	2.62	139	320	238
5	15	15	12	2.79	3.02	2.47	186	201	206	16	14	15	4.53	4.69	3.49	282	334	232
6	21	16	13	2.40	3.10	2.48	114	194	191	21	22	22	2.80	3.01	2.39	133	182	109
7	18	11	16	2.59	2.31	2.12	144	210	132	30	22	23	3.28	4.53	3.78	109	160	164
8	11	5	9	1.83	1.97	1.64	166	392	183	15	8	14	2.76	2.71	2.70	184	340	193
9	9	4	7	1.33	1.67	1.61	148	420	230	16	9	14	3.12	3.47	2.95	195	386	210
10	10	8	10	1.77	2.70	1.76	177	338	176	14	11	13	2.78	3.23	2.84	199	294	218
11	16	10	13	1.83	2.43	1.81	114	243	139	15	6	14	3.18	1.81	3.50	212	302	250
12	16	6	10	3.30	3.93	3.48	203	655	348	16	5	8	4.75	3.22	3.75	298	645	470
Mean	13.4	9.9	10.8	1.92	2.47	1.97	145.6	294.2	195.3	18.0	12·7	14.3	3.32	3.43	2.81	191.7	314.8	220.3
S.E.	1.1	1.1	0.8	0.24	0.21	0.20	16.4	45.7	26.3	1.3	1.6	1.4	0.30	0.22	0.21	19.1	30.0	38.9

I = Initial readings before interfering the vagi.

VC = Readings when vagi were cold-blocked.

V.Re = Readings when vagi were allowed to rewarm.

TABLE II

Respiratory minute volume etc. in dogs. Results after carotid denervation

	Before exercise									During exercise								
	Respiration per minute			Respiratory minute volume in litters			Tidal volume in ml			Respiration per minute			Respiratory minute volume in litters			Tidal volume in ml		
Dog Nos.	I	VC	V.Re	I	VC	V.Re	I	VC	V.Re	I	VC	V.Re	I	VC	V.Re	I	VC	V.Re
13	15	11	14	0.96	0.93	1.12	64	85	80	15	14	17	1.34	1.86	1.75	90	133	103
14	13	9	12	0.97	1.41	0.94	75	157	78	24	22	24	2.10	2.50	2.03	88	114	85
15	17	12	15	1.81	2.08	1.67	106	174	111	18	15	18	2.67	2.24	2.70	148	149	150
16	28	22	30	3.08	3.98	2.53	110	180	85	33	29	32	3.86	4.61	4.68	117	159	146
17	3	2	4	0.26	0.45	0.47	87	225	117	16	11	13	3.75	4.15	3.00	257	378	230
18	11	6	13	1.75	2.92	2.38	159	490	183	18	8	16	3.75	4.17	2.88	208	520	180
19	12	7	8	2.28	2.85	2.12	185	408	266	21	16	19	5.06	5.65	4.99	242	354	262
20	20	10	12	3.00	2.21	2.12	150	221	177	15	11	14	3.21	3.81	3.11	214	348	222
21	14	11	11	1.66	1.80	1.03	118	163	94	15	12	14	2.54	3.52	2.33	169	292	166
22	14	13	17	2.26	2.57	2.42	161	193	142	19	20	27	3.70	3.95	3.54	195	198	131
23	20	19	22	2.50	3.65	2.87	125	192	130	45	40	37	7.67	8.49	6.88	170	212	185
24	19	18	19	2.12	2.73	2.07	112	151	109	23	21	27	4.75	5.71	4.89	230	272	181
Mean	15.5	11.7	14.8	1.89	2.30	1.81	112.8	220.0	131.0	21.8	18.3	21.5	3.78	4.22	3.56	177.3	260.8	170.1
S.E.	1.5	1.7	1.7	0.84	0.99	0.72	17.0	32.3	15.9	2.8	2.6	2.0	0.47	0.52	0.43	16.6	35.4	14.7

I = Initial readings before interfering the vagi.
VC = Readings when vagi were cold-blocked.
V.Re = Reading when vagi were allowed to rewarm.

TABLE III

Mean Blood Pressure values in mm Hg in dogs

Dog No.	Rest			Exercise		
	Initial	Vagi cooled	Vagi rewarmed	Initial	Vagi cooled	Vagi rewarmed
			Before Denervation of Carotid Region			
1	120	150	122	130	160	140
3	120	180	140	120	160	150
5	120	140	123	120	125	120
6	120	150	130	100	110	95
7	120	150	118	120	140	130
8	120	130	120	120	135	130
9	120	170	140	150	190	150
Mean	120	150	128	123	146	130
			After Denervation			
14	120	150	130	125	165	130
15	110	130	120	120	125	120
17	110	128	118	120	140	120
19	120	142	130	130	140	130
20	110	130	120	120	130	115
21	120	135	120	120	130	120
22	120	142	110	120	130	110
23	100	132	100	100	140	95
24	110	120	108	110	130	120
Mean	113	134	117	118	137	118

stray observations have also been reported by Bozler and Burch (1951). The mean respiratory minute volume increased from 1·92 ± 0·24 to 2·47 ± 0·21 litres. On rewarming the vagi by placing them within the structures in the neck it came down to 1·97 ± 0·20 litres. Although the respiratory minute volume returned almost to the prevagal-block level, but the respiration rate did not increase to the same extent with the result that the tidal volume was 195·3 ± 26·3 ml. When exercise was initiated in these animals the mean respiratory minute volume increased to 3·32 ± 0·30 litres, and on cold blocking the vagi it only slightly increased to 3 43 ± 0 22 litres. It therefore, appears that exercise itself had so much increased the respiratory minute volume that any further increase by vagal block was not appreciable. The respiration rate and the tidal volume though increased, followed, both during and after vagal block, a response similar to before-exercise period (Table I).

What could be the mechanism of this increase in the respiration rate and pulmonary ventilation during exercise ? It could not be due to reflexes arising from the exercising muscles, as all the nervous connections of the exercising limbs were severed. The exercise stimulus has therefore, to be a blood borne chemical and/or physical change. With this end in view in the next series of dogs both the carotid regions were completely denervated. On such a denervation the mean initial rate of respiration, as also the rates during and after bilateral vagal block were more (Table II), than the corresponding figures observed before denervation (Table I). It was further observed that the mean blood pressure of these dogs decreased with such a denervation (Table III). Mathur and Tandon (1952) had observed that blood pressure responses similar to those of carotid sinus can be evoked on stimulation of the various arterial branchings within the body. In the light of these observations the increase in respiration rate after carotid denervation could be due to fall in blood pressure setting up a reflex elicitable from the various arterial branchings of the body. Although the mean respiration rate of the carotid denervated dogs increased but the respiratory minute volume did not materially change. Vagal block as usual increased the respiratory minute volume, but the increase was less than that observed in the series of experiments without denervation of the carotid region. On rewarming the vagi the respiratory minute volume returned to a little below the initial value.

When the hind limbs of the carotid denervated dogs were exercised the respiratory minute volume increased from the initial value of 1·89 ± 0 84 to 3·78 ± 0 47 litres - an increase of 100 per cent ; whereas the corresponding increase in the carotid innervated series was only from 1·92 ± 0·24 to 3·32 ± 0·30 litres i.e., an increase of 73 per cent. On bilateral vagal block the increase in respiratory minute volume over the corresponding rate during the before-exercise period was 83·4 per cent in carotid denervated dogs and only 38 8 per cent in carotid innervated series of dogs.

How could muscle exercise produce such a remarkable increase in respiratory minute volume after carotid denervation? Firstly, it may appear that the carotid region exercises some restraining action on the respiratory centre. Secondly, the chemical and/or physical changes in the outcoming blood from the exercising muscles act through the yet unidentified chemoreceptors in the pulmonary bed. The possibility of the existence of a chemoreceptor of the type known to be present in the carotid and aortic bodies has recently been postulated by Riley (1960). Subsequently Armstrong (1961) postulated that the fibres for the pulmonary chemoreflex might be travelling along the vagi. In the present study the vagi were blocked at 0°C. Hammouda and Wilson (1935) and Ferguson (1940) have shown that even at 0°C some vagal afferents escape the block. It thus appears that the fibres for the pulmonary chemoreflex could travel in the vagus only if they escape cold block at 0°C, but if they do not travel in the vagi then sympathetic nerves could be an alternative pathway.

If the above hypothesis is assumed to be correct then why during exercise did these pulmonary chemoreceptors not increase the ventilation rate to an equally large extent in carotid innervated series of dogs? It is possible, therefore, that carotid region exercises some restraining action on the centre and thus does not let the respiratory minute volume increase to the same extent in the carotid innervated dogs. Grodins (1950) and Sinnot (1961) did not observe any change in arterial pCo_2, po_2, pH or temperature of the arterial blood during moderate exercise. It is to these agents that the carotid chemoreceptors are known to respond by reflexly increasing the respiratory minute volume. Though this aspect of the problem has not been investigated, but in the light of these observations it is possible that muscular exercise produces certain yet unknown metabolites to which the carotid chemoreceptors respond by reflexly inhibiting the minute volume.

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