CARBON DIOXIDE ADMINISTRATION TO CALVES

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ABSTRACT

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by Seref Nezihi Ersoz

An investigational study has been made to determine the possible surgical anesthetic effect of carbon dioxide (CO_2).

A review of literature did not reveal satisfactory references in veterinary medicine with the exception of administration of CO_2 to slaughter hogs and poultry. In human medicine, CO_2 has been used during child delivery, in the attempted treatment of alcoholism, muscular rigidity and psychoneurotic cases.

The experimental equipment consisted of two CO_2 tanks, one oxygen (O_2) tank, a CO_2 gas analyzer (Ranarex), an electrocardiograph (Burdick EK III), and a kymograph (Watson Bird).

Initially 100% CO_2 was administered until the calves fell into lateral recumbency, following this 65% CO_2 and 35% O_2 was used to maintain anesthesia and the following data were collected before and during CO_2 anesthesia: Total leukocyte and erythrocyte counts, differential blood counts, packed cell volumes (hematocrit), hydrogen ion concentrations,

arterial blood pressures, electrocardiograms, pneumograms, and body temperatures. During anesthesia response to corneal and cutaneous pain stimuli were periodically observed.

The principal findings were: 1) on the basis of experimental data no consistent significant changes were noted in the hematocrit values, total erythrocyte, leukocyte, and differential counts, 2) a consistent decrease of blood pH varying between 0.3 and 1.1, 3) an increase in blood pressure ranging from 13 to 112 mm. Hg., 4) an increase of heart rate between 30 and 120 beats per minute above normal, 5) significant changes in the conduction system of the heart during CO_2 administration were tachycardia, possible heart injury, and on one calf the Wenchebach phenomena were observed.

The pertinent observations were: 1) blood stains in the nasal discharge on three calves, 2) deep respiratory movements, 3) defecation at the beginning or during CO_2 administration, 4) intermittent bellowing, 5) involuntary movements of the limbs of two calves, 6) a partial to complete absence of response to corneal and cutaneous pain stimuli.

The results of the findings and observations are discussed with a summary followed by references and a bibliography.

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By

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Dedicated to My Instructors

Prof. Dr. S. Nejat Yalki

Prof. Dr. Yasar Altan

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CHAPTER I

INTRODUCTION

Carbon dioxide (CO_2)--its production in the body, effects upon body systems, and elimination from the body--has always been of concern to anesthesiologists, as well as physiologists.

In human medicine, CO_2 has been used for a number of different conditions: child delivery (MacRae, 1951), treatment of neuroses and alcoholism (LaVerne, 1953), treatment of stutterers (Smith, 1953), and muscular rigidity (Fay, 1953). The most extensive studies with CO_2 have been made by Meduna (1953 and 1958) who has written a text book entitled "Carbon Dioxide Therapy--A Neurophysiological Treatment of Nervous Disorders." Within recent years, an increasing interest has been taken in the anesthetic properties of CO_2 in veterinary medicine (Swem, 1952; Murphy, 1953; Blomquist, 1957; Wernberg, 1957; Kitchell, et al., 1960), as well as its usage in meat packing plants to produce surgical anesthetic effects before exsanguination. The "Humane Slaughter Law" passed by the 85th U.S. Congress as a public law in 1958 required slaughter houses to dispatch with domestic animals in a humane manner. Carbon dioxide has been approved for a pre-surgical anesthetic for swine, sheep,

and calves (Title 9, Code of Federal Regulations, 1959).*

This study was conducted as a result of interest aroused by the work of previous investigators and the apparent lack of scientific data regarding the effect of CO_2 on calves.

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*Regulations governing the meat inspection of the United States Department of Agriculture, United States Government Printing Office, Washington, 1960.

CHAPTER II

REVIEW OF THE LITERATURE

In 1827, Hickman, cited by McQuacker (1929), first demonstrated that animals exposed to an atmosphere containing a high concentration of CO_2 became anesthetized. He performed experimental surgery on a dog, puppy, mouse and rabbit using CO_2 as the anesthesia inducing agent.

In 1878 Bert, cited by Loewy (1923), recommended the gas for anesthesia and reported that CO_2 concentrations of 25 to 30% in the inspired air would effect paralysis of the central nervous system with cessation of corneal and other reflexes. Zuntz and Loewi (1897) and Kropeit (1898) observed that in rabbits there occurred a short excitation stage, but no such stage has been observed in cold blooded animals (Winterstein, 1911). Albitzki (1912) stated in experiments with rabbits that if the concentration of CO_2 in inspired air was lower than 25 to 30% complete anesthesia was not attained. But following recovery from anesthesia they showed disturbances of balance, as well as a failure in the ability to keep upright and to change their positions.

Prausnitz (1928) showed that 25 to 30% CO_2 was required in the inspired air to abolish corneal and light

reflexes in experiments on dogs, cats, rabbits, guinea pigs, rats, and mice. The excitation stage was slight, and awakening occurred quickly even though the anesthesia lasted for one hour. The animals tolerated a concentration of 50% CO_2 resulting in deep anesthesia for 60 to 90 minutes. Unfortunately, after this period of anesthesia the animals showed convulsions and died of pulmonary edema.

Leake and Waters (1928), in experiments on dogs, found that 30 to 40% CO_2 with oxygen (O_2) will anesthetize the dogs in about one minute usually without struggling. The pulse rate was usually reduced as was the respiratory rate, but the blood pressure rose rapidly. The depth of respiration was greatly increased, but breathing did not seem to be labored. Upon opening the abdominal cavity, the intestines seemed relaxed and the muscles were usually flaccid. Dogs have been maintained under fairly satisfactory anesthesia for two hours. Respiratory movements became more regular and the depth of anesthesia deeper the longer the animal received the same mixture. According to Leake and Waters (1928), the lower percentages of CO_2 did not seem to anesthetize as well. Concentrations higher than 40% tended to depress respiration. Cardiac function and anoxemia became a factor with concentrations above 80%. With 100% CO_2, the blood pressure became lower and the heart and respiration stopped at about the same time. In another experiment one year later, these investigators demonstrated

anesthesia with 30-40% CO_2 in a variety of animals obtaining comparable results. They also pointed out that it was theoretically significant that high concentrations of a metabolic waste product (CO_2) would depress the central nervous system enough to produce anesthesia. These investigators concluded that the anesthetic effect, in the case of a mixture of 30 to 40% CO_2 with O_2, was not due to asphyxia. The theory being that the increased CO_2 tension in the blood prevented the escape of CO_2 from the cells, and that the gradual accumulation of this metabolic product may progressively depress cellular function.

In 1926, Loevenhart, Lorenz and Waters first introduced CO_2 inhalation therapy into psychiatry. They theorized that a disordered function of the brain may be corrected by physiological and biochemical means. The report of this study was published in 1929 but their technique has since been abandoned.

Hettwer (1938) examined the relation of excitability of frog sciatic nerve to CO_2 tension of the external medium by systemic, graphic action potential threshold determinations and found a reduced irritability of isolated nerves after exposure to CO_2.

Barbour and Seevers (1941a) conducted a series of experiments to determine the influence of cold on the narcotic action of CO_2 on rats, rabbits and dogs in a chamber at 5 C. They reported the minimal narcotic concentrations

at this temperature as follows: rat, 11%; rabbit, 17%; and dog, 14%. The induction time varied from 3 to 24 hours. These concentrations of CO_2 did not induce narcosis at 25 C. The same authors (1941b) showed in albino rat experiments that the maximum tolerated concentration of CO_2 for the first time was between 15 to 20%. At 20% an occasional animal survived. Atmospheres containing between 25 to 30% CO_2 were uniformly lethal. Survival time varied from 0.5 to 36 hours, depending on the concentration of CO_2. At 50% CO_2, no animal survived longer than five hours. Death seemed to be due primarily to pulmonary injury rather than narcosis. The edema and hemorrhage noted in the lungs were also seen on all visible mucous membranes. Continuing the experiments, Barbour and Seevers (1943a) also pointed out that during the exposure of albino rats to 11% CO_2 for 30 days, the plasma pH fell to a level as low as 7.09 in the first half hour and remained below 7.15 during the remainder of the period. A marked reticulocytosis occurred in the rat during prolonged exposure to 11% CO_2, but no corresponding increase in the number of leukocytes or erythrocytes was observed. In another experiment they (1943b) concluded that the time required to produce the state of narcosis varied with the concentration of the CO_2, the species, and previous condition of the animal.

Gellhorn and Yesinick (1941) produced convulsions in anesthetized cats by the injection of metrazol,

picrotoxin, corymyrtin, camphor, strychnine and other drugs. In the non-denervated cats, CO_2 exerted a greater anticonvulsant effect whereas in those that were denervated, anoxia was produced. In experiments on dogs, Draper and Whitehead (1944), and Parry, et al. (1949) succeeded in arresting respiration for 45 minutes by administering a barbiturate and CO_2 anesthesia and permitting the dog to rebreathe expired air. By the end of the experiments, up to 50% CO_2 was found in the alveolar air. In other experiments the acidity of the venous blood was determined after inspiration of different concentrations of CO_2. Inspiration of 40% CO_2 was found to effect an average fall of blood pH from 7.42 to 6.79. The only alteration in the electrocardiogram was an increase in the amplitude of the T wave, which returned to normal following restoration of the normal blood pH.

Paulsen (1949) described an apparatus with an arrangement for continuous production of anesthetic gas mixtures consisting of CO_2 and ether. In a series of experiments on rabbits Paulsen (1952) used 30 to 35% CO_2 and observed that CO_2 produced a marked rise of the CO_2 concentration in the blood of these animals, and at the same time a fall in the blood pH from about 7.5 to 6.5. The corneal reflex also ceased at this concentration.

In human medicine, Meduna (1950, 1953) conducted a series of experiments using 30% CO_2 and 70% O_2 on

psychoneurotic individuals. This line of therapy was given to more than 40,000 patients. No complications were reported other than tongue biting (1 case) and 3 or 4 spontaneous urination (3 or 4 cases). MacRae (1951) found that inhalation of suitable mixtures of CO_2 and O_2 produced coma which was both safe and beneficial in delivery at child birth. He stated that as an anesthetic for delivery "CO_2 coma" is more satisfactory both for the mother and the baby than other anesthetics. However, some other anesthetic is needed for surgical repair because the "CO_2 coma" is brief. LaVerne (1953), using higher concentrations of CO_2 such as 70% CO_2 and 30% O_2, demonstrated the safety of this mixture on 4,000 patients. It should be taken into consideration that the CO_2 treatment has some contraindications, such as: previous history of coronary attack, organic heart disease, advanced arterio-sclerosis, hypertension and emphysema.

Within recent years the veterinary profession has shown an increased interest in the anesthetic properties of CO_2. Swem (1952) and Murphy (1953) at Geo. A. Hormel & Co. employed a mixture of CO_2 to immobilize the slaughter hogs for ease in shackling and sticking. By using this method, both the carcass yield and by-products were improved.

Johnson (1960) believes that the ability of CO_2 to produce anesthesia is by loss of function of the consciousness center of the brain because of the associated

anesthetic properties of the gas and the markedly reduced supply of O_2 to the brain. This is accomplished before vital heart action ceases. It is known that an isolated nerve in high CO_2 tension milieu demands greater irritation to react, that is, to send out impulses. In addition, it is known that the speed of the impulse along the nerve is reduced. CO_2 also has the effect of making the transfer of impulses from one nerve cell to another more difficult because the connections between the nerve cells (synapses) are partly blocked by CO_2. Meduna (1953) is in agreement with this concept. On the other hand, Murphy (1953), working with hogs, contended that the CO_2 unites with the hemoglobin of the blood and thereby causes unconsciousness. The compound rapidly separates from the hemoglobin and is discharged by exhalation as the hog continues to breathe fresh air before and after sticking.

As a result of the swine studies, Kotula, Drewmak and Davis (1956) used 33 to 36% CO_2 in stunning chickens, and Blomquist (1957) and Wernberg (1957, 1962) further investigated reactions of hogs to CO_2 stunning during an experiment carried out by the Danish Meat Research Institute in which 70% CO_2 was used. Pietraszek (1958) and Bartels (1962) also outlined the effect of CO_2 in stunning hogs.

In the United States the Humane Slaughter Law was passed by the 85th Congress as a Public Law 85-765 and became effective August 27th, 1958. The purpose of this law

was to require the use of humane methods in the slaughter of livestock. The animals must be exposed to the CO_2 gas in such a way as to produce surgical anesthesia before they are shackled, hoisted, thrown, cast or cut. Carbon dioxide is a relatively cheap and non-flammable gas, commercially available in large quantities and when used with properly designed units, offers no hazard to employees. These factors have stimulated research to determine its value as a surgical anesthetic for use on animals.

CHAPTER III

MATERIALS AND METHODS

A--Experimental Animals

All experiments in this study were conducted on five calves as described below:

Tag No.	Breed	Age	Sex	Weight
1	Holstein	3 months	M	260 lbs.
2	Holstein	4 months	M	335 lbs.
3	Holstein	4 months	M	350 lbs.
4	Holstein	3 months	F	272 lbs.
5	Jersey	3 months	M	360 lbs.

The above animals were housed in the Veterinary Clinic of the College of Veterinary Medicine, Michigan State University, and were fed good quality alfalfa hay.

B--Experimental Equipment

The CO_2 apparatus used for induction of anesthesia consisted of:

1. Two CO_2 tanks each equipped with two gauges (cylinder contents and outflow regulator) and a flow-meter (Figure 1). The tanks were connected with a copper tubing in such a manner that the gas from one or both of them passed through an Automatic CO_2 Heater (Figure 1) before going

Figure 1. The CO_2 Apparatus

A. CO_2 tanks

B. Automatic CO_2 Heater

C. Cylinder Contents Gauge

D. Outflow regulator

E. Flow-meter

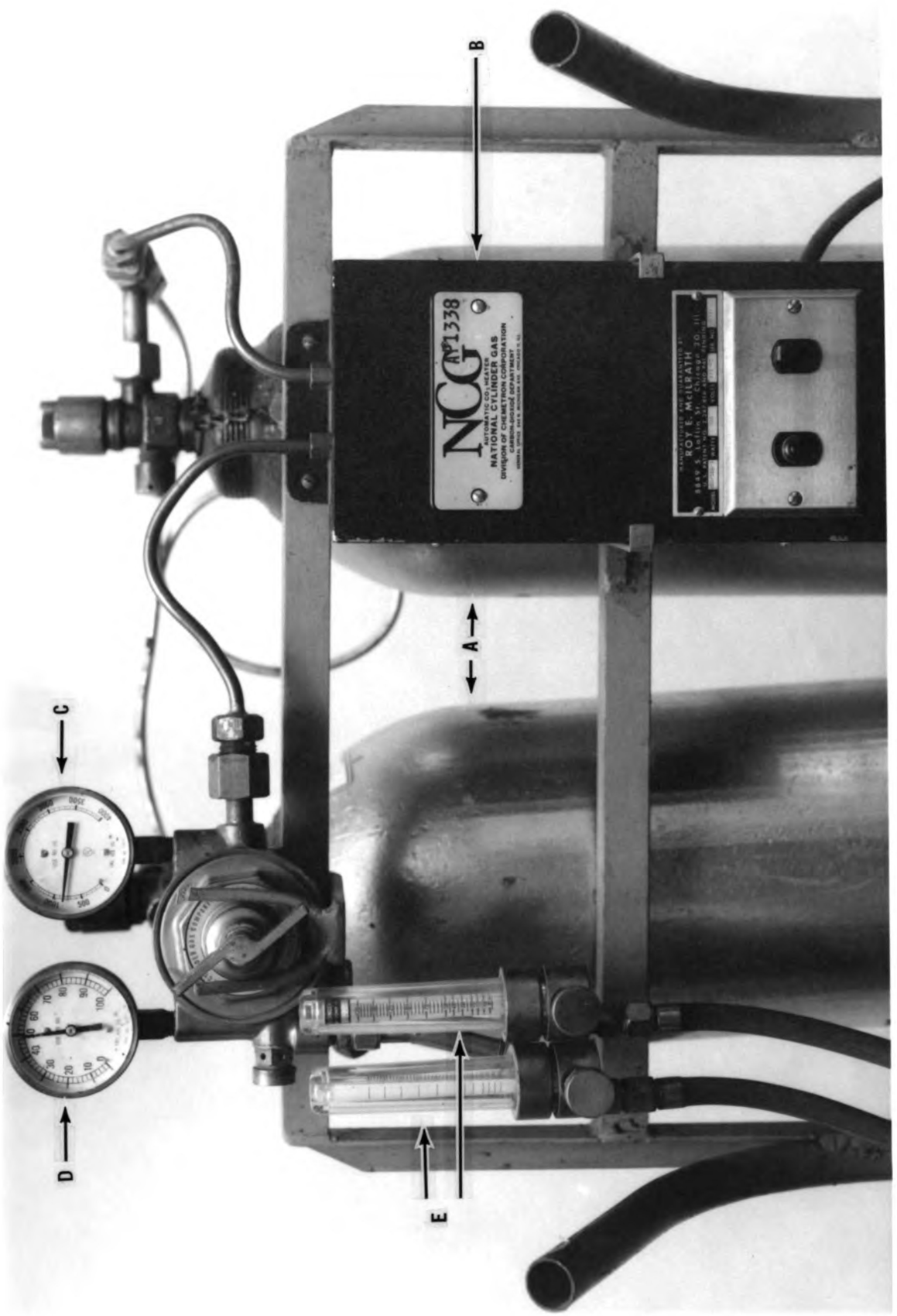
B
A
C
D
E
NCG
1338
NATIONAL CYLINDER GAS

Figure 2. The CO_2 Gas Analyzer, Ranarex


0
20
40
60
80
%CO2
AP1207
THE PERMUTIT CO.
RANAREX No P-

Figure 3. The Beginning of CO_2 Administration

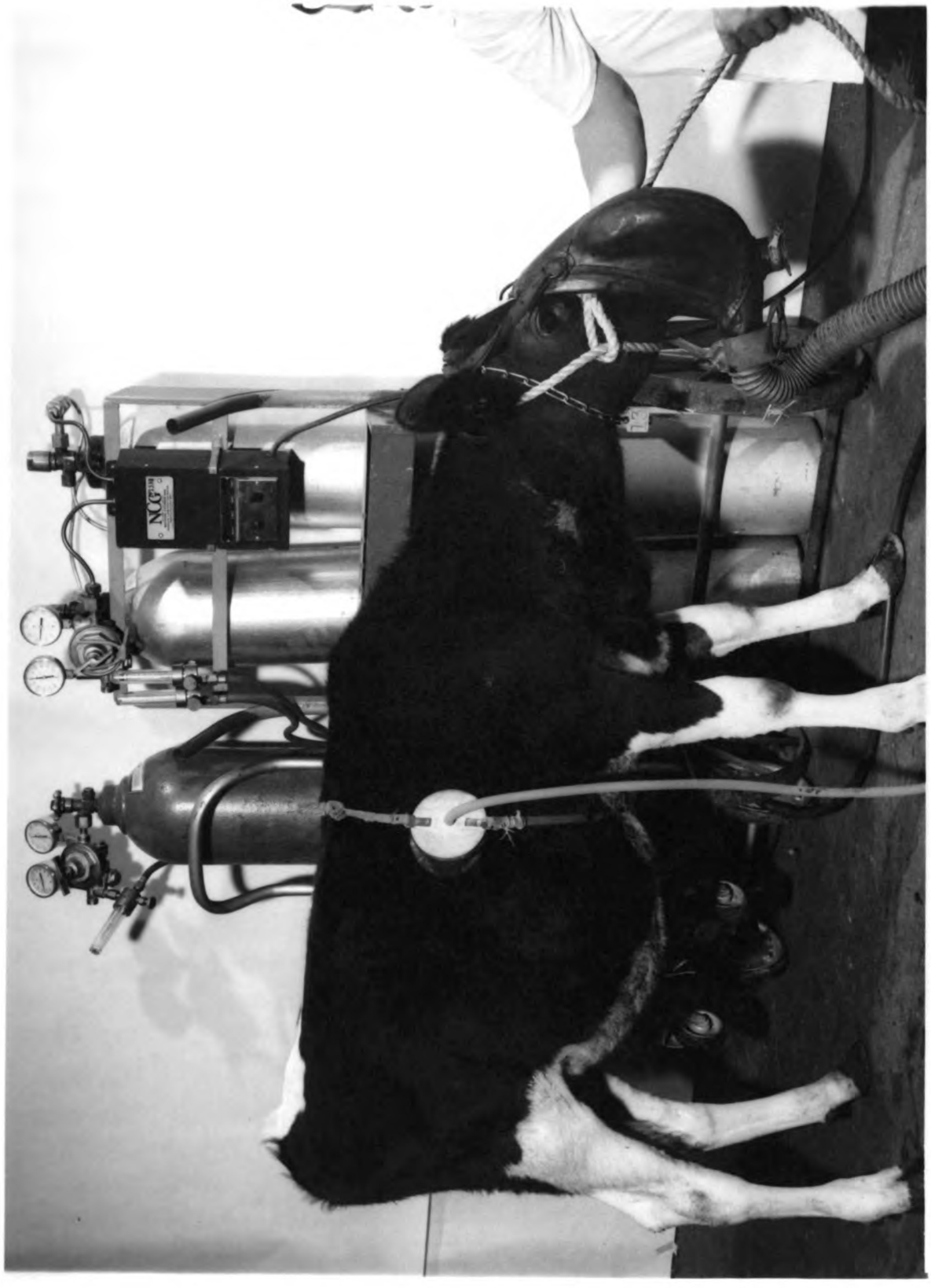
MCG

Figure 4. Calf under CO_2 Anesthesia

into the inhalation mask.* This unit was mounted on a two-wheeled truck.

2. One O_2 tank mounted on a truck and likewise equipped with two gauges (as above) and a flow-meter (Figure 1).

3. An equine protective field mask, M4, which will be called an inhalation mask.

4. A CO_2 gas analyzer, Ranarex,** which gave a continuous analysis of the concentration of CO_2 being inhaled by the calf. The gas sampling tube was connected to the tube containing the CO_2-O_2 mixture 5 ft. from the mask. At this point, the gases had flowed 25 ft. from their source and should have been thoroughly mixed.

C--Methods

The initial stages of administering the anesthesia consisted of giving the calves 100% CO_2 flowing at a rate of 150 lts. per hour. Within 25 to 37 seconds after the calves went down, a sufficient flow of O_2 was supplied to result in a CO_2 concentration of 65%. Induction of anesthesia was also attempted with 65 and 80% CO_2 in combination with either O_2 or air.

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*Chemical Supply Officer, New Cumberland General Depot, New Cumberland, Pa.

**Manual R-466, Ranarex Instrument Division, The Permutit Company, 50 West 44th Street, New York 36, N.Y., 1957.

Electrocardiographic tracings were made on a Burdick EK III* using a paper speed of 25 mm./second. Only limb leads were used and the recordings were taken before and during CO_2 administration.

Blood pressures were taken directly from the carotid artery which had previously been permanently implanted beneath the skin by surgical procedures. For pressure determinations a 16 gauge 1½ inch hypodermic needle was inserted into the carotid artery with the point directed towards the heart. This needle was connected to a mercury manometer and the blood pressure was recorded in millimeters of mercury. A series of blood pressure determinations were taken prior to any experimentation in order to establish normal ranges. Blood pressures were also taken during CO_2 administration.

Frequency and depth of respiration were recorded immediately prior to and during CO_2 administration using a Watson-Bird Variable Speed Kymograph 70-142** (Figure 6). Kymograph paper speed used for this work was 25 mm/sec.

The hydrogen ion concentration of arterial blood was determined on a Beckman pH meter, Model H-2*** using

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*Operating Manual EK III-858 for the Burdick EK III Dual-Speed Electrocardiograph, Aug., 1958.

**Tools for Biophysics, Catalog No. 5-60, Phipps and Birds, Inc., Silver Spring, Maryland.

***Beckman--Bulletin 190-B, Feb., 1948, National Technical Labs, South Pasadena, California.

a special blood electrode assembly (X 800-5) with a flow chamber.

Total erythrocyte and leukocyte counts were made on the improved Neubauer Sharpline Hemocytometer.* The blood smears for differential counts were stained with Wright stain. The packed cell volumes were read from micro-capillary tubes.

Rectal temperatures were taken before and during CO_2 administration. The corneal reflexes were tested by touching the cornea with a moistened finger and cutaneous pain reflexes by pricking the skin between the toes with a needle or by pinching with a forceps.

Each calf was subjected to CO_2 administration three times with intervening intervals varying from 2 to 8 days.

During CO_2 administration, a claw amputation was attempted on two calves and on one calf a 3 inch skin incision was made on the lateral surface of the foreleg (over the radius) and sutured.

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*Sharpline Hemocytometer, Improved Neubauer Ruling, Chicago Apparatus Co., Chicago, Ill.

Figure 5. Electrocardiograph Burdick EK III

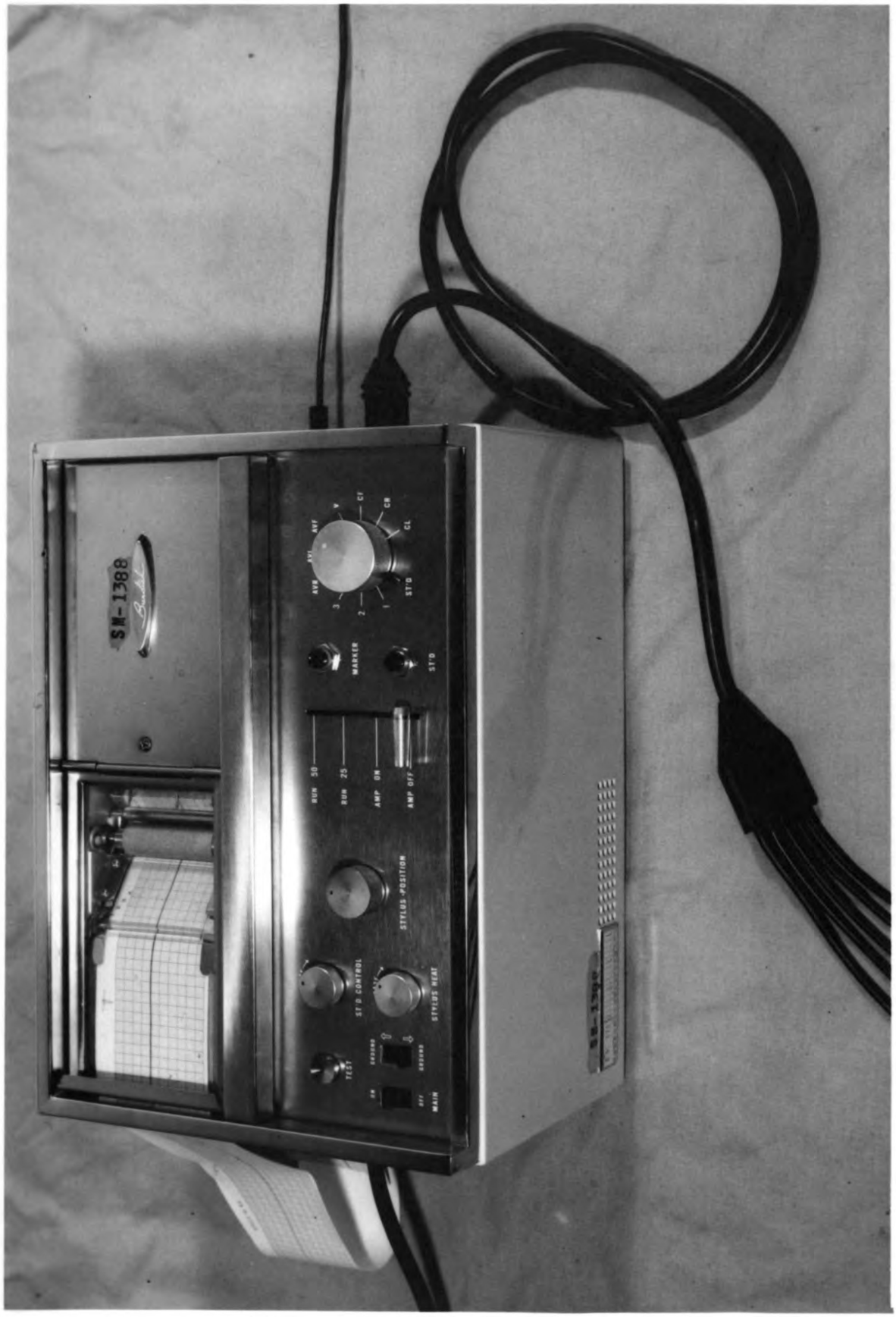
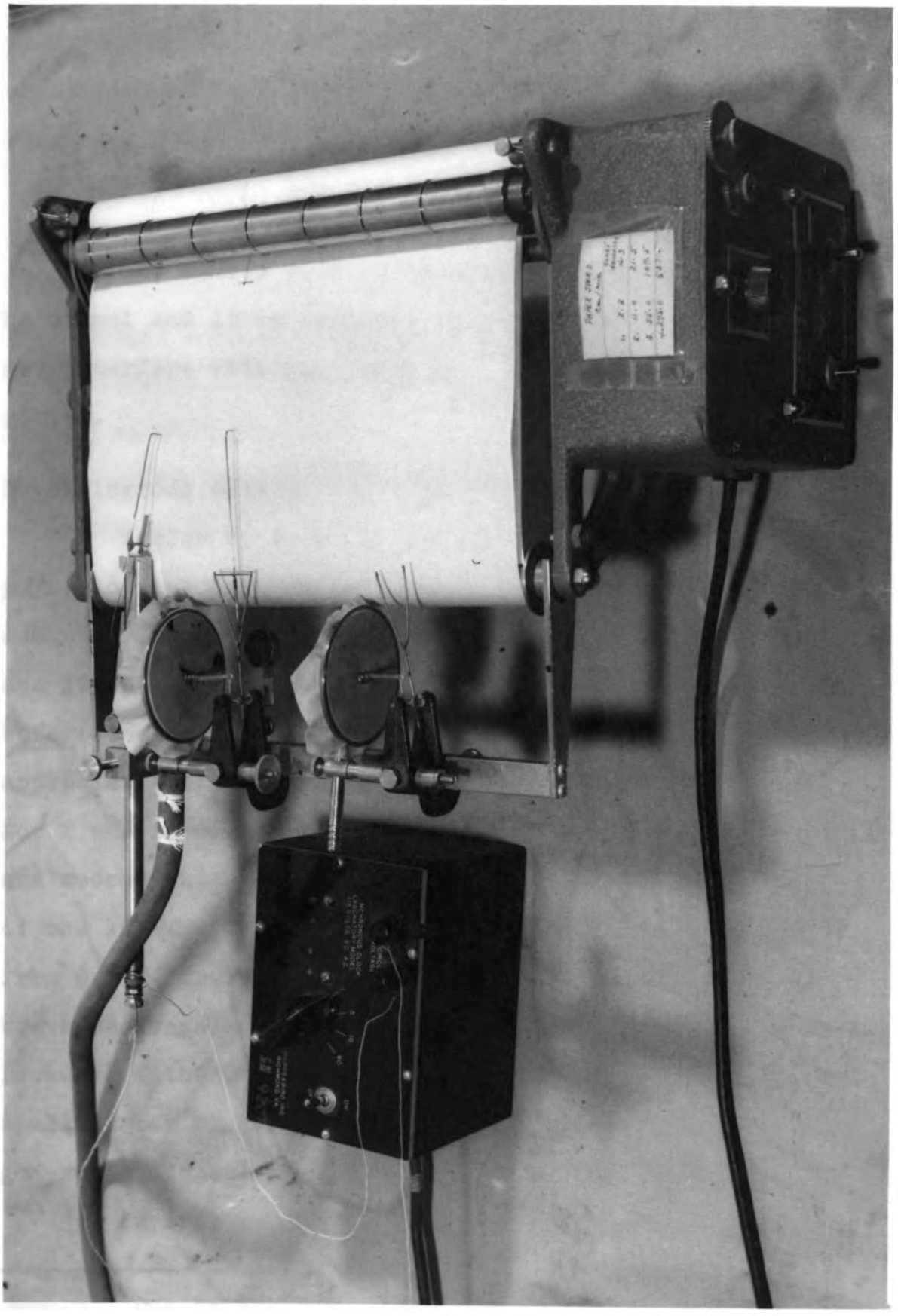

SR-1388
Beckman
MARKER
ST'D
RUN 50
RUN 25
AMP ON
AMP OFF
STYLUS POSITION
ST'D CONTROL
STYLUS HEAT
TEST
MAIN
AVF
V
CF
CM
CL
ST'D
AVR
1
2
3

Figure 6. Watson-Bird Variable Speed Kymograph 70-142



CHAPTER IV

RESULTS AND DISCUSSION

The calves used in this study were considered to be normal and it is believed that their health status did not interfere with the investigational results herein reported.

Physiological data

Tables 2, 4, 6, 8, and 10 show the experimental physiological data on each of the five calves. Before CO_2 administration, the rectal temperatures varied between 101.0 and 103.0 F. The temperature of each calf taken 5 minutes before the end of CO_2 administration did not reveal any appreciable elevation. However, the temperature of calf No. 2 was increased during the first (102.6 F. to 104.8 F.) and second experiments (102.4 F. to 103.8 F.). During 7 of the 15, there was an increase of temperature ranging from 0.1 F. to 0.7 F. In the remaining experiments, there was a decrease of temperature varying from 0.2 F. to 1.2 F. Because of the variations of temperatures observed and the small number of animals used, it is difficult to make a general statement regarding the effect of CO_2.

Superficial observation of the pneumograms* (Figs.

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*Due to the similarity of the pneumograms only one is presented for each calf (recorded during first experiment).

7, 8, 9, 10, 11) might lead one to believe that the respiratory rates during CO_2 anesthesia were increased. But actually, the rates were often the same as before CO_2 administration. However, there was a marked increase in the depth of the respiratory movement. Best and Taylor (1961) state that an excess of CO_2 in circulating blood depresses the respiratory center resulting in a decrease of respiratory rate. Before the CO_2 administration, the respiratory frequency varied between 20 and 60 per minute; during CO_2 administration it varied between 36 and 60. The most significant increase in respiratory rate was seen on calf No. 4 (Table 8, Fig. 10) where there was an increase from 20 to 44 during second experiment and from 28 to 40 during the third experiment. Also Calf No. 5 showed an increase from 24 to 48 during the second experiment.

The most significant findings of the physiological data were those pertaining to the heart rate, blood pressure, and blood pH during CO_2 administration. The heart rate on each animal increased during CO_2 administration. This increase varied from 40 to 120 beats per minute. The most marked increase was on Calf No. 2 (Table 4 and Fig. 12) during the first experiment (from 80 to 200). The increased heart rate is mainly due to the effect of CO_2 upon cardiac and vasomotor centers, and directly on the cardiovascular musculature (Best and Taylor, 1961).

The pH of venous blood decreased on each animal

during CO_2 administration. This was apparently the result of increased amounts of carbonic acid in the blood. This fall varied between 0.3 and 1.1. Pertaining to this decrease, it is noteworthy to state that the junctional tissues are particularly sensitive to high tensions of CO_2 and auriculo-ventricular conduction becomes markedly depressed when the CO_2 excess is sufficient to cause a fall in pH of the fluids bathing the cardiac muscle fibers. At a pH of around 7.0 complete heart block occurs in human beings (Best and Taylor, 1961). The excessive fall in blood pH is probably a disadvantage to the use of CO_2 in calves as a surgical anesthetic. However, there did not appear to be any serious toxic effect during the experiments.

The blood pressures also increased during experiments on each animal. According to Best and Taylor (1961) this increase is a result of high CO_2 tension in venous blood coming into the heart, thus enhancing the extensibility of the cardiac muscle fiber during diastole, and in consequence, exerts a more favorable effect upon the filling of the heart. The cardiac output is therefore increased and the hypertonicity of the vasoconstrictor center results in a high blood pressure. The highest increase was from 170 to 282 mm. Hg. on Calf No. 2 (Table 4) during the third experiment, and the smallest increase was on Calf No. 5 (Table 10) during the third experiment (from 157 to 170 mm. Hg.). In the

remaining experiments, the blood pressure increase ranged from 21 to 84 mm. Hg. above the recordings taken prior to CO_2 administration.

The corneal reflex was present on each animal with the exception of partial abolishment on Calf No. 1 during the first and second experiments. The cutaneous pain reflexes were abolished on Calf No. 1 during first and second experiments. During the balance of the experiments, cutaneous pain reflexes were either partially abolished (forelegs or hindlegs), or were present.

Hematological findings

The results of the hematological findings are presented in Tables 1, 3, 5, 7, and 9. The hematocrit (Hct.) values varied between 27 and 36.5% in all calves before CO_2 administration. During CO_2 administration in the first trials on each animal there was an increase in RBC counts varying from 290,000 to 3,840,000/mm^3. As an example, in Calf No. 5 (Table 9), the Hct. value remained constant during the experiment but the RBC count increased from 8,190,000 to 10,380,000. This picture may indicate that a new supply of RBC's entered the blood stream but that they were apparently smaller in size. A similar observation was made on Calf No. 3 (Table 5) which also shows an increase of RBC's from 7,020,000 to 10,860,000 with only a slight increase in Hct. (27.5 to 29%). In the remainder of the experiments there was no consistent increase or decrease in RBC counts.

The WBC counts before CO_2 administration varied between 5,700 and 13,200/mm^3. During CO_2 administration, the counts ranged from 5.760 to 13.000/mm^3. The foregoing WBC counts are generally considered to be the normal values. Inconsistent variations in WBC counts may be noted before and during CO_2 administration.

Electrocardiographic findings

The electrocardiograms* (Figs. 11, 12, 13, 14, and 15) were taken with the calves in the standing position before starting the experiments and in a recumbent position during CO_2 administration. All recordings were from Lead I.

In this study with calves in the standing position P waves were positive on Calf Nos. 1, 2, 3, and 4 (Figs. 11, 12, 13, and 14) and diphasic on Calf No. 5 (Fig. 15). As is known, the P wave is variable in dairy calves, at times diphasic in Lead I and sometimes inverted (Ardsel, Kreger, and Bogart, 1959), or positive (Platner, Kibler, and Brody, 1948). The PR interval varied between 0.132 and 0.182 seconds in all calves. These data are similar to the results obtained by Platner, Kibler, and Brody (1948) who reported intervals of 0.133 to 0.167 seconds.

During CO_2 administration with the calves in left lateral recumbency there was a significant change in the P

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*Due to the similarity of electrocardiographic recordings only one is presented for each calf (recorded during first experiment).

wave and the PR interval in all calves as follows:

Calf Nos. 1 and 2 (Figs. 11 and 12, Tables 13 and 14). In Calf No. 1 the T wave was superimposed on the P wave whereas the P wave almost disappeared on Calf No. 2. The PR interval showed a variation between 0.14 and 0.16 seconds and widened on Calf No. 1. This picture together with the results on Calf No. 2 may indicate a possible current injury of heart muscle. Both recordings present evidence of tachycardia.

Calf No. 3 (Fig. 13 and Table 15). The P wave for this calf is superimposed by the T wave, and there is an increase (up to 0.20 sec.) in the PR interval. This increase in the PR interval is sufficient to cause one beat to drop out. This picture reveals a special type of partial AV block, sometimes referred to in man as the Wenchebach phenomena. It occurs when the PR interval increases in length with each successive cardiac cycle until the impulse, originating in the SA node, is completely blocked at the AV node and fails to initiate a QRS complex (Burch and Winsor, 1960).

Calf Nos. 4 and 5 (Figs. 14 and 15, Tables 16 and 17). The P wave on Calf No. 4 was absent. On Calf No. 5 a pre-anesthetic diphasic P wave changed to a monophasic wave with a positive deflection during CO_2 administration. Also, the PR interval increased on Calf No. 5 (0.20 to 0.22 sec.).

Before CO_2 administration the QRS complex was diphasic on Calf Nos. 1, 2, and 4 (Figs. 11, 12, and 14; Tables 13, 14, and 16), and positive on Calf Nos. 3 and 5 (Figs. 13 and 15; Tables 15 and 17). Arsel III, Krueger and Bogart (1959) reported similar findings. The QRS interval showed a variation between 0.04 and 0.072 second which is similar to the results reported by Platner, Kibler and Brody (1948).

During CO_2 administration, the QRS complex showed a negative deflection and amplitudes were increased on all calves. During the same time the QRS interval increased during each experiment ranging from 0.01 to 0.028 seconds with one exception--Calf No. 5--during the second experiment in which there was no change in the QRS interval.

Prior to CO_2 anesthesia the T wave was positive on Calf No. 1 (Fig. 11), and negative on Calf Nos. 2, 4, and 5 (Figs. 12, 14, and 15), and there was no T wave on Calf No. 3 (Fig. 13). During the same time the QT interval showed a variation of 0.28 to 0.36 seconds which resembled the results obtained by Platner and his colleagues (1948).

Observations on anesthetic effect of CO_2

As was pointed out in Chapter II, 100% CO_2 has been used to put calves down in lateral recumbency. Near the beginning of each CO_2 administration most calves coughed once or twice and became recumbent within 25 to 37 seconds. There was an absence of struggling in Calves No. 1, 2, 3,

and 4 with the following exceptions: Calves No. 2 and 4 during the second experiment struggled intermittently. Calf No. 5 struggled intermittently during each of the three experiments.

During this series of 15 CO_2 administrations the calves occasionally emitted a slight bellowing, passed feces, and showed some involuntary movements of limbs. At the end of some of the experiments there were blood stains mixed with nasal discharge in the inhalation mask.

In an evaluation of the anesthetic effect of 65% CO_2 and 35% O_2 for surgical procedures, a 12 cm. skin incision was made on the forelimb over the radius (lateral surface) of Calf No. 4. The incision was made and suturing was accomplished without the calf showing any evidence of pain.

Two attempts were made to perform a claw amputation operation on two calves while under the influence of 65% CO_2 and 35% O_2. There was not sufficient desensitization of the interdigital skin to permit this surgery.

Table 1. Hematological findings, Calf No. 1

Experiment		Hct. %	RBC 10^6	WBC 10^3	Differential Count* Neut. %	Lymph. %	Mono. %	Eosin. %
1st	Before	27.0	6.52	6.55	25	67	3	5
	During**	28.0	6.81	7.00	4	89	4	3
2nd	Before	29.0	6.47	7.15	8	88	4	0
	During	34.5	8.56	8.30	6	91	1	2
3rd	Before	35.0	6.65	5.70	18	79	2	1
	During	36.5	6.65	5.76	21	74	2	3

Table 2. Physiological data, Calf No. 1

Experiment		Duration*** /min.	Temp. F.	Resp. rate /min.	Heart rate /min.	Blood pres. mm.Hg.	pH	Reflexes Cornea	Skin
1st	Before		102.4	52	100	166	7.1		
	During**	17	102.5	38	160	200	6.6	PA	A
2nd	Before		102.4	36	100	166	6.9		
	During	20	102.6	40	150	210	6.6	PA	A
3rd	Before		101.1	52	80	166	7.4		
	During	45	101.8	36	120	250	6.4	P	PA

*Basophils were not observed on the blood smears.
**Taken 5 minutes before the end of CO_2 administration.
***Duration of CO_2 administration.

Legend:

A--Abolished; PA--Partially abolished; P--Present.

Table 3. Hematological findings, Calf No. 2

Experiment	Hct. %	RBC 10^6	WBC 10^3	Differential Count* Neut. %	Lymph. %	Mono. %	Eosin. %
Before 1st	29.0	5.78	8.35	25	72	2	1
During**	30.0	7.11	12.55	36	60	4	0
Before 2nd	27.0	6.65	6.60	20	78	1	1
During	27.0	6.35	10.45	18	82	0	0
Before 3rd	29.0	6.45	6.30	26	70	4	0
During	31.0	7.10	6.73	28	68	4	0

Table 4. Physiological data, Calf No. 2

Experiment	Duration*** /min.	Temp. F.	Resp. rate /min.	Heart rate /min.	Blood pres. mm. Hg.	pH	Reflexes Cornea	Skin
Before 1st		102.6	42	80	170	7.5		
During	21	104.8	44	200	212	6.6	P	PA
Before 2nd		102.4	60	80	170	6.9		
During	30	103.8	48	120	194	6.5	P	P
Before 3rd		101.6	52	80	170	7.3		
During	27	101.2	56	110	282	5.6	P	PA

*Basophils were not observed on the blood smears.
**Taken 5 minutes before the end of CO_2 administration.
***Duration of CO_2 administration.

Legend:

P--Present; PA--Partially abolished.

Table 5. Hematological findings, Calf No. 3

Experiment	Hct. %	RBC 10^6	WBC 10^3	Differential Count* Neut. %	Lymph. %	Mono. %	Eosin. %
Before 1st	27.5	7.02	13.20	42	53	1	4
During**	29.0	10.86	10.10	49	41	1	9
Before 2nd	28.0	6.16	10.60	19	77	3	1
During	27.0	5.26	13.00	12	84	2	2
Before 3rd	32.0	7.06	11.25	44	55	1	0
During	32.0	6.40	11.45	40	55	3	2

Table 6. Physiological data, Calf No. 3

Experiment	Duration*** /min.	Temp. F.	Resp. rate /min.	Heart rate /min.	Blood pres. mm. Hg.	pH	Reflexes Cornea	Skin
Before 1st		102.4	44	60	178	7.2		
During	30	102.2	44	90	223	6.6	P	PA
Before 2nd		102.6	32	60	178	7.1		
During	22	103.0	52	100	212	6.5	P	PR
Before 3rd		102.0	40	60	178	7.3		
During	27	102.6	38	120	250	6.2	P	PR

*Basophils were not observed on the blood smears.
**Taken 5 minutes before the end of CO_2 administration.
***Duration of CO_2 administration.

Legend:

P--Present; PA--Partially abolished; PR--Partially abolished rear legs.

Table 7. Hematological findings, Calf No. 4

Experiment	Hct. %	RBC 10^6	WBC 10^3	Differential Count* Neut. %	Lymph. %	Mono. %	Eosin. %
Before 1st	35.0	8.19	10.80	8	91	0	1
During**	36.5	10.38	7.90	11	87	1	1
Before 2nd	28.0	7.70	9.10	24	76	0	0
During	35.0	13.35	8.14	24	76	0	0
Before 3rd	32.0	8.08	11.45	16	82	2	0
During	33.0	8.09	11.25	25	72	2	0

Table 8. Physiological data, Calf No. 4

Experiment	Duration*** /min.	Temp. F.	Resp. rate /min.	Heart rate /min.	Blood pres. mm. Hg.	pH	Reflexes Cornea	Skin
Before 1st		102.4	36	90	174	7.7		
During	42	101.2	52	140	224	7.0	P	PA
Before 2nd		102.6	24	96	174	7.5		
During	25	102.4	48	148	210	6.7	P	P
Before 3rd		101.8	28	90	174	7.3		
During	18	101.2	32	140	220	7.0	P	PF

*Basophils were not observed on the blood smears.
**Taken 5 minutes before the end of CO_2 administration.
***Duration of CO_2 administration.

Legend:

P--Present; PA--Partially abolished; PF--Partially abolished forelegs.

Table 9. Hematological findings, Calf No. 5

Experiment	Hct. %	RBC 10^6	WBC 10^3	Differential Count* Neut. %	Lymph. %	Mono. %	Eosin. %
Before 1st	36.5	8.19	10.80	8	91	0	1
During**	36.5	10.38	7.90	10	89	1	0
Before 2nd	30.5	9.49	10.20	13	84	2	1
During	31.0	9.77	9.40	10	86	3	1
Before 3rd	30.0	8.25	10.50	18	78	2	2
During	32.0	10.30	8.45	23	75	2	0

Table 10. Physiological data, Calf No. 5

Experiment	Duration*** /min.	Temp. F.	Resp. rate /min.	Heart rate /min.	Blood pres. mm. Hg.	pH	Reflexes Cornea	Skin
Before 1st		102.0	52	70	157	7.6		
During	40	101.0	60	140	210	7.1	P	P
Before 2nd		101.8	20	100	157	7.6		
During	15	101.6	44	144	178	6.9	P	P
Before 3rd		101.6	28	70	157	7.4		
During	23	101.4	40	130	170	6.7	P	P

*Basophils were not observed on the blood smears.
**Taken 5 minutes before the end of CO_2 administration.
***Duration of CO_2 administration.

Legend:

P--Present.

Table 11. Electrocardiographic findings, Calf No. 1

Experiment		PR interval sec.	QRS interval sec.	QT interval sec.
1st	Before	0.14	0.072	0.28
	During	0.16	0.080	0.22
2nd	Before	0.15	0.048	0.28
	During	0.16	0.080	0.23
3rd	Before	0.16	0.072	0.32
	During	0.16	0.080	0.24

Table 12. Electrocardiographic findings, Calf No. 2

Experiment		PR interval sec.	QRS interval sec.	QT interval sec.
1st	Before	0.16	0.040	0.35
	During	No P wave	0.052	0.20
2nd	Before	0.14	0.044	0.32
	During	No P wave	0.072	0.24
3rd	Before	0.16	0.040	0.30
	During	No P wave	0.064	0.20

Table 13. Electrocardiographic findings, Calf No. 3

Experiment		PR interval sec.	QRS interval sec.	QT interval sec.
1st	Before	0.180	0.040	No T wave
	During	0.13-0.20	0.080	0.28
2nd	Before	0.182	0.040	No T wave
	During	0.13-0.20	0.070	0.28
3rd	Before	0.180	0.040	No T wave
	During	No P wave	0.078	0.30

Table 14. Electrocardiographic findings, Calf No. 4

Experiment		PR interval sec.	QRS interval sec.	QT interval sec.
1st	Before	0.160	0.060	0.36
	During	No P wave	0.070	0.28
2nd	Before	0.160	0.048	0.32
	During	Not recorded*		
3rd	Before	0.168	0.048	0.35
	During	No P wave	0.080	0.28

*Because of the movements of calf.

Table 15. Electrocardiographic findings, Calf No. 5

Experiment		PR interval sec.	QRS interval sec.	QT interval sec.
1st	Before	0.140	0.080	0.328
	During	0.220	0.128	0.360
2nd	Before	0.132	0.080	0.320
	During	0.200	0.080	0.360
3rd	Before	0.128	0.080	0.340
	During	Not recorded*		

*Because of the movement of calf.

Figure 7. Pneumogram, Calf No. 1

A. Before CO_2 administration

B. During CO_2 administration

C. Time interval 1 sec.

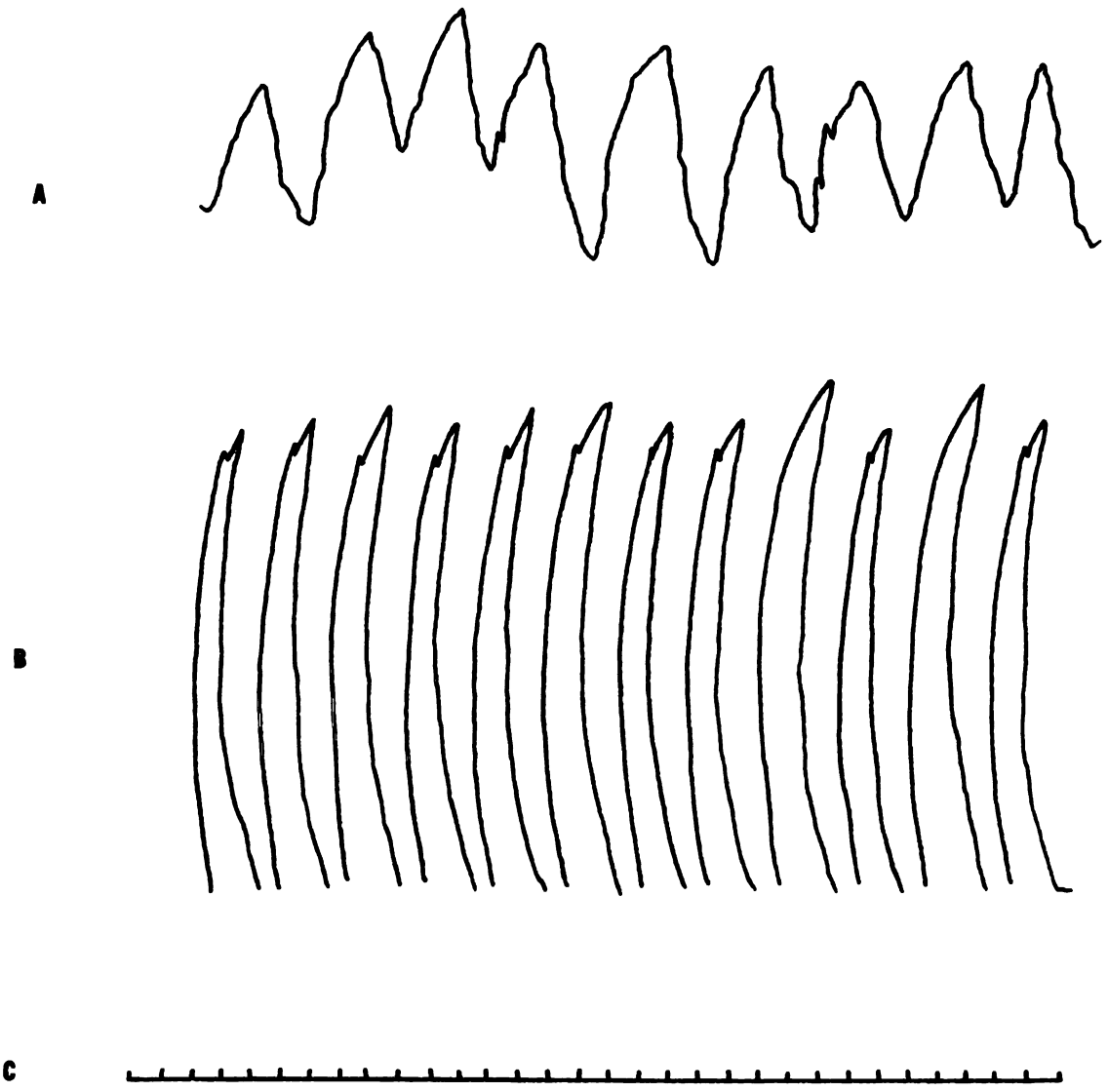

A
B
C

Figure 8. Pneumogram, Calf No. 2

A. Before CO_2 administration

B. During CO_2 administration

C. Time interval 1 sec.

Figure 9. Pneumogram, Calf No. 3

A. Before CO_2 administration

B. During CO_2 administration

C. Time interval 1 sec.

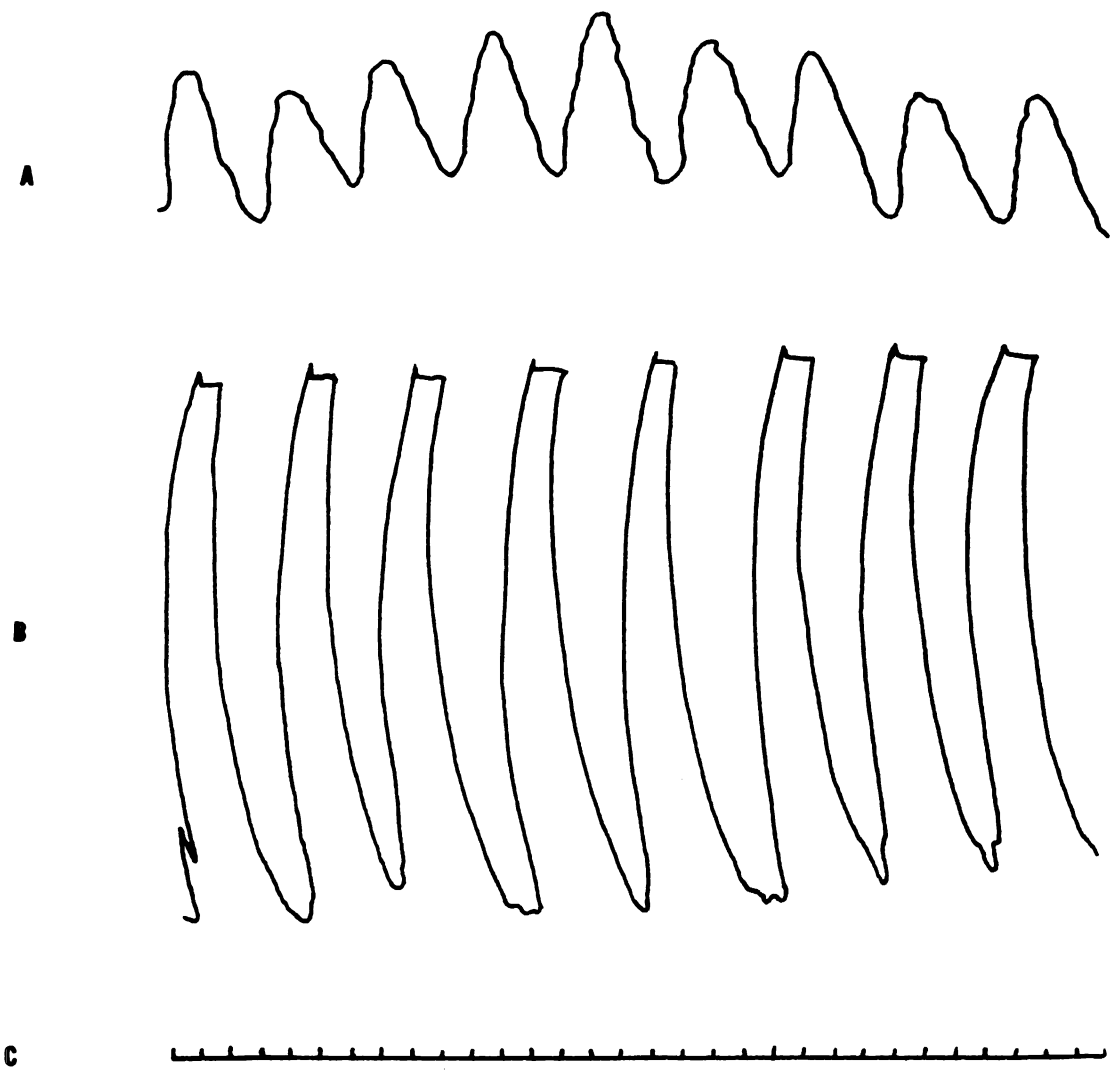

A
B
C

Figure 10. Pneumogram, Calf No. 4

A. Before CO_2 administration

B. During CO_2 administration

C. Time interval 1 sec.

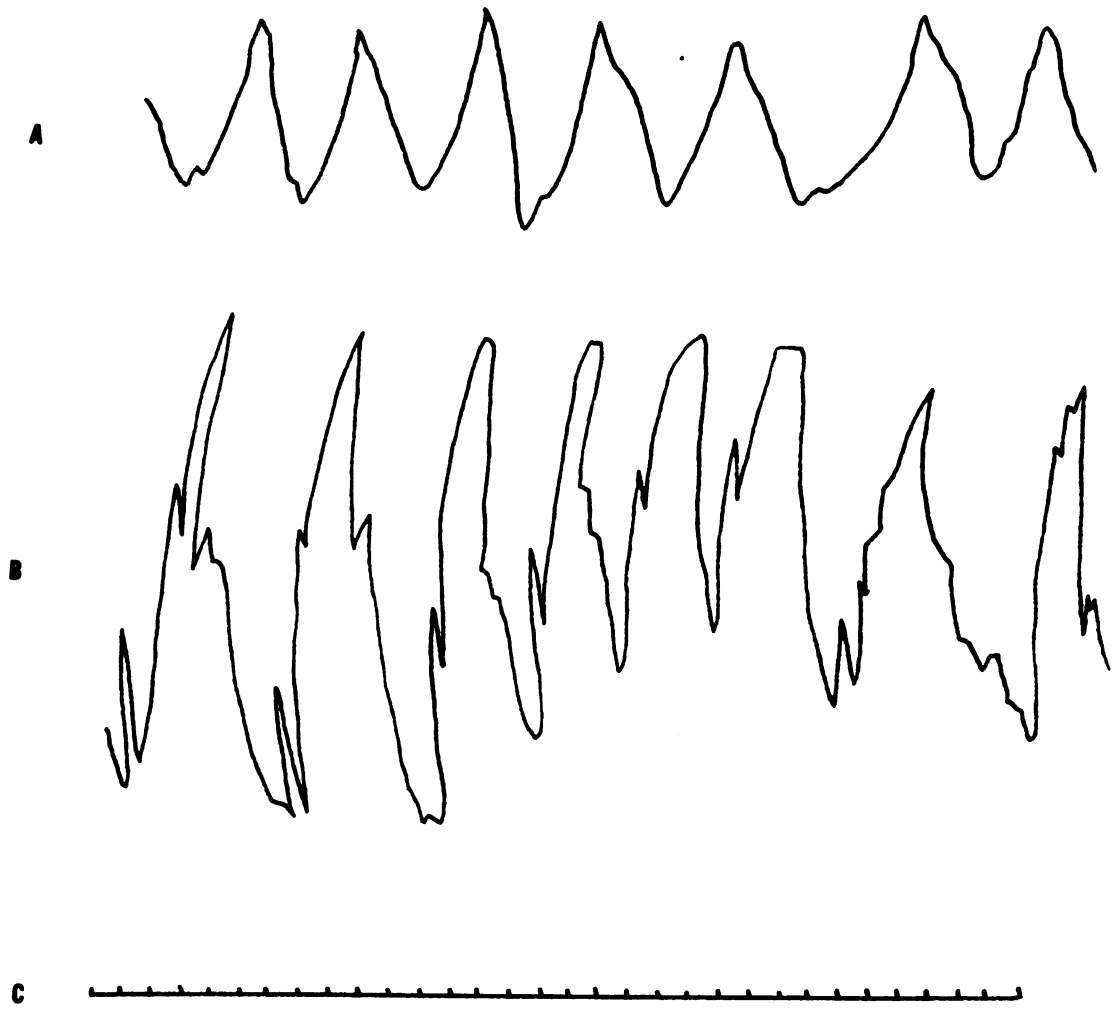

A
B
C

Figure 11. Pneumogram, Calf No. 5

A. Before CO_2 administration

B. During CO_2 administration

C. Time interval 1 sec.

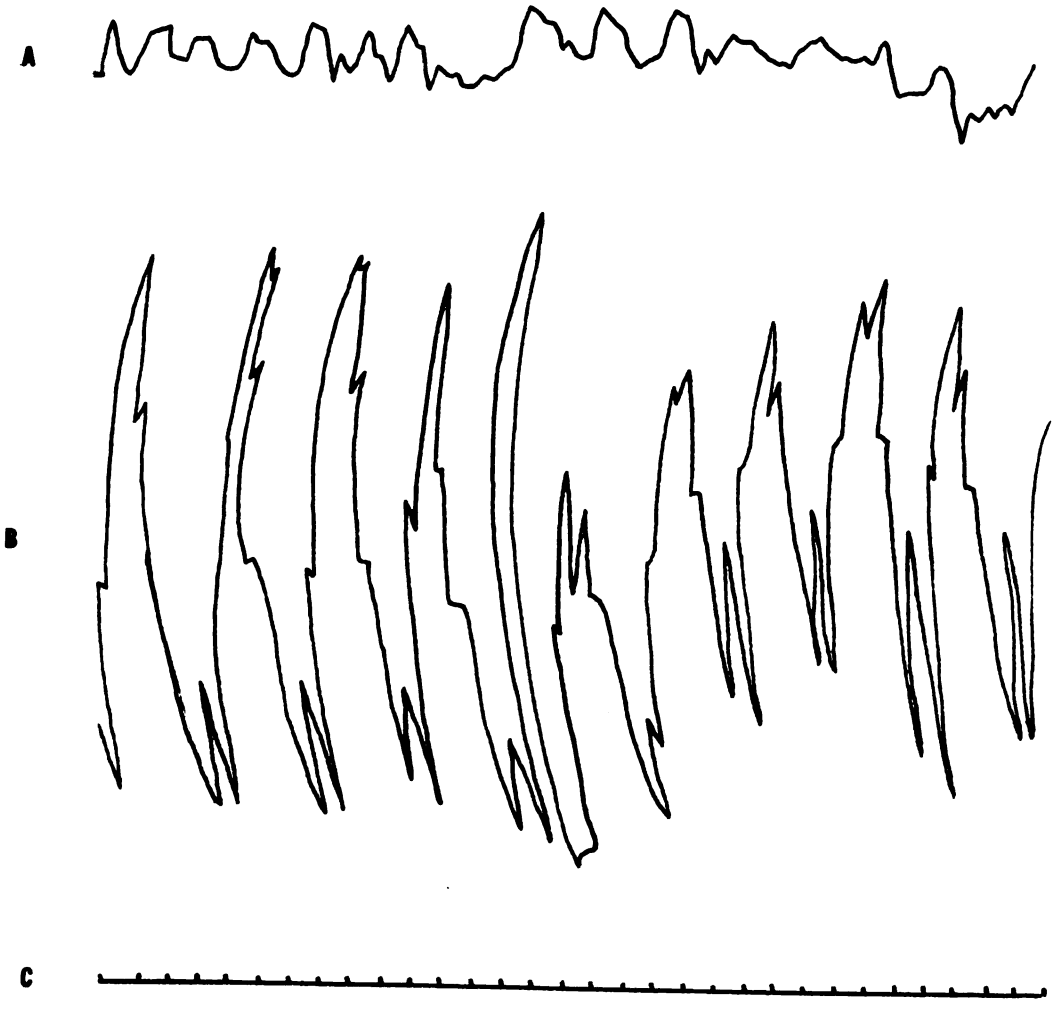

A
B
C

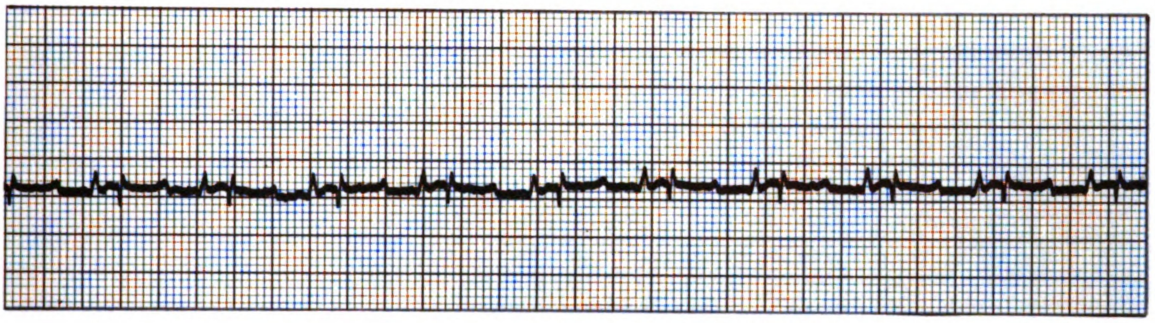
Figure 12. Electrocardiogram, Calf No. 1

A. Before CO_2 administration

B. During CO_2 administration

(Five large squares represent a time interval of 1 sec.)

A



B

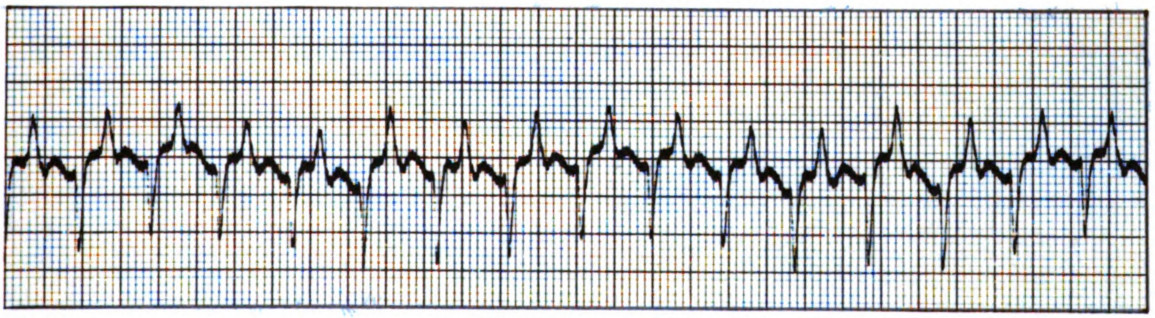


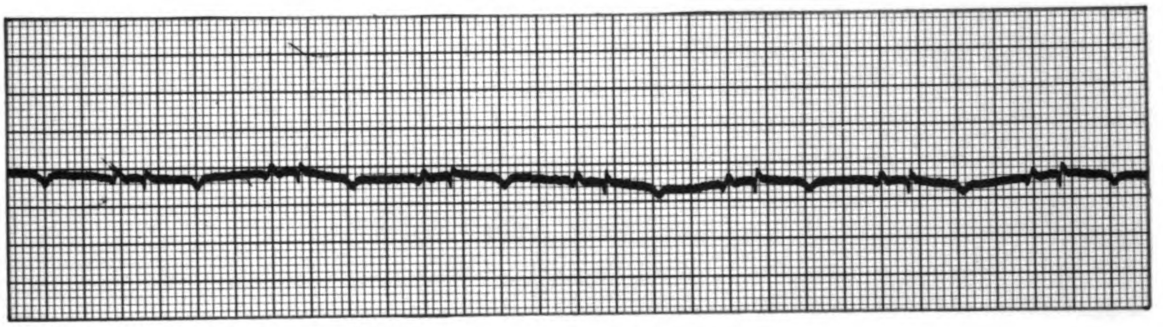
Figure 13. Electrocardiogram, Calf No. 2

A. Before CO_2 administration

B. During CO_2 administration

(Five large squares represent a time interval of 1 sec.)

A



B

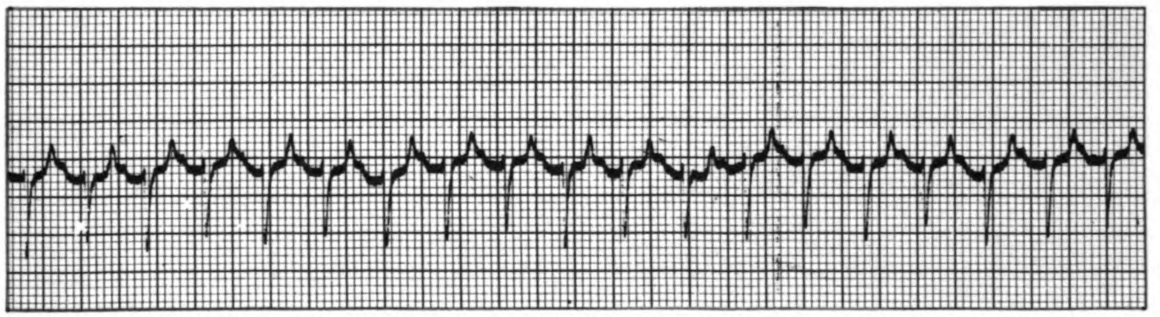


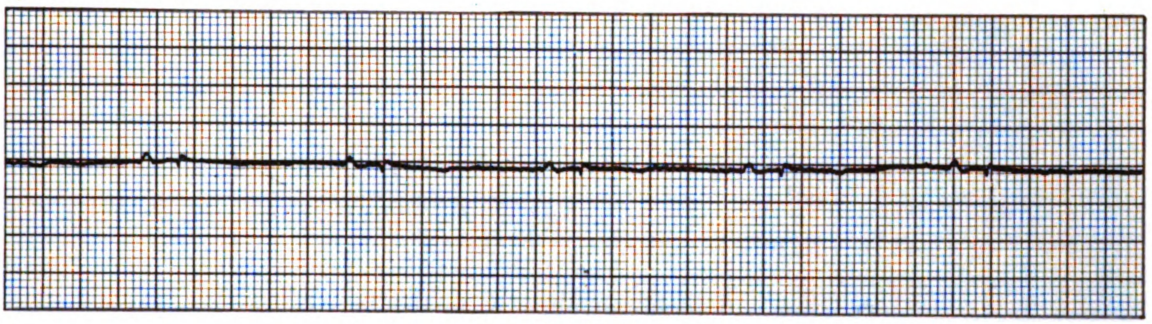
Figure 14. Electrocardiogram, Calf No. 3

A. Before CO_2 administration

B. During CO_2 administration

(Five large squares represent a time interval of 1 sec.)

A



B

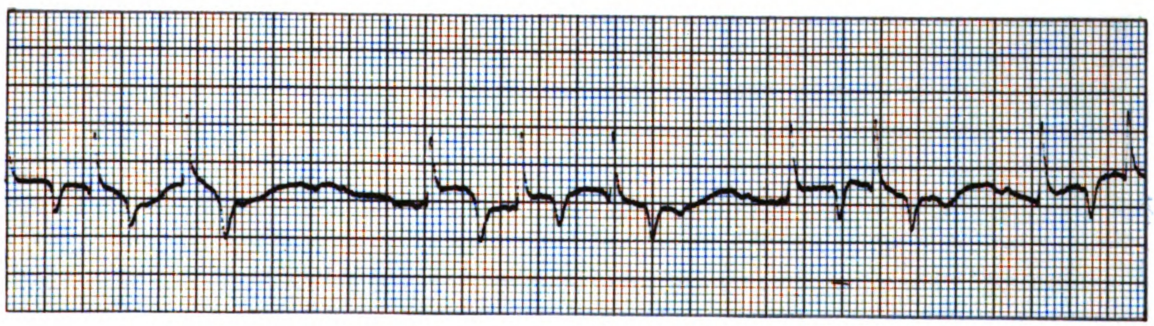


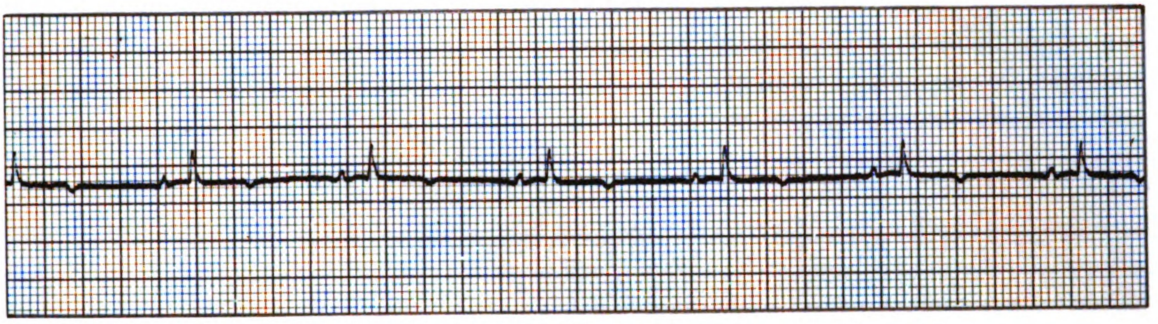
Figure 15. Electrocardiogram, Calf No. 4

A. Before CO_2 administration

B. During CO_2 administration

(Five large squares represent a time interval of 1 sec.)

A



B

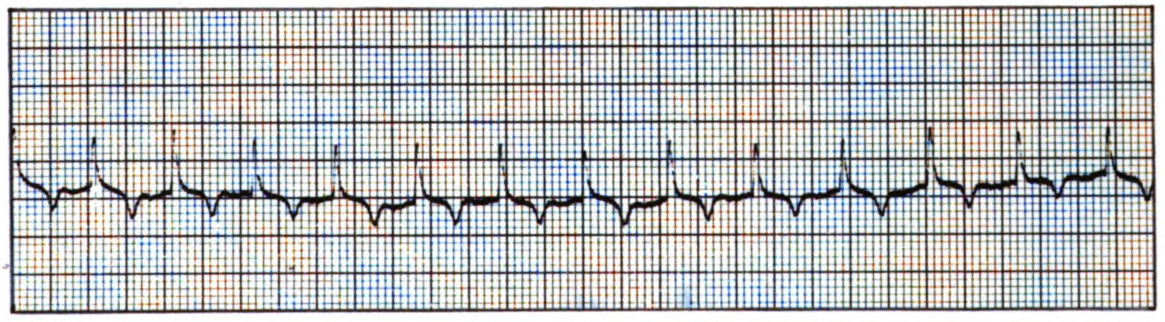


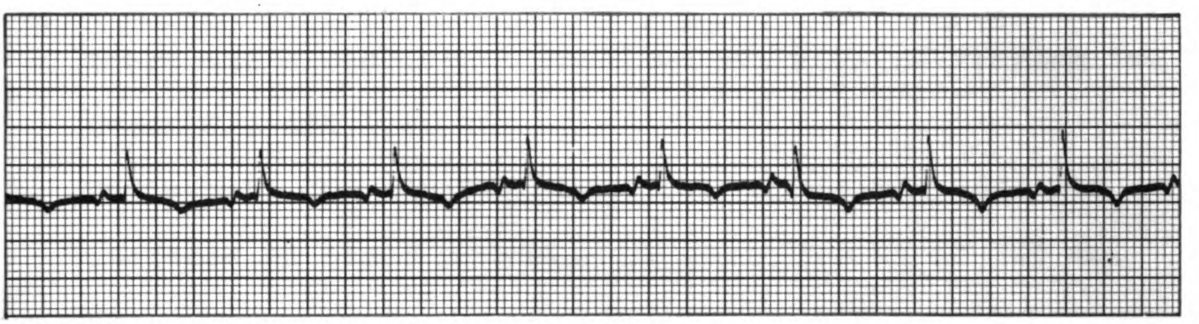
Figure 16. Electrocardiogram, Calf No. 5

A. Before CO_2 administration

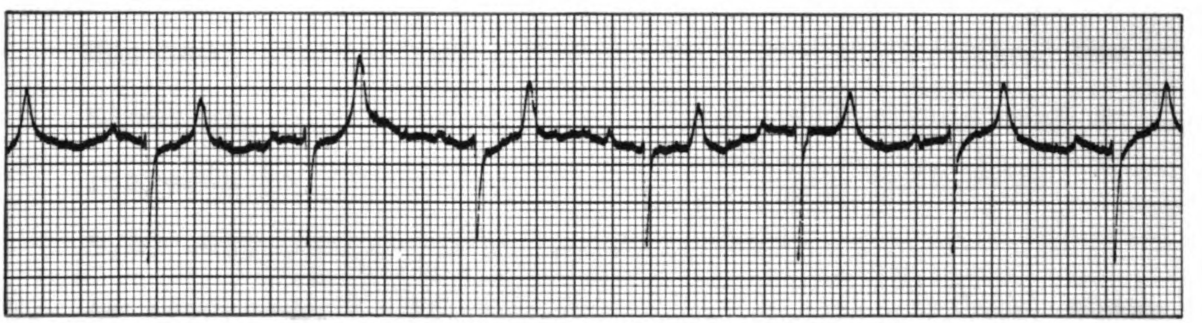
B. During CO_2 administration

(Five large squares represent a time interval of 1 sec.)

A



B



CHAPTER V

SUMMARY

1. During the administration of 65% CO_2 and 35% O_2 to calves, there was a consistent decrease of blood pH varying between 0.3 and 1.1.
2. During all CO_2 administrations, there was a definite increase in blood pressure ranging from 13 to 112 mm. Hg.
3. The heart rate showed an increase between 30 and 120 beats per minute.
4. The hematological studies conducted during CO_2 administration revealed only minor fluctuations from the values determined before the administration of CO_2. The most significant fluctuation was noted during the first CO_2 experiments on each calf where there was an increase in the RBC count varying from 290,000 to 3,800,000 cells per cubic millimeter.
5. As evidenced by the electrocardiographic studies, there appeared to be a significant change in the conduction system of the heart during CO_2 administration. Tachycardia, possible heart injury, and on one calf (No. 3; Fig. 13), the Wenchebach phenomena (partial AV block), were observed on the electrocardiograms.

6. During CO_2 anesthesia, the depth of respiratory movements increased but the rate did not appreciably change.
7. The corneal reflex was present during CO_2 anesthesia. Cutaneous pain reflexes were sometimes absent, at other times present, especially in the interdigital areas.
8. Rectal temperatures did not reveal any consistent decrease or increase during CO_2 administration.
9. The nasal discharges of 3 calves contained small amounts of blood noticed upon completion of CO_2 administration.
10. Calves would not fall into lateral recumbency when CO_2 was administered in concentrations of 65 or 80%, in combination with either O_2 or air.

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