Narcotic Properties of Carbon Dioxide in the Dog

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$P_{co_2}$ ranging from 15 mm. to 95 mm. of mercury with arterial pH values from 7.64 to 7.10 had no effect on the minimum anesthetic concentration (MAC) for halothane in dogs. $P_{co_2}$ levels above 95 mm. of mercury with arterial pH below 7.10 were progressively narcotic, and replaced the halothane required to maintain a constant depth of anesthesia. Anesthesia was achieved with CO$_2$ alone at $P_{co_2}$ of 245 mm. of mercury. The mechanism of CO$_2$ narcosis correlated well ($P > 0.05$) with the pH changes in the brain as measured in the cisternal CSF, and appeared to be independent of arterial pH, $P_{co_2}$, and cerebrospinal fluid $P_{co_2}$.

In 1820 the narcotic properties of CO$_2$ were demonstrated by Hickman, and a century later anesthesia was produced in man with 30 per cent CO$_2$ and O$_2$. However, muscle movements and convulsions precluded further investigations of CO$_2$ as an anesthetic. Because wide fluctuations of CO$_2$ may occur during general anesthesia and in respiratory failure, this study was undertaken to examine the narcotic effects of CO$_2$ over a wide range of concentrations in the dog. The first question considered is how CO$_2$ influences the concentration of an anesthetic gas (halothane) required to maintain a constant depth of anesthesia. Specifically, at what level does CO$_2$ exert a narcotic effect as determined by a reduction in halothane requirement, and at what concentration does CO$_2$ behave as an anesthetic as evidenced by its complete replace-

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Methods

The technique of determining the minimum anesthetic concentration (MAC) needed to prevent gross movement in response to a given painful stimulus was employed in all experiments. This provides a constant index of depth of anesthesia below which the animal moves and above which he does not move when stimulated in a standard manner. Although this method has not been previously used for CO$_2$, it is known to be stable over a wide range of arterial pH and P$_{o_2}$ and constant over periods of 8-10 hours.

With this technique one can observe the effect of a given concentration of CO$_2$ upon a constant level of anesthesia.

Healthy mongrel dogs (15–25 kg.) were anesthetized with halothane and O$_2$ by mask using a semi-closed circle system including a CO$_2$ absorber. Their tracheas were intubated, and spontaneous breathing was recorded with an in circuit ventilator connected to a Gilson polygraph. Catheters were inserted into the femoral artery and vein for blood pressure recording on the polygraph, and for blood gas analysis with appropriate p$_{a_4}$, P$_{co_2}$, and P$_{o_2}$ electrodes. All values were corrected for temperature measured with an esophageal thermometer and maintained between 36° and 38° C.
With the dog's head flexed, a plastic cannula was placed through the foramen magnum into the cistern for sampling of cerebrospinal fluid. Approximately 2 ml. were drawn into an oil-glass syringe, the dead space rinsed first with cerebrospinal fluid, and immediately analyzed for pH and P\textsubscript{CO\textsubscript{2}}. In the final group of experiments cerebrospinal fluid bicarbonate was measured with the Van Slyke apparatus. If gross bleeding occurred in the subarachnoid space the sample was discarded and no cerebrospinal fluid was collected.

End-tidal CO\textsubscript{2} and halothane were measured by sampling through respective infrared analyzers. The halothane analyzer was repeatedly calibrated against a cylinder of known halothane concentration. The crossover effect of CO\textsubscript{2} was determined and halothane concentrations corrected accordingly. Establishment of the MAC for halothane required testing the animals' response to 4 or 5 different concentrations, each level held constant for a minimum of 15 minutes before stimulation. Therefore when the initial or base line MAC was determined, the animal had equilibrated to the extent that expired halothane approached 80 per cent of the inspired.

Elevation of CO\textsubscript{2} was achieved by removing the CO\textsubscript{2} absorber and adding appropriate flows of CO\textsubscript{2} from a cylinder to the halothane-oxygen mixture. Using end-tidal CO\textsubscript{2} recording on the polygraph as a guide, each level of CO\textsubscript{2} was held constant while the halothane MAC was determined. This required at least one hour at each level of CO\textsubscript{2} and at the end of each period samples of arterial blood and cerebrospinal fluid were taken.

First, 12 dogs were anesthetized with halothane-oxygen as described, and after the initial halothane MAC, and analyses of arterial blood and cerebrospinal fluid they were hyperventilated to reduce the P\textsubscript{ACO\textsubscript{2}} until a new constant level was attained. After approximately 30 minutes of hypocapnia halothane MAC was determined and arterial blood and cerebrospinal fluid sampled. The dogs then breathed spontaneously until P\textsubscript{ACO\textsubscript{2}} and halothane MAC returned to the initial resting value. At that point CO\textsubscript{2} was added to the halothane-oxygen mixture in increments of 50 to 75 mm. of mercury, each new level of CO\textsubscript{2} maintained constant while halothane MAC, arterial blood, and cerebrospinal fluid measurements were made. In this manner CO\textsubscript{2} was raised until the halothane MAC approached zero, that is, no movement occurred in response to stimulation when less than 0.15 per cent expired halothane could be detected. As the CO\textsubscript{2}, not halothane, now maintained the same anesthetic depth (MAC) this represented CO\textsubscript{2} narcosis. Because this level of CO\textsubscript{2} narcosis could not exclude the influence of residual halothane, the following experiments were done without halothane.

Six dogs were given CO\textsubscript{2} and O\textsubscript{2}, approximately 50 per cent each, by mask using the same circle system without a CO\textsubscript{2} absorber. When consciousness was lost, cyclopropane was added to the CO\textsubscript{2}-O\textsubscript{2} mixture to facilitate tracheal intubation, as well as cisternal, arterial and venous catheterization. Cyclopropane was discontinued and anesthesia maintained with 30–40 per cent inspired CO\textsubscript{2} for 30–60 minutes while cyclopropane was eliminated. At this level of CO\textsubscript{2} there was no response to painful stimuli, that is, there was complete CO\textsubscript{2} narcosis. By lowering CO\textsubscript{2} in 20–40 mm. of mercury decrement, and keeping each concentration a steady level for 15 minutes before testing, the CO\textsubscript{2} MAC was established, at which time arterial blood and cerebrospinal fluid samples were taken.

To study the problem of how CO\textsubscript{2} produced narcosis an attempt was made to reverse the acidosis that accompanies CO\textsubscript{2} retention, by administering sodium bicarbonate. Six dogs anesthetized with halothane-oxygen were given increasing concentrations of CO\textsubscript{2}, as in the first group of dogs. At the same time NaHCO\textsubscript{3} (30 mEq./kg.) in a 0.1 per cent solution was given intravenously to maintain the arterial pH between 7.1 and 7.3 while the CO\textsubscript{2} concentration was elevated to the point of CO\textsubscript{2} anesthesia. Arterial blood and cerebrospinal fluid samples were taken at each point of elevated CO\textsubscript{2}.

We then attempted to reproduce the changes in arterial pH observed with CO\textsubscript{2} anesthesia without using CO\textsubscript{2}. Eight dogs anesthetized with halothane-oxygen were given 0.3 N hydrochloric acid (30 mEq./kg) into the stomach via an inflated urinary catheter to prevent regurgitation. Over 3–4 hours, arterial
spinal fluid bicarbonate. Hyperventilation was then abruptly terminated, and CO\textsubscript{2} added to the halothane-oxygen mixture in a step-like fashion until the point of complete CO\textsubscript{2} anesthesia was attained. This point could then be compared with the level of CO\textsubscript{2} anesthesia in the first group of dogs whose cerebrospinal fluid bicarbonate was not lowered.

Results

The first 12 dogs anesthetized with halothane-oxygen followed by increasing amounts of CO\textsubscript{2} demonstrated no narcotic effect until a Pa\textsubscript{CO\textsubscript{2}} of 94 mm. of mercury was reached (fig. 1a). Nor was there any stimulant effect of CO\textsubscript{2} which could have raised the halothane MAC. From Pa\textsubscript{CO\textsubscript{2}} of 94 mm. of mercury to 170 mm. of mercury there was a progressive decline in the halothane MAC as the halothane was replaced by CO\textsubscript{2}. The effect of CO\textsubscript{2} continued to a level of 245 mm. of mercury, when the halothane required for constant depth anesthesia was completely taken over by CO\textsubscript{2}. This represented the point of CO\textsubscript{2} anesthesia. Figure 1b shows the arterial and cerebrospinal fluid pH changes as Pa\textsubscript{CO\textsubscript{2}} ranged from 15 mm. to 245 mm. of mercury in the same experiments. There was no narcotic effect (no change in halothane MAC) until the pH in both blood and cerebrospinal fluid fell below 7.10. As the blood and brain became more acid there was an increasing narcotic effect of CO\textsubscript{2} until the point

![Graph showing MAC vs PaCO2 with pH data](http://anesthesiology.pubs.asahq.org/pdfaccess.ashx?url=/data/journals/jasa/931614/)

Fig. 1b. Halothane MAC and arterial pH (solid line) with CSF pH (broken line) in the same experiments shown in 1a. Each point corresponds to a Pa\textsubscript{CO\textsubscript{2}} level indicated in 1a. Note the stability of MAC over a wide range of pH. The decline in MAC (onset of narcosis) begins when the pH falls below 7.10 and reaches the point of CO\textsubscript{2} anesthesia when the pH falls below 6.80.
of CO₂ anesthesia, when the arterial pH was 6.75 and the cerebrospinal fluid pH was 6.79.

In the 6 dogs anesthetized with CO₂ and O₂ the point of anesthesia was reached at an average PaCO₂ of 222 mm. of mercury. Figure 2 indicates the response of each dog to a standard painful stimulus at various levels of CO₂. The mean value of the positive and negative responses was considered to be the CO₂ MAC for each animal. At this point average arterial pH was 6.76 and the average cerebrospinal fluid pH 6.79, identical to arterial and cerebrospinal fluid pH in the dogs anesthetized with halothane prior to CO₂ administration. This indicates that at the point of CO₂ anesthesia there was no influence of halothane in the first 12 dogs since any residual effect would have lowered the CO₂ level required to produce narcosis. On the contrary these dogs needed a slightly higher CO₂ concentration for anesthesia (245 mm. of mercury versus 222 mm. of mercury). This difference would disappear if dog no. 4, which convulsed while being anesthetized with CO₂, were excluded.

In the 6 dogs given sodium bicarbonate attempting to reverse the CO₂ narcosis there was no change in the PaCO₂ required for CO₂ anesthesia (244 mm. of mercury). Despite the fact that arterial pH remained above 7.12 cerebrospinal fluid pH fell to 6.57 which demonstrated the well known blood brain barrier to the passage of ions. Because of the bicarbonate induced diuresis in these dogs there was insufficient cerebrospinal fluid for analysis at the point of CO₂ anesthesia in 2 of the 6 animals. The data from these experiments are plotted in figures 5–8 on the curve labelled metabolic alkalosis.

In the 6 dogs given HCl, arterial pH fell to 6.90 while cerebrospinal fluid pH in 6 of 8 dogs ranged between 7.13 and 7.32. Figure 3 shows the values for each experiment where arterial pH is plotted against the halothane MAC. The mean data are indicated by the heavy line showing that the halothane MAC fell less than 15 per cent over the wide range of arterial pH (7.34 to 6.90). The average dose of HCl was 500 mM over 3–4 hours. One animal whose halothane MAC, declined 50 per cent developed pulmonary edema and expired. There were no serious effects observed in the other seven dogs.

The final experiments on 6 dogs where cerebrospinal fluid bicarbonate was lowered by hyperventilation showed the most significant results. As seen in figure 4 the point of CO₂ anesthesia was reached at a PaCO₂ of 139 mm. of mercury compared with 245 mm. of mercury in the dogs whose cerebrospinal fluid bicarbonate was not lowered. The remarkable fact about this point of CO₂ narcosis is that the cerebrospinal fluid pH was 6.82, very close to 6.79 in the other group, despite the
CENTRAL ACIDOSIS

![Graph showing central acidosis and halothane requirement](image)

Fig. 4. Halothane MAC and PaCO₂ in group of 6 dogs anesthetized with halothane-O₂ and hyperventilated to reduce the CSF bicarbonate (13 mEq/liter), and the MAC-PaCO₂ curve from the first 12 dogs whose CSF bicarbonate was normal (25 mEq/liter) before CO₂ administration. Note at every level of CO₂ a greater fall in MAC in the group with lowered CSF bicarbonate. At the point of CO₂ anesthesia (PaCO₂ 139 versus 245), however, the CSF pH was almost the same in both groups.

HALOTHANE REQUIREMENT VS. PaCO₂

![Graph showing halothane requirement vs. PaCO₂](image)

Fig. 5. Halothane requirement (MAC) with increasing PaCO₂. Number of dogs is given beside each point. Solid line (control group), dotted line (metabolic alkalosis group), dashed line (central acidosis group). Comparable points in each group are denoted by: * Hypocapnia (PaCO₂ < 15 mm. of mercury), △ normocapnia (PaCO₂ 43 mm. of mercury), ○ hypercapnia (PaCO₂ 94 mm. of mercury), ▲ hypercapnia (PaCO₂ 170 mm. of mercury), and ● zero halothane requirement where anesthesia is due to CO₂ only. Note wide difference in PaCO₂ values at point of zero halothane (CO₂ anesthesia).

HALOTHANE REQUIREMENT VS. Pcsf CO₂

![Graph showing halothane requirement vs. Pcsf CO₂](image)

Fig. 6. Halothane requirement (MAC) for anesthesia and increasing CSF Fco₂ in same animal groups as in figure 5. Curves and points are labeled the same as in figure 1. Note wide variation of CSF Fco₂ at zero halothane (CO₂ anesthesia).

difference in PaCO₂. Figures 5–8 compare arterial pH, Pco₂, cerebrospinal fluid pH and Fco₂ in this group labelled as central acidosis, with the first 12 dogs referred to as controls, and the metabolic alkalosis group. Figure 5 shows that CO₂ narcosis may occur over a wide range of PaCO₂ values (139 mm. to 245

ANESTHETIC REQUIREMENT VS. ARTERIAL pH

![Graph showing anesthetic requirement vs. arterial pH](image)

Fig. 7. Anesthetic requirement (MAC) for halothane and arterial pH in same experiments as in figure 5 (increasing hypercapnia). Points are also marked as in figure 5. Note that alkalosis (pH > 7.6) had no effect on anesthesia required. Again note wide scatter in arterial pH where CO₂ begins to reduce anesthetic requirement and at zero halothane (CO₂ anesthesia).
NARCOTIC PROPERTIES OF CARBON DIOXIDE

FIG. 8. Anesthetic requirement (MAC) for halothane and CSF pH. Points represent the same PCO₂ as in figure 5 (increasing hypercapnia). Note striking similarity of curves and points at each level of CSF pH. Halothane requirement was zero when CSF pH fell below 6.90 (CO₂ anesthesia).

TABLE 1. pH and PCO₂ at MAC for CO₂ Anesthesia

<table>
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<th>Groups</th>
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<tr>
<td></td>
<td>PCO₂</td>
<td>pH</td>
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<td>CO₂ alone</td>
<td>222</td>
<td>6.762</td>
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<td>±46</td>
<td>±0.100</td>
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<td></td>
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<td>(6)</td>
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<td>Halothane and CO₂</td>
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<td>±0.019</td>
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<td></td>
<td>(12)</td>
<td>(12)</td>
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<tr>
<td>Metabolic alkalosis and CO₂</td>
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Note large differences in arterial PCO₂, pH and CSF PCO₂ values among the 4 groups of experiments and the small differences in CSF pH values. One standard deviation and the number of experiments are given below each figure.

mm. of mercury), and figure 6 shows a similar scatter for cerebrospinal fluid PCO₂ (146 mm. to 262 mm. of mercury). The PCO₂ in cerebrospinal fluid parallels PaCO₂ but is normally about 9 mm. of mercury higher. Figure 7 shows the same curves plotted for arterial pH which varied from 6.75 to 7.11 at the point of CO₂ narcosis. Figure 8 demonstrates the similarity of all three curves in terms of pH. At the point where CO₂ began to substitute for halothane cerebrospinal fluid pH ranged between 7.01 to 7.03, and the same narrow range of pH was found at the point of total halothane replacement or CO₂ anesthesia (6.79 to 6.87).

The data from dogs anesthetized with CO₂ alone are not shown in figures 5–8 because these are plots of halothane MAC at constant depth anesthesia. The data when CO₂ alone was given fell within the ranges (PCO₂ and pH of arterial blood and cerebrospinal fluid) seen in the three curves plotted in figures 5–8 and are presented in table 1 together with all CO₂ values for narcosis.

The systemic effects of elevated CO₂ are well known resulting from sympathetic and respiratory stimulation. Figure 9 demonstrates the respiratory and circulatory responses in the dogs anesthetized with CO₂–O₂ only. Peak responses occurred when PaCO₂ was between 200 mm. and 250 mm. of mercury. At higher PaCO₂ there was a decline in ventilation and systolic pressure corresponding to hyperventilation and lower levels of PaCO₂.
with the narcotic effects of CO₂. Between Paco₂ 300 mm. and 400 mm. of mercury however, the ventilation and systolic pressure remained constantly higher than the control values. Tachycardia developed in all dogs with elevated CO₂ and the course paralleled that of the blood pressure. Arrhythmias of supraventricular origin were seen with higher concentrations of CO₂ in several animals, but were not serious.

Other aspects of CO₂ anesthesia included labored respiration, characterized by little change in frequency but marked increase in tidal volume, increased muscle tone and muscle twitching. Convulsions occurred in approximately one-fourth of the animals during the period of highest CO₂ concentration. They were unsustained and untreated, and apparently did not affect the ability to make a purposeful movement in response to painful stimuli at CO₂ levels below CO₂ narcosis.

**Discussion**

These results showed that CO₂ exerts a narcotic influence in dogs at a concentration above 95 mm. of mercury and at a level of 245 mm. of mercury CO₂ produces anesthesia. This effect correlated well with changes in pH in the brain which, presumably are reflected in the cisternal cerebrospinal fluid. CO₂ anesthesia was found over a wide range of Paco₂ cerebrospinal fluid PCO₂ and arterial pH values but was always associated with acidosis (pH 6.79 to 6.87) of the cerebrospinal fluid. Thus it appears that CO₂ narcosis is not a result of any inert or toxic property of the gas, nor is it a result of peripheral acidosis.

With Paco₂ between 15 and 95 mm. of mercury, there was little or no alteration in the halothane MAC. This was contrary to expectations for it has been a clinical impression that severe hypocapnia deepens the level of anesthesia, though much of the published data are conflicting. Previous studies showed a correlation between respiratory alkalosis (pH > 7.50) and slow wave EEG activity suggesting a narcotic effect which could be reversed by adding 12 per cent CO₂. The influence of hypocapnia on pain thresholds is unsettled, as both an increased and a decreased threshold have been demonstrated. Many authors believe that the effect of hyperventilation on cerebral blood flow is the critical factor. Specifically, the lowered Pco₂ produces cerebral vasoconstriction and may lower cerebral oxygen tension. In the present studies however, halothane may have increased cerebral blood flow and thereby attenuated any ischemic consequences of hypocapnia.

It was of interest that moderate elevation of CO₂ (Paco₂ 40–90), more likely to be seen clinically, had no effect on the halothane MAC. Elevated CO₂ augments reticulo-cortical activity, increases excitability and awareness of the environment; therefore one might expect moderate hypercapnia to increase the requirement for halothane. However, there is also evidence that moderately increased Paco₂ is a central nervous system depressant. Confusion and irritability are seen in healthy subjects breathing 5 to 12 per cent CO₂, which if inhaled long enough, leads to loss of consciousness. Qualitative studies on the influence of 5 to 10 per cent CO₂ added to ether have shown a deepening of the anesthetic level but this has not been found in the present study with halothane. It has also been reported that small concentrations of CO₂ decrease the amount of nitrous oxide necessary to produce loss of consciousness.

With higher concentrations of CO₂ (Paco₂ > 95 mm. of mercury) in the present study there was a progressive narcotic effect as CO₂ supplanted the halothane needed to maintain constant depth anesthesia. Though the CO₂ levels were chosen arbitrarily, the lowering of halothane MAC continued in linear fashion (fig. 1a) as the CO₂ concentration increased, to the point of CO₂ anesthesia where the halothane requirement was zero. The point of complete CO₂ narcosis occurred at an average Paco₂ of 245 mm. of mercury, which agrees with the observations of Leake and Waters on CO₂ narcosis in rabbits. Thus CO₂ appears much more potent than nitrous oxide whose physical properties are identical, and less potent than halothane whose MAC in the dog is 0.9 per cent or 7 mm. of mercury.

Using CO₂ alone, anesthesia occurred at a Paco₂ of 225 mm. of mercury (fig. 2). EEG activity was not recorded, therefore it is difficult to evaluate the effects of convulsions on the narcotic process. Seizure activity occurred
in at least 25 per cent of the dogs, although it was noted only randomly among the different experimental groups.

Brooks and Eccles and others have shown that inhalation of CO₂ above 10 per cent produces direct depression of post-synaptic responses and prolongs synaptic delay within the spinal cord.²¹ With CO₂ narcosis a delayed and decreased response to motor nerve stimulation was noted (unpublished data), but there was no evidence of paralysis. The influence of depressed neuromuscular function on the MAC technique is uncertain; however positive responses to painful stimuli were elicited up to the level of CO₂ narcosis, and the strength of these responses was no less than those observed at lower CO₂ levels. Therefore it seems that a painful stimulus, if applied long enough, produces a useful qualitative response under conditions of severe hypercapnia and acidosis, providing of course that convulsions do not occur during the time of testing.

From the data presented it is clear that the narcotic properties of CO₂ are related to hydrogen ions, and that because of rapid diffusion of CO₂ into all tissues, an acid pH change occurs throughout the organism. Cerebral pH can be assessed by the pH of the fluid bathing it which approaches equilibration with arterial and jugular venous changes in P₉₀₂ within 15 minutes.²² Cerebrospinal fluid bicarbonate rises with CO₂ administration, though this rise may be less than ²³ or greater than ²⁴ the rise in plasma bicarbonate. The rise in arterial and cerebrospinal fluid P₉₀₂ however, is greater than the bicarbonate rise, with a resulting increase in hydrogen ion concentration. At higher CO₂ concentrations, the rise in bicarbonate is proportionately less, hence an even greater fall in pH—both arterial and cerebrospinal fluid.

The discrepancy between pH of blood and cerebrospinal fluid during infusion of HCl demonstrates the influence of cerebrospinal fluid pH on the development of narcosis, or the reduction in halothane MAC (fig. 3). Because the cerebrospinal fluid pH did not fall below 7.13, there was no significant change in the halothane requirement, despite marked arterial acidosis. In the other direction, the administration of sodium bicarbonate had no effect on the cerebrospinal fluid pH (metabolic alkalosis, figure 8); consequently CO₂ narcosis and anesthesia occurred regardless of the arterial pH which remained above 7.12.

In the present experiments (fig. 1b) an average P₉₀₂ of 95 mm. of mercury produced a lowering of cerebrospinal fluid pH from 7.32 to 7.02 corresponding to the onset of CO₂ narcosis, or a fall in halothane MAC. This is similar to the cerebral pH threshold (jugular venous blood) for EEG slowing resulting from CO₂ inhalation, reported by Meyer,²⁵ and similar to the cerebrospinal fluid pH associated with loss of consciousness in respiratory failure, reported by Posner.²⁶ This value for cerebrospinal fluid pH (7.02) was similar in all groups given CO₂ (fig. 8). A cerebrospinal fluid pH of 6.80 appears to represent the critical level of cerebral pH associated with lack of responsiveness to painful stimuli in all the experiments. That pH is independent of P₉₀₂ or arterial pH and P₉₀₂ can be seen in figures 4–8 and in table 1. In studies on monkeys with cortical surface electrodes, Mayer ²⁷ demonstrated EEG changes indicating severe depression when the brain pH was reduced below 6.9 to 6.6.

The curious state of CO₂ narcosis wherein respiration, blood pressure, and muscle tone are increased while consciousness and pain perception are decreased suggest a differential action of CO₂ within the brain. Celhorn ²⁸ has shown that CO₂ affects various synaptic relays within the brain depending upon the level of CO₂. Thus, inhalation of 10 per cent CO₂ depressed local responses of cortical neurones to acoustic and visual stimuli but enhanced those of neurones in the hypothalamic region of the brain stem. Increasing CO₂ to 20–25 per cent, depressed responsiveness of the brain stem neurones as well as depressing cortical responses further. It is of interest that as CO₂ exceeded the narcotic level (fig. 9) the respiratory and circulatory stimulus declined, suggesting brain stem depression. Other investigators have observed apnea when the P₉₀₂ exceeded 300 mm. of mercury.²⁹

Since the central nervous system depressant influence of CO₂ results from its hydrogen ion effect, CO₂ narcosis in pathological conditions may be modified by bicarbonate in cerebrospinal fluid. Intrathecal bicarbonate has been
used successfully to reduce the hyperventilation consequent to subarachnoid bleeding (Crampton-Smith, personal communication). Intolerance to hypercapnia may be anticipated in subjects whose cerebrospinal fluid bicarbonate has been lowered by hyperventilation or by treatment with carbonic anhydrase inhibitors. In respiratory failure narcosis is seen over a wide range of $P_{\text{CO}_2}$. This variation may be explained by coexisting factors, such as hypoxia, drug therapy, and cerebrovascular disease which may render some areas of the brain more sensitive narcosis by $P_{\text{CO}_2}$. The common denominator in all these cases, however, is probably the cerebrospinal fluid $pH$.

**Summary**

The data presented show that $P_{\text{CO}_2}$ in concentrations from 15 mm. to 95 mm. of mercury has no influence on halothane anesthesia in the dog. At higher levels, $P_{\text{CO}_2}$ behaves as a narcotic as it reduces the halothane requirement for constant depth anesthesia. At a partial pressure of 245 mm. of mercury $P_{\text{CO}_2}$ becomes a narcotic and eliminates the need for halothane.

The mechanism of $P_{\text{CO}_2}$ narcosis is closely related to a fall in cerebrospinal fluid $pH$; this can occur independent of arterial $pH$, $P_{\text{CO}_2}$ or cerebrospinal fluid $P_{\text{CO}_2}$. The narcosis begins when cerebrospinal fluid $pH$ falls below 7.10 and reaches a maximum when the cerebrospinal fluid $pH$ approaches 6.80. We conclude that the narcosis resulting from $P_{\text{CO}_2}$ inhalation results solely from its hydrogen ion effect.

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**References**


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**Drugs**

**DELIRIUM TREMENS** Acute alcohol withdrawal syndrome may lead to death from aspiration, pneumonia, physical exhaustion, hyperpyrexia, coexisting injuries, hypovolemic shock, and serum electrolyte imbalance. Psychomotor agitation is the characteristic manifestation of the acute withdrawal syndrome. Besides the general measures of restraint, supplying fluid, vitamin, and caloric replacement, treatment consisted of “keeping the patient quiet” by giving a combination of chlorpromazine with either chlor Diazepoxide or diazepam. The following dosage schedules were used: chlorpromazine 300 mg. intramuscularly initially and 50 to 100 mg. every six hours for at least 72 hours; chlor Diazepoxide 100 mg. intramuscularly initially and repeating this dosage every eight hours; and diazepam orally in dosages of 10 to 40 mg. every eight hours. In addition, supplemental orders of the medication were given on a prn basis. Methylphenidate was given intravenously for oversedation. (Hoagland, R. J.: Treatment of Delirium Tremens, South. Med. J. 59: 1041 (Sept.) 1966.)