THE VARIABILITY AND INCIDENCE OF TYPES OF BREATHING IN THE ANÆSTHETISED DOG.[1] By ROBERT GESELL and CARL MOYER, Department of Physiology, University of Michigan, Ann Arbor, Michigan.

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VARIABILITY in the type of breathing has been commonly noted both in man and dog. Not only may the type of breathing differ from one individual to another, but the mode of breathing may change from time to time in any given individual. The causes of prevailing types of breathing in different individuals and the causes of changing type of breathing in any given individual are still obscure. It occurred to us that a study of the mode of breathing in the dog, where mechanical and chemical variables are readily controlled, might provide suggestive leads relating to the control of breathing. Accordingly, changes in circumference of the torso along with changes in tidal air were recorded under numerous conditions.

The first paper of this group presents miscellaneous data pointing to the extensiveness of the central regulating mechanism, and indicating the importance of spinal reflex control. The second paper deals with a comparison of differences in breathing produced by lowered alveolar oxygen pressure and by increased alveolar carbon dioxide pressure. The third paper deals with effects of sensory nerve stimulation on costal and abdominal breathing, and the fourth paper deals with the effects of administrations of chemicals on reflex changes in breathing, raising the question of whether breathing may not be fundamentally a reflex phenomena.

METHOD.

Changes in torso circumference were recorded with encircling bands of paper arranged as in fig. 1. The animals were anæsthetised with morphine and urethane. They were clipped and depilated with barium sulphide and placed, back down, on a specially constructed dog-board with movable rungs distributed to support the dog at points between the bands. To minimize the resistance of the recording systems the bands and the torso were dusted with talcum powder, and the recording equipment was made of the lightest material consistent with the

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necessary strength. The hind legs were bound to the board in the usual way. The front legs were taped in a vertical position to two upright bars. One end of each recording band was glued to the under surface of a metal block, which is held in contact with the body over the mid-ventral line by means of an adjustable handle and a phosphor-bronze spring. A thread, attached to the free end of the paper band, runs horizontally over a small pulley mounted on the upper surface of the metal block, spanning a distance of one metre, to a pulley directly under a vertically moving recording rod. An increase in body circumference, registered as a down stroke, draws the recording rod downwards and tightens the supporting spiral spring. A decrease in circumference allows the recorder to rise and take up the slack in the band and thread. Up and down movements of the mid-ventral line and recording blocks produce no appreciable record, due to the length and direction of the thread running from the recording band. As a routine procedure changes in torso circumference were recorded at six levels indicated in fig. 1 and Table I.

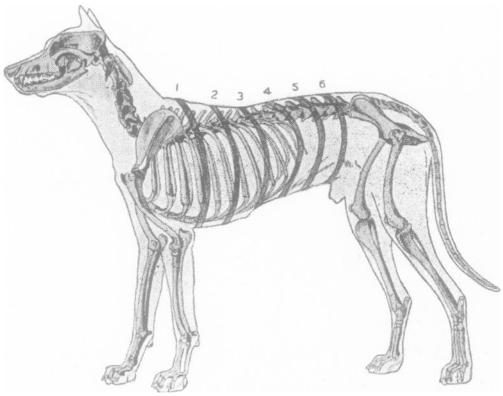

Fig. 1.—Schema showing location of paper bands, which record the changes in costal and abdominal circumference.

Table I.—Recording Band Positions.

Band.	Mid-ventral line.	Mid-dorsal line.
1	4th sterno costal junction	4th thoracic vertebra
2	7th ,, ,,	7th ,, ,,
3	Tip of xiphoid	10th ,, ,,
4	Mid point between tip of xiphoid and umbilicus	1st lumbar vertebra
5	Umbilicus	4th ,, ,,
6	6th lumbar vertebra	6th ,, ,,

Records such as fig. 2 show that expiratory and inspiratory circumferences and respiratory excursions may differ at all costal and abdominal levels. For that reason it is frequently desirable to publish the records complete, but in general a condensation of the records by elimination of two costal and two abdominal tracings still suffices to illustrate the fundamental points.

Gaseous mixtures were administered through a system of multiple rebreathing tanks, permitting rapid shifting from one mixture to another. Tidal air was registered with a Hutchinson spirometer connected with the tanks. Changes in lung volume at the end of inspiration and expiration are superimposed on the curve of basal oxygen consumption. Lung volumes at the end of inspiration and expiration will be referred to as inspiratory and expiratory volumes. The corresponding circumferences are designated as inspiratory and expiratory circumferences.

1
2
3
4
S.
5
6

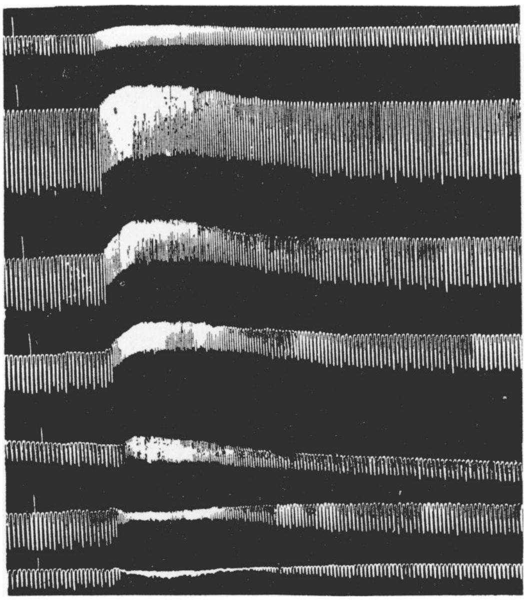

FIG. 2.—A complete record showing respiratory changes in circumference of the torso, resulting from injection of sodium citrate. 1, 2 and 3, costal records; 4, 5 and 6 are abdominal records. S, spirometer tracing.

Mean blood-pressure and time (seconds, ten seconds and minute intervals) were routinely recorded. In many experiments intratracheal pressures were followed, and in some intra-thoracic pressures as well.

The method of recording abdominal movements obviously will not evaluate the relative effects of contraction of the abdominal muscles and relaxation of the active diaphragm. Neither will it evaluate the relative effects of contraction of the diaphragm and relaxation of the active abdominal muscles. For the time being we will not attempt a complete analysis of mechanical effects accomplished in the respiratory act under various conditions. However, an interpretation of our results is assisted by the common findings represented in fig. 3, showing the effects of double phrenectomy on costal and abdominal breathing. The first effect is an immediate cessation of abdominal excursions and

C

FIG 3

A

S

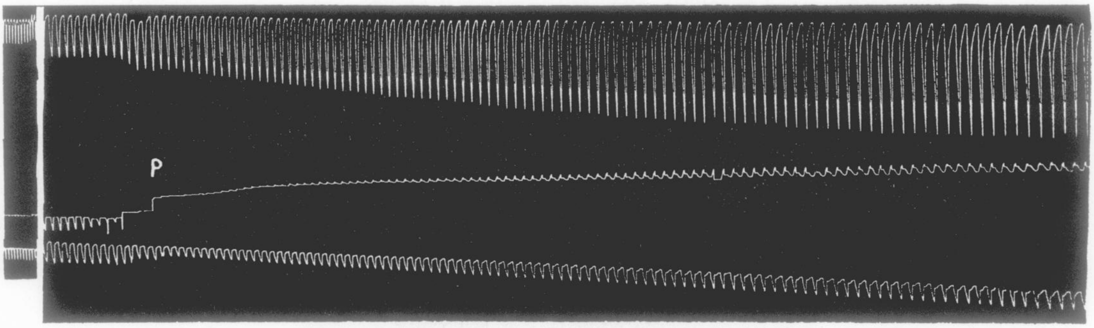

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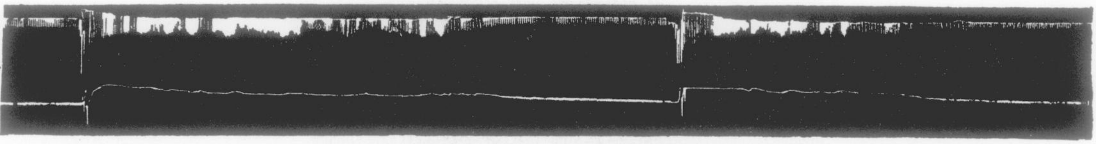
FIG 4

A

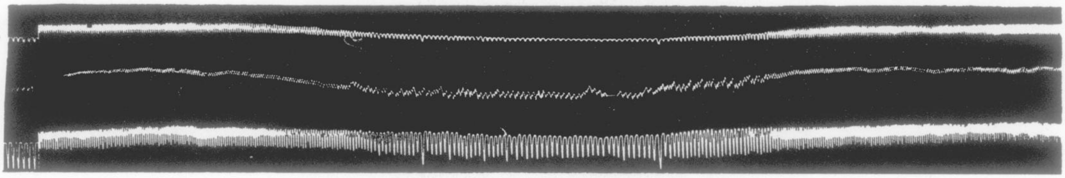


C

B P

FIG 5

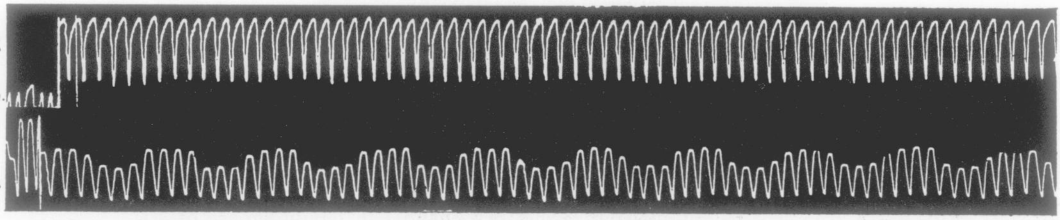
A



C

FIG. 6

A

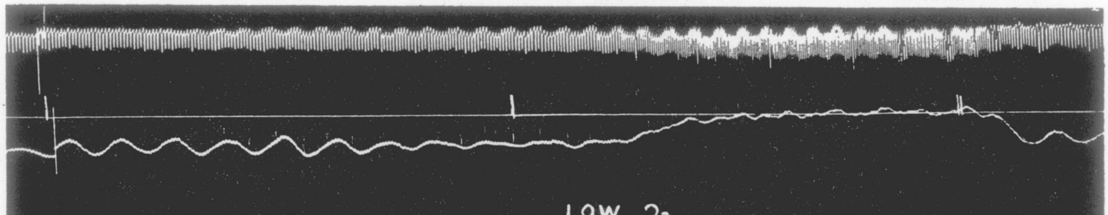


C

FIG. 7

B. P.

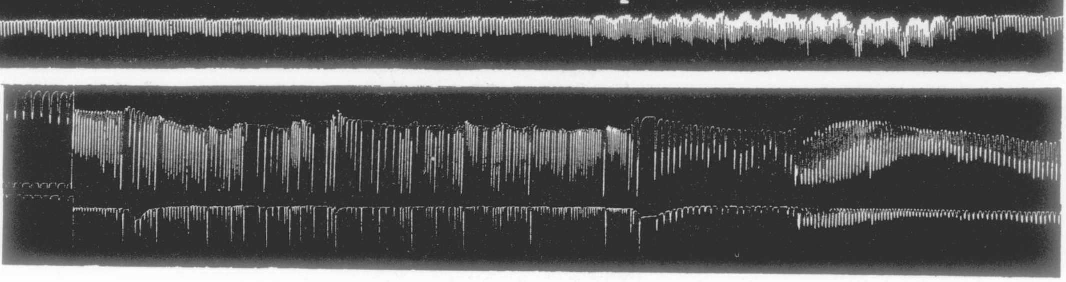
A



C

FIG. 8

A



a reduction in tidal air. This reduced ventilation then gives way to gradual and progressive return to the normal tidal air accompanied by a marked increase in costal movements. As the costal movements increase above normal, abdominal excursions return, altered, however, in configuration and time relation. The stroke now rises during inspiration and falls during expiration, indicating that the excursions are passive in nature. With normal breathing abdominal excursions are, therefore, as a rule indicative of diaphragmatic activity.

Results.

In some dogs breathing is carried on almost exclusively by the chest; in others the chest is quiet, and only the abdomen expands; in most, both modes of breathing are well developed. The type of breathing is referred to according to the degree of development of both modes of breathing—costal or abdominal where the breathing is primarily of either type, costo-abdominal and abdomino-costal where both types of breathing are distinctly effective. A good example of costal breathing appears in fig. 3 (left vertical strip), of costo-abdominal breathing in fig. 2, and of abdomino-costal breathing in fig. 5.

Continuous registration of respiratory movements for a period of four to eight hours in approximately one hundred dogs has shown frequent variations in the mode of breathing in the same individual. Sometimes these variations were effected by the introduction of new variables; at other times they occurred without apparent cause.

In fig. 3 breathing is seen to change from an almost purely costal type to costo-abdominal following double vagotomy. The first vertical strip shows breathing before vagotomy. The second part of the record shows breathing after vagotomy and after combined vagotomy and phrenectomy.

In fig. 4 the change in breathing is spontaneous and entirely different. At the beginning of the record breathing proceeds in a perfectly regular fashion, and the type is costo-abdominal. The dog then momentarily stretches its legs, and with this act the breathing increases in volume and rate and becomes purely costal and periodic. Again, without

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Fig. 3.—Changes in breathing produced by double vagotomy and, later, double phrenectomy at P. C, costal excursions; A, abdominal excursions; S, spirometer excursions.

Fig. 4.—Sporadic changes in type of breathing following stretching of the extremities.

Fig. 5.—Prolonged periodic fluctuations in breathing where abdominal excursions increase while costal excursions decrease.

Fig. 6.—Periodic breathing confined to the abdomen.

Fig. 7.—Periodic breathing confined initially to the chest. With administration of a low oxygen mixture periodicity spreads to the abdomen as well.

Fig. 8.—Simultaneous costal and abdominal records, showing that the abdominal expiratory circumference may remain uniform while costal expiratory circumference fluctuates.

apparent cause, respiration suddenly subsides and reverts to the original type only to change once more with stretching of the extremities. We have no explanation of this phenomenon, but under the conditions of our experiments it has proved to be a relatively common occurrence. Stretching may lead to a change in type towards greater abdominal as well as towards greater costal breathing.

Fig. 5 shows prolonged periodic fluctuations in breathing associated with periodic fluctuations in mean blood-pressure and heart rate. As the blood-pressure falls and the pulse rate diminishes, the respiratory rate decreases and the tidal air increases. As the blood-pressure rises and the pulse accelerates, the respiratory rhythm increases and the tidal air falls off. Rhythmical changes in the expiratory circumference occur at all levels, but the phases of periodicity are reversed in the costal and abdominal regions. As the excursions of the abdominal region increase, those of the chest decrease and *vice versa.*

Fig. 6 shows costo-abdominal breathing in which the periodic fluctuations are confined to the abdominal levels only. These fluctuations will be seen to be due, almost entirely, to changes in the expiratory circumference. In contrast to this record, periodicity is momentarily confined to the chest in fig. 7. Here, too, the fluctuations in amplitude of the respiratory excursions are due primarily to variations in the expiratory circumference. When ventilation is increased by administration of a low oxygen mixture periodicity develops in the abdomen as well. Such observation suggests that the cord or a portion of the cord may be a site of periodic respiration as well as the higher centres in the brain stem. If these localised periodic changes are a result of periodic central chemical changes, they are indicative of a relatively high development of chemical sensitivity within the cord. It is, of course, possible that the periodicity may have its origin in the peripheral endings of the proprioceptive fibres.

In fig. 8 breathing suddenly becomes very irregular both with respect to rate and tidal air. After this irregularity is well established the abdomen contracts down to almost the same circumference with each expiration, the great oscillations in amplitude being due to changes in depth of inspiration. Some mechanism seems to prevail which checks inspiration at varying stages, while expiration goes on to the same degree of completion with every breath. In the costal segments, however, this precise control of expiration is missing, and the fluctuations in amplitude are a combined effect of changing expiratory and inspiratory circumferences. This difference in checking of expiration in the chest and in the abdomen suggests that the vagus fibres are not the only afferent fibres functioning to control the volume of the lungs, but are importantly assisted by proprioceptive fibres from the respiratory muscles, which may at times exert a localised effect upon limited groups of respiratory muscles.

In fig. 8 the changes in amplitude of excursions in the chest and abdomen are roughly proportional. This proportionality, we have seen, does not always occur (fig. 5). The changes in excursions may be diametrically opposed, and the type of breathing may shift slowly from one to the other.

Figs. 9, 10, 11 and 12 are records selected from four different experiments in which deep breaths occur sporadically at irregular intervals, and with such breaths the proportionality between costal and abdominal breathing may also change very radically. In the first dog, fig. 9,

FIG. 9

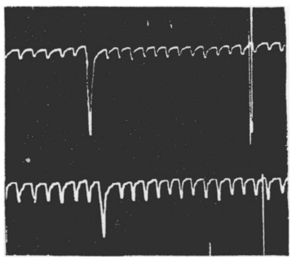


FIG. 12

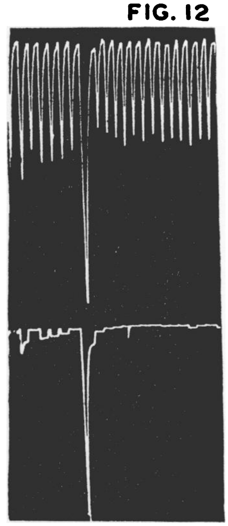


FIG. 10

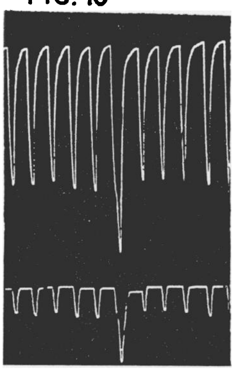
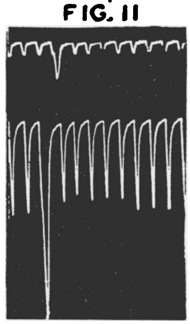


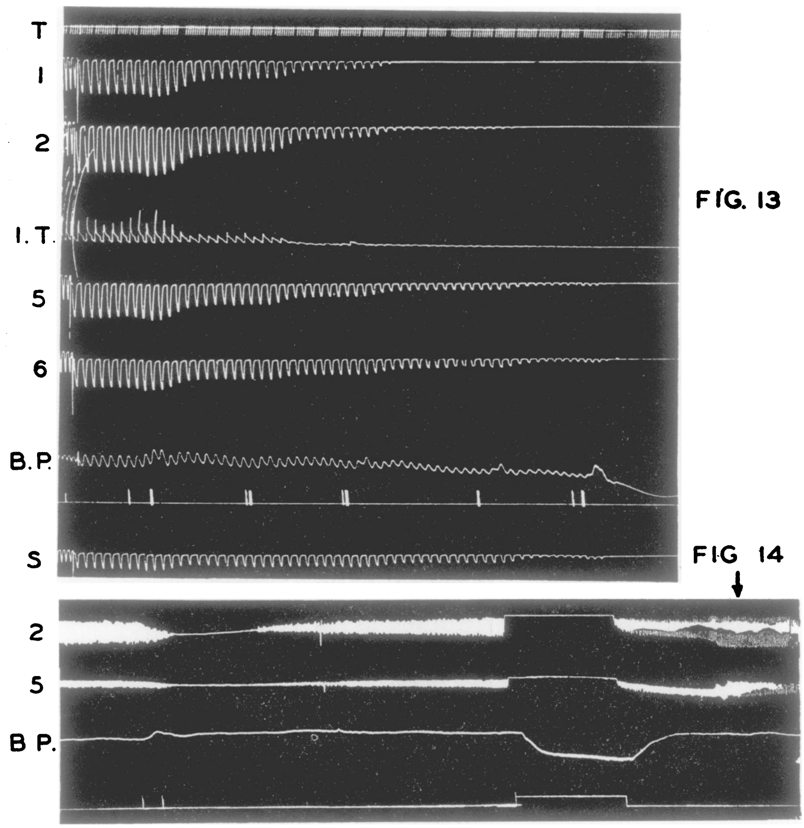
FIG. 11



FIGS. 9, 10, 11 and 12.—Momentary changes in type of respiration resulting from sporadic deep breaths.

with abdomino-costal breathing, the costal sporadic breath is much greater than the abdominal sporadic breath, and for the moment breathing changes to the costo-abdominal type. In the fourth experiment, fig. 12, breathing is almost purely costal. The sporadic breath is powerful in the abdomen as well as in the chest, and breathing therefore shifts momentarily to an almost evenly balanced costo-abdominal type. In the third dog there is an approximately proportionate increase in costal and abdominal excursions, leaving the type unchanged. In the second dog the change is from the costal toward the abdominal type. This uncertain change in type of breathing with sporadic deep breaths is in contrast to the changes which usually develop when respiration increases gradually to meet some increasing need. Under these conditions (see below) respiration tends to become more costal. These sudden momentary changes in type of breathing occurring with sporadic deep breaths indicate that the local checking mechanism, which may be responsible for the mode of breathing that obtains, suddenly gives way along with the vagal checking mechanism.

Chemical administrations are likely to produce differential effects on respiration as is seen in fig. 2, where an accidental injection of sodium



Figs. 13 and 14.—Inhibition of costal excursions is greater than that of abdominal excursions with intravenous injection of urethane.

citrate occurred through the blood-pressure cannula into the femoral artery. In another experiment in which breathing was of the abdomino-costal type, such injections decreased the costal and increased the abdominal breathing. Without more experiments further comment is uncalled for, but with regard to the effects of intravenous injection of urethane, a relatively frequent procedure in our experiments, we have sufficient data to show a definite tendency towards a differential effect on costal and abdominal respiratory movements. In general, urethane inhibits costal movements more than abdominal movements (see figs. 13 and 14).

When a dog is breathing quietly and maintaining a uniform expiratory circumference, as in fig. 13, urethane reduces ventilation by curtailing inspiration. During this record there are five injections of urethane, each one producing a greater costal than abdominal inhibition. Despite the fact that costal breathing was greater at the outset, after the fourth injection abdominal contractions still continue though costal movements have ceased completely. When a dog is breathing rapidly, as in fig. 14, urethane is more likely to curtail both expiration and inspiration, but in these cases, too, the effect is usually greater in the chest than in the abdomen.

Further experiments, to be described in a later paper, in which the effects of lowered alveolar oxygen and increased alveolar carbon dioxide are studied, show marked differential effects on costal and abdominal breathing. It, therefore, seems possible that not only does the cord and its innervated parts possess sufficient chemical sensitivity to be a factor in the control of respiration, but that this sensitivity is sufficently different at various locations to account for changes in type of respiration.

Regarding the incidence of costal and abdominal breathing, we have data from 106 experiments. In these experiments the usual method of comparing the magnitude of the increase in circumference of the chest and abdomen was employed, but rather than use single values we have divided the average increase in circumference, as recorded by the three costal bands, by the average increase in circumference, as recorded by the abdominal bands. Animals with a quotient below 1 are, according to this method, considered to have predominance of abdominal breathing, and those having a quotient above 1 are considered to have a predominance of costal breathing. A summary of the experiments (see Table II.) show that in 36 animals (or 34·3 per cent.) breathing

Table II.—Summary of Results with Two Methods of Determining the Costo-Abdominal Ratio.

	Females and males.		Females.		Males.	
Number of costal breathers .	36	80	12	20	24	58
Per cent. ,, ,, ,, .	34·3	75·5	38·7	64·5	32·9	79·40
Number of abdominal breathers .	69	26	19	11	49	15
Per cent. ,, ,, ,, .	65·7	24·5	61·3	35·5	67·1	20·50
Mean costo-abdominal index .	0·99	2·15	0·92	2·03	1·00	2·18

was more costal, and in 69 (or 65·7 per cent.) breathing was more abdominal. The mean quotient obtained by dividing the sum total of all of the costal increases by the sum total of all of the abdominal increases equals 0·99. Accepting another criterion for the type of breathing relating costal and abdominal accommodation of air, the percentage of types changes considerably. Since the circumference and length of the chest are greater than the circumference and length of the abdomen, expansion of the chest must accommodate more air than expansion of the abdomen. Correcting each costo-abdominal index accordingly, there are now 80 costal breathers and 26 abdominal breathers, or 75·5 per cent. as compared with 24·5 per cent. The mean quotient obtained by dividing the sum total of costal accommodations by the sum total of abdominal accommodations equals 2·15.

The more direct criterion so far as ventilation is concerned, therefore, indicates that breathing is predominantly costal in the anæsthetised dog under the conditions of our experiment. So far as we are aware due cognisance has not been given to the relative volume accommodation of air provided by costal and abdominal excursions, which may partly account for the high incidence of abdominal breathing described by other workers. An inspection of the human skeleton indicates that this mechanical factor is of sufficient importance to warrant further study on man.

Since the observation of Boerhaave [1855] quoted by Crip [1923] that infant girls breathe primarily with the chest and infant boys with the abdomen, the effect of sex on type of breathing has been studied in man by many observers. The shadow graphs of Hutchinson [1846] convinced him of the predominance of costal and abdominal breathing in the female and male respectively, and led to the proposal that costal breathing is a provision against those periods when the abdomen contains the gravid uterus. The results of Fitz [1896], Halls Dally [1908], Cotton [1932] support the findings of Hutchinson. The tracings of Smith [1890] and of Mays [1887] working on North American Indians not accustomed to restricting dress contradict these observations.

While our results on the dog can hardly be used to support either view concerning the type of breathing in man, they offer material of related interest. Thirty females and seventy-three males were studied (see Table II.). The results of these findings are summarised at the bottom of the table. Using the volume accommodation criterion, 64·5 per cent. of the females and 79·5 per cent. of the males arrange themselves in the costal type of breathers. The mean ratio of costal accommodation over abdominal accommodation for the females is 2·03; for the males it is 2·18. Our findings definitely indicate the preponderance of costal breathing in both females and males, but we are not prepared to say that the limited number of observations and the relatively small difference between the indices indicate that the female dog breathes less costally than does the male.

In a few animals it was distinctly noticeable that breathing became relatively more costal towards the close of a prolonged experiment.

This point is analysed in Table III. On account of frequent double phrenectomy and vagotomy during the early part of experiments the number of experiments permitting comparison was limited to only 20. Of these, 17 belonged to the costal type at the beginning of the experiment, and 19 belonged to this type at the end of the experiment. Of the 20 animals, 16 showed a change in the direction of relatively greater costal breathing; 4 showed a change in the direction of relatively greater abdominal breathing. Fourteen dogs showed an absolute increase in

TABLE III.—COMPARISON OF TYPES OF BREATHING.

No. of Experiment.	At beginning of experiment. $\frac{\text{Inc. cost. acc.}}{\text{Inc. abd. acc.}}$	At end of experiment. $\frac{\text{Inc. cost. acc.}}{\text{Inc. abd. acc.}}$	No. of Experiment.	At beginning of experiment. $\frac{\text{Inc. cost. acc.}}{\text{Inc. abd. acc.}}$	At end of experiment. $\frac{\text{Inc. cost. acc.}}{\text{Inc. abd. acc.}}$
3	1·78	4·42	62	1·82	2·23
5	6·62	6·82	63	3·70	4·51
7	2·95	3·24	65	1·37	1·55
8	4·91	4·56	66	0·28	1·28
50	1·08	1·27	69	0·85	2·15
53	2·17	4·88	54	1·76	3·96
58	0·56	2·17	56	1·17	0·93
59	1·63	3·05	57	1·02	1·07
60	1·80	5·32	52	3·08	1·89
61	1·19	2·90	55	3·44	2·09

Summary of Results.

	At beginning of experiment.	At end of experiment.
Number of costal breathers . .	17	19
Per cent. ,, ,, ,, . .	85	95
Number of abdominal breathers .	3	1
Per cent. ,, ,, ,, .	15	5
Costo-abdominal index . . .	2·15	3·01

costal breathing, and 6 showed an absolute decrease. Eight dogs showed an absolute increase in abdominal breathing, and 12 showed an absolute decrease. The mean index changed from 2·15 to 3·01, supporting quite definitely the trend toward proportionately greater costal breathing. The cause of this trend is perhaps to be found in the same factors which lead to a disproportionate increase in costal breathing with increasing tidal air, for the table shows a greater tidal air at the end of the experiments compared with that at the beginning.

We have already called attention to one figure in which double vagotomy produced a change in breathing from a purely costal type to a costo-abdominal type. In a series of twenty experiments, in which the ratios of increased costal breathing and increased abdominal breathing were computed before and after vagotomy, the changes were not as

TABLE IV.—COMPARISON OF TYPES OF BREATHING.

No. of Experiment.	Before vagotomy. Inc. cost. acc. / Inc. abd. acc.	After vagotomy. Inc. cost. acc. / Inc. abd. acc.	No. of Experiment.	After vagotomy. Inc. cost. acc. / Inc. abd. acc.	Before vagotomy. Inc. cost. acc. / Inc. abd. acc.
14	3·67	3·47	65	0·35	0·53
44	4·52	3·81	38	23·4	18·7
47	4·79	5·08	40	3·19	2·50
50	6·28	4·68	43	8·34	5·58
11	1·62	2·14	48	3·24	4·01
13	1·84	1·72	54	4·88	2·09
18	2·22	1·55	64	3·50	1·50
23	0·73	0·77	17	4·34	5·93
39	1·30	1·50	41	4·06	3·84
46	1·88	1·83	42	3·51	3·54

Summary of Results.

	Before vagotomy.	After vagotomy.
Number of costal breathers . .	18	18
Per cent. ,, ,, ,, . .	90	90
Number of abdominal breathers .	2	2
Per cent. ,, ,, ,, .	10	10
Costo-abdominal index . . .	3·24	2·65

TABLE V.—COMPARISON OF TYPES OF BREATHING.

No. of Experiment.	Before dorsal root section. Inc. cost. acc. / Inc. abd. acc.	After dorsal root section. Inc. cost. acc. / Inc. abd. acc.	No. of Experiment.	Before dorsal root section. Inc. cost. acc. / Inc. abd. acc.	After dorsal root section. Inc. cost. acc. / Inc. abd. acc.
24	3·76	0·00	30	1·58	1·07
26	2·42	2·34	31	0·24	0·18
27	0·63	0·48	32	1·70	1·94
28	3·49	3·84	33	0·72	1·47
29	1·43	1·38			

Summary of Results.

	Before dorsal root section.	After dorsal root section.
Number of costal breathers . .	6	7
Per cent. ,, ,, ,, . .	66·6	77·7
Number of abdominal breathers .	3	2
Per cent. ,, ,, ,, .	33·4	22·3
Costo-abdominal index . . .	1·24	1·45

striking (see Table IV.). After vagotomy there were 4 abdominal breathers as compared with 4 before. Twelve animals showed a change towards greater abdominal or less costal breathing, but 8 showed a change towards greater costal or less abdominal breathing. The reduction of the mean index from 3·24 to 2·65 only suggests a possible tendency towards less costal breathing following vagotomy. The change is contrary to that which usually accompanies an increase in tidal air.

Dorsal root section in our experiments, 9 in all (see Table V.), showed an increase in costal breathers from 6 to 7. There was no uniform change toward any particular type. In 5 animals the breathing became less costal or more abdominal, and in 4 animals it became less abdominal or more costal. The mean index indicates a trend toward greater costal breathing. These results are not in accord with the decrease in costal respiration noted by Pike and Coombs [1918] in the cat. Possibly our failure to find greater costal breathing after dorsal root section was due to incomplete root section. Pike and Coombs point out that a single dorsal root may exert a surprising amount of control of respiration.

SUMMARY.

Changes in body circumference associated with respiratory movements were simultaneously recorded in the dog at six different levels—three costal and three abdominal.

Continuous registration of respiratory movements with this method showed variations in type from time to time in the same individual.

Some of these changes were spontaneous; others were elicited by deliberate introduction of new variables.

A shifting from a more costal or more abdominal type towards the other respective type was frequently preceded by a momentary and sporadic stretching of the extremities.

At times periodic fluctuations in respiratory movements occurred, limited to either costal or abdominal levels. These findings suggested that periodicity may be a localised phenomenon dependent on a high development of chemical sensitivity in the cord or its innervated parts.

Great irregularities in the magnitude of respiratory excursions occurred mostly from changing inspiratory circumference. Under these conditions the expiratory circumference may remain surprisingly uniform.

In some experiments the expiratory circumferences changed as well. At times the expiratory circumference of the chest showed gross fluctuations, while those of the abdomen remained perfectly constant. The reverse also occurred.

These results may indicate, that in addition to a higher reflex

mechanism there are lower localised mechanisms in the cord which serve to check the extent of respiratory movements. These mechanisms may operate through the proprioceptive fibres of individual muscles or muscle groups.

The magnitude of costal and abdominal expansion in sporadic deep breaths varied out of proportion to the prevailing respiratory movements. The deep breaths were, therefore, frequently of opposite type to the prevailing type. It was suggested that these momentary changes in type of breathing are due to a transitory loss of the local checking mechanisms, which may be responsible for the mode of breathing that prevails.

Backward injection of sodium citrate into the femoral artery produced differential effects in costal and abdominal breathing. Intravenous injection of urethane inhibited costal breathing more than abdominal. These and other findings indicate a high degree of chemical sensitivity of the cord, important not only in controlling the degree of ventilation, but the type of breathing as well.

Comparing the magnitude of increased costal circumference with the magnitude of increased abdominal circumference, 34·3 per cent. of 106 dogs were found to breathe more with the chest than with the abdomen.

Using our new method of comparing costal and abdominal accommodation of air, by grossly correcting for the greater costal circumference and greater length of chest, 79 per cent. were found to be costal breathers.

The mean ratio of costal to abdominal accommodation for all of the dogs studied was 2·15, indicating a decided predominance of costal breathing in the dog.

Analysis of measurements on 31 female and 73 male dogs failed to show any relation between sex and mode of breathing.

Prolonged experiments were frequently associated with a progressive change in type to or towards greater costal breathing. This change may be related to the accompanying augmented ventilation.

The effects of double vagotomy and dorsal root section on type of breathing were uncertain.

It is concluded that the central mechanism controlling respiration is extensive, and that the spinal cord is important in modifying the type of breathing.

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