THE LOCATION AND FUNCTION OF THE CHEMORECEPTORS OF THE AORTA

JULIUS H. COMROE, JR.

From the Laboratory of Pharmacology, University of Pennsylvania, Philadelphia

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Although Heymans and Heymans (1927) demonstrated the presence of chemically sensitive nerve receptors in the region of the aortic arch several years before Heymans et al. (1931) discovered similar receptors in the carotid sinus area, the former have received little attention since that time while the latter have been investigated repeatedly. Consequently the localization and physiological significance of the carotid receptors are now fairly well understood, but even the existence of the aortic receptors has been denied (Dautrebande and Wegria, 1937; Beyne, Gautrelet and Halpern, 1933), and their localization and significance are both uncertain. A number of investigators (Selladurai and Wright, 1932; Schmidt, 1932; Jongbloed, 1936; Gesell and Moyer, 1937; Lambert and Gellhorn, 1938) have confirmed the presence of extracarotid chemoreceptors by showing that, even after complete carotid denervation, anoxemia still produces some increase in respiration which disappears when the vagodepressor nerves are cut. However no attempts at precise physiological localization have been reported since the work of Heymans and Heymans (1927). Anatomical studies made by Penitschka (1931), Palme (1934), Muratori (1934), Seto (1935), Nonidez (1935, 1937), and Boyd (1937) have demonstrated the presence about the aortic arch of cell groups which are similar in appearance to the chemoreceptors of the carotid bodies—a structural relationship which has led to the suggestion that these cells represent the chemically sensitive areas of the aortic region. Until now this suggestion lacked physiological confirmation.

The objects of the present experiments were to ascertain the anatomical

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and physiological characteristics of the aortic chemoreceptors, i.e., to
determine their location, blood and nerve supply, and to obtain information
about their significance to the organism. Owing to the relative inacces-
sibility of the aortic reflex zone, the various perfusion methods which
have been successfully employed by a number of workers in investigating
carotid reflexes, when applied to the aortic region, involve such wide
departures from normal conditions that the results are of limited value
beyond an indication that reflexes are aroused there by certain chemical
agents. We hoped that useful information could be obtained by simple
methods, now that the characteristics of the carotid reflex mechanism are
fairly well understood; this hope was justified.

The experiments were performed on dogs and cats under anesthesia by
chloralose (about 50 mgm. per kilogram) supplemented by urethane (about
0.6 gram per kilogram, this and the chloralose being given together intra-
peritoneally in dogs and cats) or by morphine (2 mgm. per kilo intramus-
cularly in dogs, following which the chloralose was given intravenously).
A valved tracheal cannula was inserted; blood pressure was recorded by
a mercury manometer from a femoral artery with thiosulfate or heparin-
saline in the cannula; respiration was recorded by a pneumograph and
tambour and occasionally the volume of expired air was measured by a
gas meter. The sinus and aortic nerves and their receptor fields were
scrupulously avoided until it was desired to inactivate them.

I. The physiological significance of the aortic chemoreceptors in the dog.
Information on this point was obtained by testing the responses of respi-
ration and blood pressure to systemic anoxemia (produced by inhalation of
nitrous oxide) and to intravenous injections of α-lobeline and sodium
cyanide, before and after complete bilateral carotid denervation. The
responses after the denervation were assumed to be due to aortic reflexes—
an assumption which appears to be justified, as will be seen below.

It should be emphasized at the outset that the results elicited by these
simple procedures were quite variable from animal to animal, not only
in the intensity of the total response (hyperpnea and hypertension) pro-
duced by the same agency in different animals, but also in the partition
of the total response between the carotid and aortic receptors. However,
three results were consistently obtained:

1. The hyperpneas produced by acute anoxemia and by α-lobeline and
cyanide were usually reduced considerably though never completely
abolished by carotid denervation.

2. The hypertension during acute anoxemia was usually intensified,
and that produced by intravenous injections of α-lobeline and cyanide
was always greatly intensified, after carotid denervation.

3. The hyperpnea and hypertension elicited by any of these agents
after carotid denervation as a rule were abolished by section or blocking
of the depressor or vagodepressor nerves and pure depression of respiration and blood pressure occurred.2

The type of evidence upon which these statements are based is illustrated in figure 1. In the intact dog (fig. 1a) anoxemia caused intense hyperpnea and marked hypertension. When both vagi were blocked with procaine (fig. 1b) anoxemia still caused marked hyperpnea but the hypertension was completely lacking although the carotids were untouched. After the vagus block wore away (fig. 1c) anoxemia again produced both hypertension and hyperpnea. When both carotids were denervated with vagi intact (fig. 1d) the hyperpnea of anoxemia was greatly reduced though not abolished, while the hypertension was greater than before. Finally when both vagi were again blocked after carotid denervation, (fig. 1e), anoxemia failed to cause any increase in either blood pressure or respiration.

As pointed out above, the results of this simple experiment were quite variable from animal to animal. To show the nature and extent of these variations it will be necessary to take up the respiratory and circulatory effects separately. The respiratory effects shown in figure 1 are typical of

2 There are several exceptions to this statement: (1) A smaller, more gradual increase in blood pressure followed intravenous injections of large doses (1.0 mgm.) of a lobeline, presumably due to direct sympathetic ganglion stimulation. (2) An increase in respiration sometimes occurred during systemic anoxemia even after denervation of the carotid and aortic chemoreceptors. Occasionally this occurred only after the N₂O inhalation was carried to the point of an abrupt fall in blood pressure, and was probably due to the accumulation of metabolic products in the respiratory center because of reduction in its blood supply (Gesell, 1925; Schmidt, 1928, 1932). In a few instances a slight, delayed increase in respiration occurred without fall in blood pressure. In the absence of other known peripheral chemoreceptors this probably represents a direct stimulation of the respiratory center as described by Gesell (1939).
those obtained in 12 out of 49 dogs (24 per cent) subjected to inhalation of N₂O or to intravenous injection of α-lobeline or cyanide, before and after carotid denervation. In such cases the hyperpnea of aortic origin (fig. 1d), while distinct, was decidedly less than that arising in the carotids. In another 18 of these 49 animals (37 per cent) the aortic component of the total respiratory response was even less marked than this, though still perceptible. Thus in 61 per cent of these unselected animals the major portion of the hyperpnea produced by anoxemia, α-lobeline, or cyanide, arose from the carotid chemoreceptors. In 14 of the 49 dogs (28 per cent) the respiratory response was approximately half as great after carotid denervation as before, indicating that the carotid and aortic areas contributed about equal shares to the total respiratory effect. In 5 of the 49 animals (11 per cent) the respiratory response was almost as great after carotid denervation as before; in these exceptional animals the aortic component of the respiratory response evidently exceeded the carotid.

The circulatory effects shown in figure 1 are typical of those obtained in 19 out of 36 dogs in which N₂O inhalation was tested before and after aortic denervation. The rise in pressure produced by the inhalation with all nerves intact in these 36 dogs ranged from 18 to 126 and averaged 48 mm. Hg. After inactivation of the vagodepressor nerves the corresponding range was 0 to 76, average 12 mm., this representing the carotid body component. In 19 of these 36 dogs (53 per cent) the carotid component did not exceed 5 mm., in 13 of the 36 (36 per cent) the carotid component ranged from 5 to 30 mm. Hg, and in only 4 of the 36 dogs (11 per cent) did it exceed 30 mm. Thus in our series of unselected dogs, under conditions not far removed from the normal, only exceptional animals showed signs of strong vasomotor reflexes arising from the carotid chemoreceptors in response to acute systemic anoxia. Even in these exceptional cases, the hypertension of carotid body origin was not immediate and sharp, but began 10 to 30 seconds after the onset of the reflex hyperpnea and then progressed gradually; apparently the carotid vasomotor chemoreceptors have a higher threshold than those of the aortic region, or else their influence is too weak to produce hypertension in the face of increasing anoxia of the heart muscle. Certainly in the great majority of our animals the aortic component of the total vasomotor response to systemic anoxia was much more important than the carotid.

3 This does not mean that reflexes from the carotid bodies are incapable of affecting the circulation reflexly. Evidence has been presented that such reflexes can produce strong reflex bradycardia (Ieymans et al., 1933) and reflex vasoconstriction (Ieymans et al., 1933, 1935; Bernthal, 1934, 1938). In the present experiments abundant confirmation of these findings was obtained, but the reflex bradycardia (effective through the vagi) was by far the stronger component; it usually overshadowed com-
A diagrammatic representation of the usual parts played by the various chemoreceptor groups in the circulatory and respiratory responses of the dog to acute systemic anoxia is shown in figure 3.

II. Localization of the aortic chemoreceptors in the dog. The procedures used for this purpose were the same as those already enumerated (p. 177) with the following additions: Both carotids were denervated at the outset, and vagus nerves were cut. The procedures used were the same as those already enumerated (p. 177) with the following additions: Both carotids were denervated at the outset, and vagus nerves were cut.

![Diagram of vasomotor reflexes from carotid body](image)

**Fig. 2. Vasomotor reflexes from carotid body.** Representative tracings of effects produced by intracarotid injections of lobelin (0.1 mgm.). The figures refer to blood pressure changes only; they indicate the number of observations in a large series which were similar to those pictured. Thus, so long as the cardioinhibitory fibres were intact (first two records) no significant change in B.P. occurred in 93 per cent and 88 per cent of the cases. (See footnote.) When these nerves were severed (vagodepressors cut) a slight or no increase in B.P. occurred in 54 per cent, a rise of 10-20 mm. Hg occurred in 28 per cent, and an increase of more than 20 mm. Hg in only 18 per cent. A marked hyperpnea was observed in 100 per cent of all five groups.

Comroe and Schmidt (1938) found no reflex hypertension in dogs during perfusion of the carotid body with anoxic blood, but in those animals one or both vagi were intact (although the depressors were cut) and only one carotid body was perfused. In recent experiments (unpublished) on vagotomized dogs with carotid pressure receptors denervated, we have frequently seen reflex hypertension upon perfusion of both carotid bodies with anoxic fluid; injection of cyanide into the fully oxygenated perfusion stream produced some hypertension in 89 per cent of 46 cases, and the average rise in pressure was 34 mm.; in 60 per cent the hypertension exceeded 20 mm. These circumstances are ideal for obtaining maximum reflex hypertension (i.e., perfusion of all functionally active chemoreceptors in an animal with the opposing aortic and carotid pressure receptors denervated and vagi cut). Since no comparable experiment can as yet be done with the aortic chemoreceptors we do not know how greatly the reflex hypertension arising from them would be exaggerated under equivalent circumstances.
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so that any reflexes of chemical origin could be attributed to the aortic receptors. A small soft rubber catheter, filled with lobeline or cyanide solution, was passed down a common carotid or subelavian artery, or up the abdominal aorta toward the heart, and with the tip of the catheter at various points lobeline or cyanide was injected through it repeatedly (0.1–0.2 cc. at a time) until the region of maximum reactivity was ascertained. At this point the response was similar to that elicited by intravenous injections of lobeline or cyanide after carotid denervation but the hyperpnea and hypertension following intra-arterial injection appeared immediately and were more intense (fig. 4A). After such a reaction was obtained the catheter was withdrawn measured distances until the response disappeared. In most animals an opening was made in the superior mediastinum and through this the position of the tip of the catheter could be palpated during the experiment; in all cases the position was checked at autopsy.

Experiments of this sort were performed on 38 dogs. Figure 4A shows the positions of the catheters at which positive responses were obtained in each of 33 dogs, while figure 4B shows the positions at which no responses could be obtained, with only 5 exceptions, in the 38 animals. Excluding

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**Fig. 3. Schema showing roles of aortic and carotid bodies in respiratory and circulatory response of the dog to anoxia.** If the increase in respiration and B.P. due to anoxia is regarded as 100 per cent for the intact dog, the carotid bodies alone are usually capable of producing respiratory stimulation equal to that of the entire dog (100 per cent), while the aortic area alone usually produces a rise in B.P. even greater than that in the intact animal (due to removal of carotid body reflex bradycardia and carotid sinus inhibition by complete carotid denervation). The last column is an estimate of the part played by carotid reflexes (C) and aortic reflexes (A) when both are functioning simultaneously.
these 5, in which some receptors apparently were supplied from the brachio-
cephalic trunk, the chemosensitive area could always be localized in the
ascending aorta or in the first portion of the aortic arch. Confirmation
of this finding was obtained in another way, as shown in figure 5.

a. The blood supply of the aortic chemoreceptors. At postmortem ex-
amination a small vessel was regularly found to arise from the dorsocaudal
aspect of the aorta at the level of the brachiocephalic orifice, which cor-
responds to the region of maximum sensitivity (fig. 4). In only 2 out of
35 dogs examined was this vessel lacking, and in these it arose from the
first portion of the brachiocephalic; its subsequent course and distribution
were the same in all the animals.

Fig. 4. Localization of aortic chemoreceptors in dog. After carotid denervation
fine catheters were passed down a common carotid or subclavian artery or up the
abdominal aorta toward the heart. Lobelin or NaCN was injected at various
points. The positions at which positive responses were obtained are shown on the
left; the positions at which no responses were elicited are shown on the right. Near
point of maximum sensitivity there is present regularly a small artery to the aortic
body.

This portion of the aorta was submitted to serial sectioning in 8 dogs,
and it was regularly found (Addison and Comroe, 1938) that a large cell
mass lay in the aortic adventitia surrounding the numerous small branches
of this vessel, less than a millimeter from its aortic orifice. This cell mass
corresponds closely with the paraganglion aorticum supracardiale of
Penitschka (1931) or the aortic body of Nonidez (1937). The structure
of the aortic body is very similar to that of the carotid body, both being
essentially vascular in nature and containing many nerve endings in
intimate relationship with blood spaces (fig. 6).

Nonidez (1937) described other smaller cell groups, lying in newborn
dogs at the very origin of the aorta, which receive their blood supply from a branch of the left coronary artery. We have not as yet been able to confirm the presence of these cell groups in full-grown dogs, though in a few experiments we found that aortic injections produced no response until the catheter was pushed almost to the aortic valves.

Since the aortic body lies between the aorta and the pulmonary artery there is reason to suspect that the receptors may receive blood from the pulmonary artery. This possibility was investigated in 3 dogs by passing

one catheter down the right jugular vein into the right ventricle, another up the abdominal aorta into the left ventricle, and injecting lobeline or cyanide through these catheters. The results showed clearly that the receptors do not receive blood from the pulmonary artery, for the responses (hyperpnea and hypertension) from right ventricular injections were delayed 12 to 13 seconds while left ventricular injections were effective in 3 to 4 seconds. Furthermore, examination of the pulmonary artery and its two main subdivisions in 30 consecutive dogs revealed no branches visible with a hand lens.

Fig. 5. Localization of aortic chemoreceptors in dog. After injection of lobeline at the mouth of the brachiocephalic had produced no response (A), the catheter was pushed into the ascending aorta (B) and injection of lobelin at this site produced marked hypertension and hyperpnea. In C, although the left subclavian was ligated at its origin and the aorta occluded by inflation of a strong rubber balloon pushed up the abdominal aorta, lobelin produced an immediate and even more pronounced hyperpnea (catheter in same position as in B). The hypertension (C) of course was decreased because of the huge reduction in the vascular bed. Since the brachiocephalic and its branches had previously been found to be insensitive (A), the chemoreceptors or their afferent artery were necessarily located in the ascending aorta (see fig. 4).
b. The nerve supply of the aortic chemoreceptors. In dogs whose carotids were previously denervated, section of either vagodepressor nerve in the neck diminished, and section of both nerves usually abolished the circulatory and respiratory responses to \( N_2O \) inhalation, lobeline and cyanide. If, however, the vagi were cut below the point of entrance of the recurrent laryngeal nerves but were intact above that point, the responses were not altered in the least. This shows clearly that the afferent pathways for the aortic body reflexes are the aortic or cardiac branches of the vagi. In 4 favorable subjects it was possible to dissect out a nerve running from the aortic body to the right vagus (entering the latter along with the right recurrent laryngeal nerve, fig. 6) and to stimulate it electrically in a spon-

Fig. 6. Location of aortic chemoreceptors in dog. Note the infraaortic position of the aortic body, lying between the aorta and pulmonary artery. Its afferent nerve fibers enter both vagi, probably along with the recurrent laryngeal nerves. Electrical stimulation of the branch to the right vagus produced hyperpnea and hypertension as shown in lower right hand record. Upper right is photomicrograph of the aortic body, showing its afferent artery leaving the aortic wall. The position of this vessel is fairly constant, and coincides with the point of maximum sensitivity to chemical substances (as shown in figs. 4 and 5).
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taneously breathing animal: the result was the same as that of an intra-
aortic injection of lobeline or cyanide, i.e., intense hyperpnea and distinct
hypertension (fig. 6). On the left side we have been unable to identify
the corresponding nerve, but believe that it runs with the left recurrent
laryngeal because section of the vagus below this level does not alter the
systemic or intra-aortic response and stimulation of all branches of the left
vagus accessible above the aorta has not as yet reproduced the hyperpneic-
hypertensive response.

In one experiment on a dog with denervated carotids it was possible,
by crushing the nerves in the vicinity of the aortic body, to abolish com-
pletely the aortic chemical reflexes without inactivating the pressure re-
flexes, as shown by abrupt rise in blood pressure when the vagi were
subsequently cut. This observation, together with the occurrence of
hyperpnea and hypertension upon stimulating the aortic body nerves
directly, indicates that in the aorta, as in the carotids, the pressoreceptors
and chemoreceptors are anatomically separable though closely associated.

Chemoreceptors in the cat. The respiratory and circulatory responses of
the cat to anoxia, like those of the dog, are dependent upon aortic and
carotid reflexes, but the relative parts played by the carotid and aortic
bodies are much more variable in the cat. Taking first the respiratory
response, the carotids appeared to contribute the greater portion of the
total hyperpnea of anoxemia and cyanide in 12 out of 26 cats (46 per cent);
in 5 of these the aortic response was insignificant. The aortic region was
relatively more important in 9 (35 per cent); in 3 of these there was prac-
tically no carotid response. In the remaining 5 (19 per cent) each zone
appeared to contribute about equally to the total hyperpnea. The average
respiratory responses to anoxemia were a 61 per cent increase in minute
volume from the carotid bodies alone (average of 23 determinations in 18
cats) and a 64 per cent increase from the aortic region alone (average of 33
inhalations in 20 cats) but the individual variations were much wider in
cats than in dogs. It is quite apparent, however, that the aortic body of
the cat contributes more to the hyperpnea of anoxemia than that of the dog.

The circulatory responses to anoxia in these cats differed from those of
dogs similarly prepared in two respects:

First, the hypertension of anoxia was less marked in the cat than in
the dog: the average rise in blood pressure produced by 87 N₂O inhalations
in 26 cats with all nerves intact was only 22 mm. Hg (range 2–76 mm.),
while that in 55 dogs was 40 mm. (range 12–126 mm.).

Second, the partition of this response between the carotid and aortic
chemoreceptors was not so clear-cut as in the dog. Of 25 cats, the aortic
region was relatively more important to the circulatory response in 11
(44 per cent); in two of these 11, the carotid response was negligible. The
carotid region appeared to contribute more than the aortic to the total
circulatory response in 10 (40 per cent); in 3 of these the aortic response was insignificant. In the remaining four (16 per cent) the two zones appeared to contribute about equally. Here again extreme variations were encountered in individual cats, but the average anoxemia (N₂O inhalation) increase in blood pressure due to the carotid region alone was 16 mm. (42 determinations in 17 cats), that due to the aortic region alone 15.2 mm. (50 determinations in 22 cats). Similarly, following intravenous NaCN, the average increase in blood pressure due to the carotid bodies was 12 mm. (35 determinations in 16 vagotomized cats); that due to the aortic factor was 13 mm. (36 determinations in 14 cats with carotids denervated).

It is evident that the carotid body is a more important factor in the vasomotor response to acute systemic anoxemia in the cat than in the dog. This was confirmed by intracarotid injections of NaCN, which produced some reflex hypertension in 18 of 23 cats (78 per cent) even though the vagi were intact; in dogs similar injections rarely raised blood pressure as long as these nerves were intact. In only 3 cats however did the rise in blood pressure exceed 15 mm. (maximum 72 mm. Hg in one cat) and the average increase in 91 such injections in the 23 cats was only 9 mm. As in the dog, this was exaggerated by section of the vagodepressor nerves; the average increase in blood pressure following 29 intracarotid injections of cyanide in 14 vagotomized cats was 20 mm. Furthermore some increase in blood pressure was produced by 100 per cent of the injections under these conditions.

Physiological localization of the aortic chemoreceptors was accomplished in 4 cats by passing a fine ureteral catheter filled with NaCN down one common carotid into the left ventricle. In each case the carotids were denervated. Injection of NaCN through the catheter produced immediate hyperpnea and hypertension only when the tip of the catheter was within the left ventricle; the reaction disappeared when the catheter tip lay distal to the aortic valves. This indicates that the blood supply of the aortic body in the cat is derived from the coronary arteries, and this was confirmed by histological studies. Serial sections showed that these physiologically active chemoreceptors in the adult cat lie beneath the aorta near the coronary orifices.

As in the dog, the chemoreceptors do not appear to receive blood from the pulmonary artery, for right ventricular injections (via ureteral catheters passed down an external jugular vein) of cyanide or lobeline regularly showed a considerably longer interval between injection and response than left ventricular injections. The pulmonary artery region was also studied histologically in 6 adult cats: in one a patent vessel arose from the pulmonary artery and entered the chemoreceptor tissue, in another a similar vessel was found but the opening on the pulmonary artery side was obliterated; in the remaining four, no patent vessel or orifice could be found.
The existence of supra-aortic bodies (described by Nonidez in new born kittens) has not yet been confirmed by our preliminary physiological and anatomical studies in adult cats.

As in the dog, the aortic body fibres enter both vagodepressor nerves; section of these invariably abolishes the aortic chemical reflexes in the cat. The course of the fibres from the aortic body to the vagodepressor trunks has not yet been traced.

Discussion. These experiments show clearly that the chemoreceptors first described by Heymans and Heymans (1927) in the cardio-aortic region are localized in the aortic body just as definitely as the carotid chemoreceptors are confined to the carotid body. This is a matter of considerable interest because these two chemoreceptor zones are very similar, not only in function, but in embryological derivation, structure, and relationship to the vascular and nervous systems. Although the localization of the aortic chemoreceptors seems to be accomplished, final conclusions concerning their physiological significance must be postponed. However, several points of value have emerged from the present studies. These will now be considered.

The first point is concerned with the relative physiological importance of the carotid and aortic chemoreceptor areas. There seems to be an unmistakable tendency in the dog for the carotid body to affect the respiratory center more than the vasomotor, and for the aortic body to affect the vasomotor center more than the respiratory. Only the carotid chemoreceptors act directly upon the cardio-inhibitory center. In the cat, the partition of the circulatory and respiratory responses between the two chemoreceptor zones appears in average figures to be much more nearly equal than is the case in the dog, but the averages include wider extremes in the cat.

The second point is the matter of individual variation among different animals of the same species. The experimental conditions under which these observations were made were certainly closer to normal than would have been the case in the perfusion or crossed-circulation experiments that have been used so extensively in investigating these chemoreceptors. In all the present experiments, the chemoreceptor zones and nerves were carefully avoided until we desired to inactivate them. Clearly the weak responses cannot be ascribed to damage to the reflex mechanisms and discarded in favor of the strongest ones, which would then be taken to be representative of the normal state. Instead, the variations must be accepted as inherent in the animals themselves and the factor of individual variability deserves greater prominence than it has been accorded in evaluating results of such experiments. For example, in one dog of this series the aortic respiratory response to anoxemia was far greater than the carotid respiratory effect in many of the animals, yet in only 5 of 49 dogs did the aortic respiratory response exceed the carotid, and in no other
animal did the aortic response closely approach this one in intensity. On
the other hand, in 18 of the 49 dogs the aortic respiratory response was
barely perceptible. Obviously in a small series one exceptional result of
either of these types would incorrectly influence the observer's viewpoint,
and conclusions of lasting value can be drawn only from studies on a series
of animals sufficiently large to permit determination of the general tendency
amid individual variations.

Because of these natural variations individual investigators in this field,
having different purposes in view, may arrive at conclusions which seem
to be widely divergent but which actually are not at all at variance. An
excellent illustration of this is the vasomotor reflex originating in the
carotid bodies. If one wishes to demonstrate the maximum influence
which this can exert, one may find an occasional dog in which, under suit-
able conditions, chemical stimulation of the carotid bodies will cause a
tremendous rise in blood pressure; in one dog of this series a rise of 138
mm. Hg was observed. Yet this turned out to be distinctly unusual in
a large series, and it occurred only after bilateral vagotomy and after
selective denervation of the carotid pressure receptors. Heymans and
Bouckaert (1939) emphasize the necessity for preventing reduction in
the CO₂ tension of the blood (consequent on the simultaneous hyperpnea)
by curare and artificial respiration if the carotid body hypertension is to
be seen in its fully developed state. Yet if the investigator's purpose is
to estimate the importance of this reflex to the intact animal, he cannot
base his conclusions on results which are intentionally exaggerated or
admittedly exceptional. In the present series it was clear that in the
intact anesthetized dog the carotid body receptors alone are incapable of
stimulating the circulation in times of acute anoxia, despite marked rises
in blood pressure obtainable from them in selected animals under highly
abnormal conditions. On the other hand the aortic chemoreceptors of the
dog can and regularly do maintain an increased blood pressure during acute
anoxemia, and this despite the opposing influence of the carotid and aortic
pressoreceptors, the bradycardia arising from the carotid chemoreceptors,
the increasing anoxia of the heart muscle, and the reduction in the CO₂
tension of the blood produced by the concomitant hyperpnea. The
carotid chemoreceptors can do this only exceptionally, and then only
after the opposing tendencies of aortic pressoreceptors and reflex brady-
cardia have been eliminated by bilateral vagotomy.

These experiments confirm the belief that the aortic and carotid chemo-
receptors together constitute the main and in many cases the sole source
of the hyperpnea and hypertension associated with anoxemia and with
the action of chemicals such as cyanide; when both sets of receptors are
inactivated, systemic anoxia is always much less stimulant than before to
respiration and blood pressure; most frequently it is purely depressant
in anesthetized animals. The conclusion that anoxia does not directly stimulate the medullary centers has been fairly generally accepted with regard to respiration, but not to circulation. Our results confirm the conclusions of Brewer (1937) and Lambert and Gellhorn (1938) that the characteristic vasomotor response to anoxia, like the respiratory, is due to reflexes, not to direct central stimulation.

The fact that powerful vasopressor nerve impulses originate in the aortic body and are carried in the vagodepressor nerves is interesting in connection with the reflex described by McDowall (1924). Information obtained from the present experiments indicates that at least a portion of the phenomena described by McDowall originates in the aortic body as a result of chemical changes in the blood. If the vagoi are cut when the blood pressure is normal or high, a rise in blood pressure is the rule, for inactivation of the more powerful pressoreceptors occurs simultaneously with inactivation of the chemoreceptors. But if the vagoi are cut when blood pressure is low, a further fall in blood pressure usually results, for only the chemoreceptors are now inactivated by vagotomy (the pressoreceptors being already partially or wholly inactivated by the subthreshold level of blood pressure). This is in conformity with the observations of Reed (1925) that the McDowall reflex is most consistently observed at the end of long experiments with a low arterial blood pressure. As evidence that removal of vasopressor impulses from aortic chemoreceptors is indeed responsible for the fall in blood pressure when the vagoi are cut under such circumstances, an experiment may be cited in which the aortic chemoreceptors of a dog were denervated without severing the vagoi or interfering with the innervation of the great veins. In this case, vagotomy led to a rise—and not a fall—in blood pressure even though performed at the end of a long experiment with a low arterial blood pressure.

Furthermore, O₂ inhalation as well as vagotomy may cause an abrupt fall in blood pressure in a cyanotic dog with denervated carotids—an effect presumably due to inactivation of aortic chemoreceptors. It must be pointed out however that oxygen inhalation does not lower pressure as consistently as bilateral vagotomy under similar circumstances, indicating that systemic anoxia is not the only factor in these vagal pressor reflexes. In view of the findings of Bernthal and Weeks (1938) that the carotid chemoreceptors are tonically active under similar experimental conditions, it is probable that the aortic chemoreceptors also set up a continuous discharge of impulses to the vasomotor center. Interruption of this discharge by vagotomy of course would tend to lower blood pressure. In those cases in which vagotomy does, but O₂ inhalation does not lower blood pressure, some other chemical influence, probably increased CO₂, lowered pH, or stagnant anoxia acting through the aortic body, may have been the driving factor. Evidence on this point is not yet available.
SUMMARY

1. The extra-carotid chemoreceptors of the dog have been localized by physiological and anatomical studies in the aortic body, a structure fundamentally similar to the carotid body.

2. Both carotid and aortic bodies set up reflexes to the respiratory and vasomotor centers in response to anoxia, whether this be produced systemically by oxygen lack in the inspired air, or locally by interference with tissue oxidations.

3. The major rôle of the aortic chemoreceptors in the dog is the initiation of powerful reflexes to the vasomotor center during anoxemia. By far the greater portion of the hypertension of acute systemic anoxia is produced by aortic body reflexes; vascular reflexes from the carotid body are inconstant and relatively ineffective. The carotid body, however, usually contributes by far the greater portion of the hyperpnea of anoxemia in the dog; the aortic body component, though invariably present, is often insignificant. In the cat the carotid chemoreceptors are relatively more important to the vasomotor response to anoxia than is the case in the dog.

4. The blood supply and afferent nervous pathways for the aortic chemoreceptors have been determined in the dog and cat. In the dog the blood supply is from the transverse aorta, in the cat from the coronary arteries. In both species the nerve fibers reach the vagus trunk close to (probably by way of) the recurrent laryngeal nerves.

5. The possibility that the McDowall reflex may result from chemical stimulation of the aortic body rather than from alterations in venous pressure has been discussed.

6. In view of the close functional and structural similarity to the carotid body, it is proper to use the term aortic body suggested by Nonidez, to designate structures now known as paraganglion aorticum supracardiale, paraganglion of Penitschka, paraganglion aorticum supracardiale superius.

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