

**THE EFFECTS AND CHARACTERISTICS OF INCREASED
RESPIRATORY DEAD SPACE IN DOGS**

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FOREWORD

This report was prepared under Contract No. AF 33(616)-6261. The work was performed in support of Project No. 7163, "Physiology Research, " Task No. 71819, "Studies in Mammalian Respiratory Functions." The work was accomplished by the Department of Medicine and Surgery of the University of North Carolina School under the direction of Dr. Thomas B. Barnett and Dr. Richard M. Peters. Dr. Raymond F. Kline of the Respiration Section, Physiology Branch, Aerospace Medical Division, served as contract monitor.

ABSTRACT

Artificial breathing apparatus such as oxygen masks involves added external respiratory dead space. In dogs with permanent tracheostomies, chronic increase in dead space has been maintained with lengths of 0.75-inch interior diameter vinyl plastic tubing. A dead space of 20-30 cc./kg. is not tolerated for more than 24 hours. The amount of mixing and air streaming within this tubing and in tubing of 0.5-inch interior diameter and 1.5-inch interior diameter was determined. There was very little mixing in the two smaller tubes but, in the large one, the amount of mixing was significant.

PUBLICATION REVIEW



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Contrails

INTRODUCTION

We have developed a method of maintaining permanent tracheostomies in dogs to which large volumes of respiratory dead space can be added. In addition, ventilatory studies can be done with ease in these dogs. Mixing of air within the dead space was studied and the tolerable limits of added dead space were determined.

A. STUDY OF MIXING WITHIN THE DEAD SPACE TUBING

Method

In the original contract it was proposed to use two Liston-Beckman infrared CO₂ analyzers; one of these to measure the gas front either as it entered the dead space or at the tracheostomy and the other at different levels along the tube. Flow and volume were to be simultaneously recorded, flow with an electronic flowmeter and volume by electrical integration of this signal. This method of study proved unsatisfactory because of the slow response time of the CO₂ analyzer. This slow response time made it possible to analyze only the plateaus on the curve. Therefore, mixing could not be evaluated. After considerable effort had been invested in attempts to overcome these difficulties it was decided to attempt other methods of recording. A Custom Engineering and Development Company nitrogen analyzer was then tried. This necessitated the substitution of a breath of oxygen for the endogenous indicator gas carbon dioxide. For this reason it was necessary to use human subjects who could cooperate.

Figure 1 demonstrates the method of study finally worked out. The tube to be studied had nine needle holes at equal intervals along its length. One end of the tube was connected to a Y tube, one arm of which could be open to the air and the other to a bag containing 100% oxygen. Near the subject or spirometer was a parallel plate flowmeter. A Custom Engineering and Development Company nitrogen analyzer with a response time of less than 0.05 second was used to measure the nitrogen concentration. The sensing needle was introduced into one of the nine needle holes for serial sampling of the different breaths. The output of the nitrogen analyzer and flowmeter was fed into an Offner recorder and the signal from the flowmeter was electronically integrated to give volume. The subject then breathed through the tubing and, at the end of an expiration, clamp No. 2 was closed and No. 1 removed before the next inspiration. This process allowed the subject to take in a breath of oxygen. The front that this oxygen presented to the nitrogen analyzer was recorded, together with the flow and volume. In one group of experiments an electronic spirometer was used rather than a human subject. The tracings were then analyzed to determine the percent of nitrogen at different inspired volumes, as illustrated graphically in Figure 2. The concentration of nitrogen is shown on the vertical axis and the volume inspired minus the volume from the oxygen source to the nitrogen pickup on the horizontal axis. The heavy line illustrates the recording at the point nearest the oxygen source and, in essence, represents the type of front presented to the rest of the tubing. When the concentration of oxygen falls on the negative side of the volume graph, this represents a deviation from a square front. In other words, the oxygen concentration falls in the dead space tube before the volume of inspiration equals the distance from the source of oxygen.

ResultsSpirometer Studies:

Using a spirometer model in which less than the dead space is breathed, the following results were obtained:

1. Tubing with 0.5-inch interior diameter and 325-cc. volume: The front moves as a nearly square front with little mixing in the tube. This is illustrated in Figure 2.
2. There is very little mixing of air and oxygen at this front.

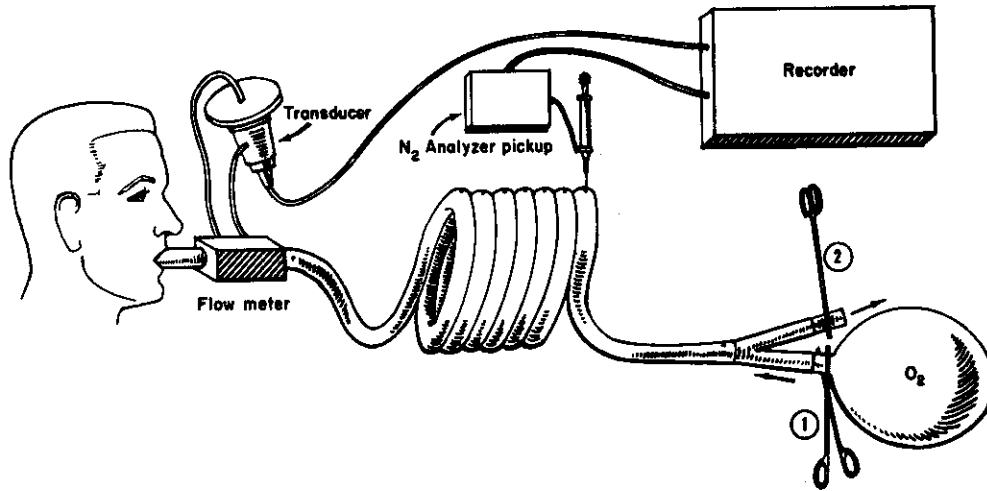


Figure 1. Diagram of the Apparatus Used for Analyzing within the Dead Space Tubing

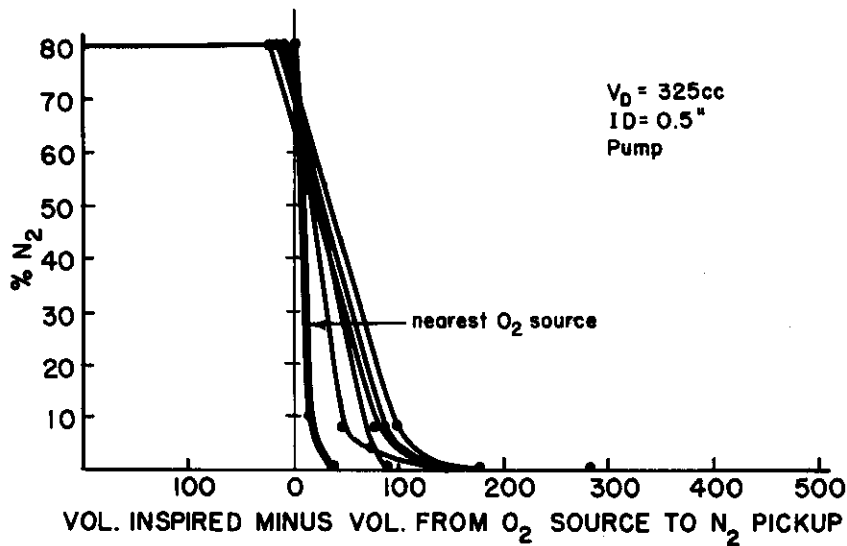


Figure 2. Graph of Gas Mixing, Tubing with 0.5-Inch Diameter and 325-cc. Volume, Using an Electronic Flowmeter

2. Tubing with 0.75-inch interior diameter and 1200-cc. volume (Figure 3): In this case there is again very little mixing with the subsequent curves resembling quite closely the original curve. However, at the lower volumes there are the flat plateaus which suggest that a small amount of oxygen has admixed late in the respiration.

3. Tubing with 1.5-inch interior diameter and 1200-cc. volume (Figure 4): In this tube there is considerable mixing. This is indicated by the deviation from the oxygen source sample. The plateaus represent the lowest nitrogen concentration reached at these points, zero being achieved in only a small number. Also, note that air is diluted by oxygen long before the inspired volume equals the dead space volume.

Studies in Humans:

1. Tubing with 0.5-inch interior diameter and 300-cc. volume (Figure 5): Tidal volume is greater than the dead space. It indicates movement of oxygen essentially as a square front.

2. Tubing with 0.75-inch interior diameter and 1200-cc. volume (Figure 6): In this example the graph represents a breath greater than the dead space, and also a breath less than the dead space. The front is again relatively square if the volume exchanged exceeds the dead space volume. This becomes less square at lower inspiratory volumes. This mixing apparently is small enough that it does not effectively alter the dead space (see discussion).

3. Tubing with 1.5-inch interior diameter and 1200-cc. volume (Figure 7): This is again represented both with breaths greater and smaller than the dead space.

Discussion

Major problems in methodology have plagued this part of the investigation and much time and effort were expended in developing methods. The techniques reported here were arrived at after most of the contract year had passed.

Conclusions regarding mixing in the dead space can only be tentative at this time. In the 0.5- and 0.75-inch interior diameter tubing the front is apparently nearly square and the added dead space acts essentially as real dead space. This result agrees with the finding in dogs that additions to the airway of 0.75-inch interior diameter tubing produce a corresponding increase in physiologic dead space as determined with the Bohr equation. With tubing of 1.5-inch interior diameter this is not so clearly the case. There is apparently considerable mixing within tubing of this large a diameter. The degree of this mixing is being studied further. In particular, the effect of rate and depth of respiration must be evaluated. The data collected to date suggest that mixing is greater when less dead space is ventilated. This would explain the findings of Schwartz et al.* that, when 1.5-inch interior diameter tubing is added to the airway, patients may breathe with tidal volumes less than the dead space.

Summary

The rate and depth of respiration together with the size and length of tubing affect the degree of mixing within dead space tubing. This tubing seems to have minimum mixing when the interior diameter of the tubing is nearer that of the trachea and when the diameter of the tubing increases above this the mixing becomes greater and the actual prediction of effective dead space uncertain.

* Schwartz, S. I., A. M. Dale, and Hermann Rahn, "Dead Space Rebreathing Tube for Prevention of Atelectasis," J. A. M. A., Vol 103, p 1248, 1957.

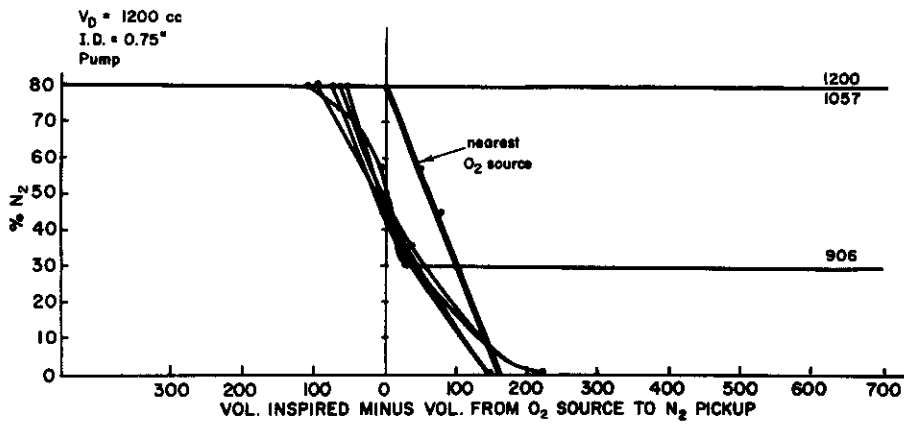


Figure 3. Graph of Gas Mixing, Tubing with 0.75-Inch Diameter and 1200-cc. Volume, Using an Electronic Flowmeter

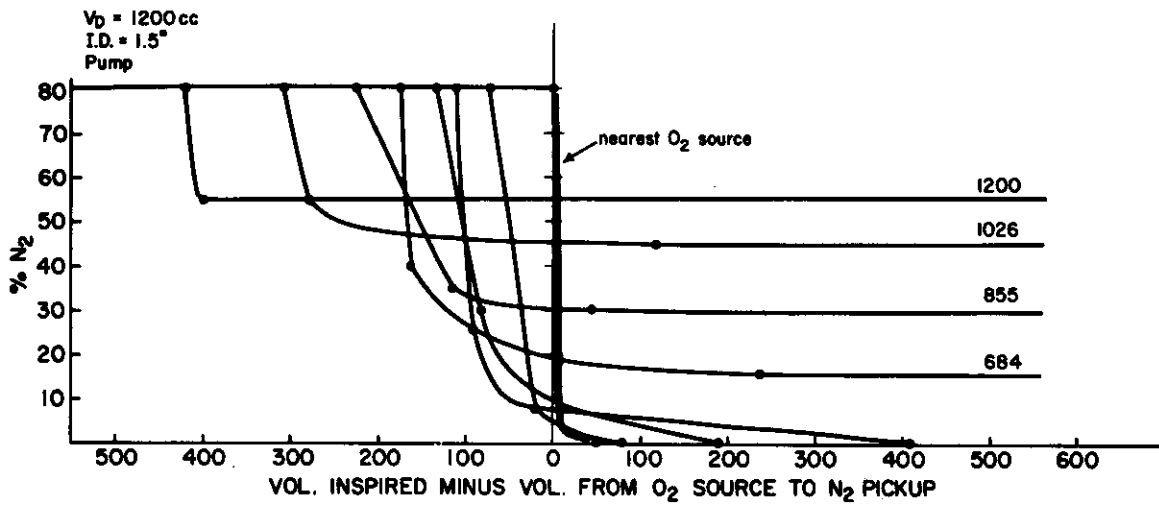


Figure 4. Graph of Gas Mixing, Tubing with 1.5-Inch Diameter and 1200-cc. Volume, Using an Electronic Flowmeter

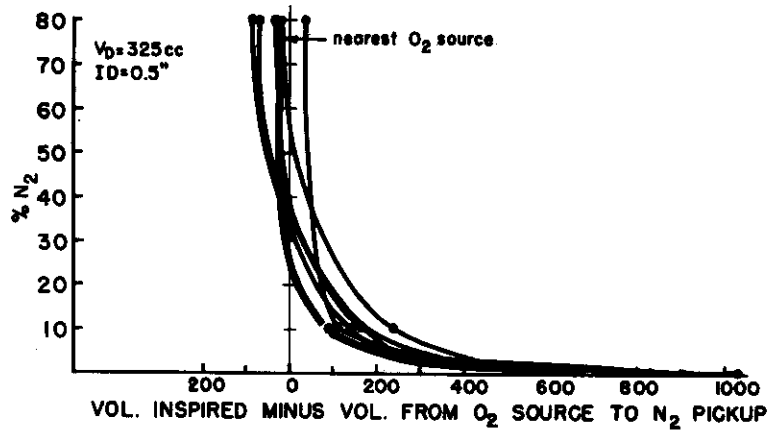


Figure 5. Graph of Gas Mixing, Tubing with 0.5-Inch Diameter and 320-cc. Volume, in Human Subjects

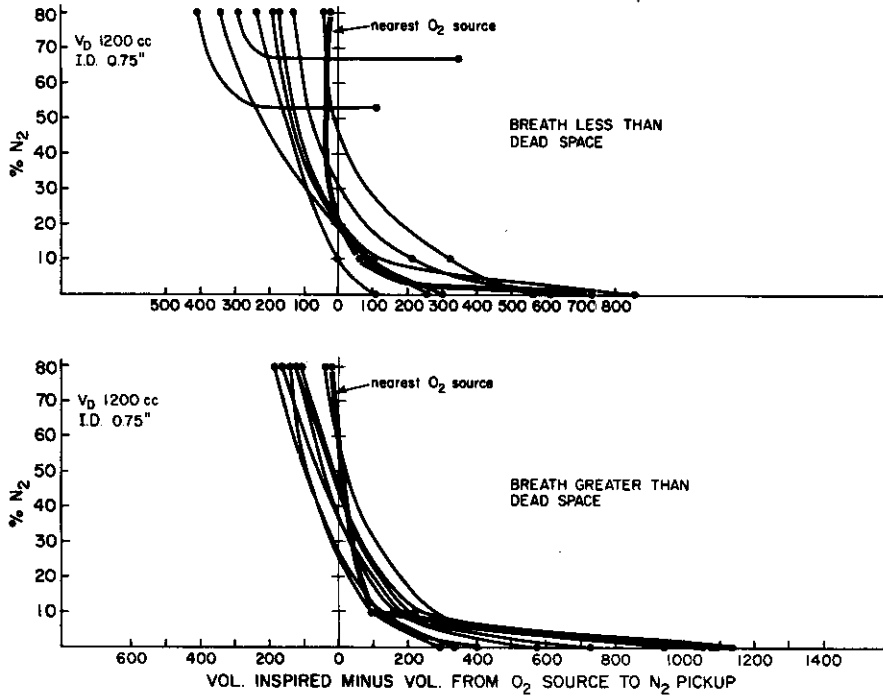


Figure 6. Graph of Gas Mixing, Tubing with 0.75-Inch Diameter and 1200-cc. Volume, in Human Subjects

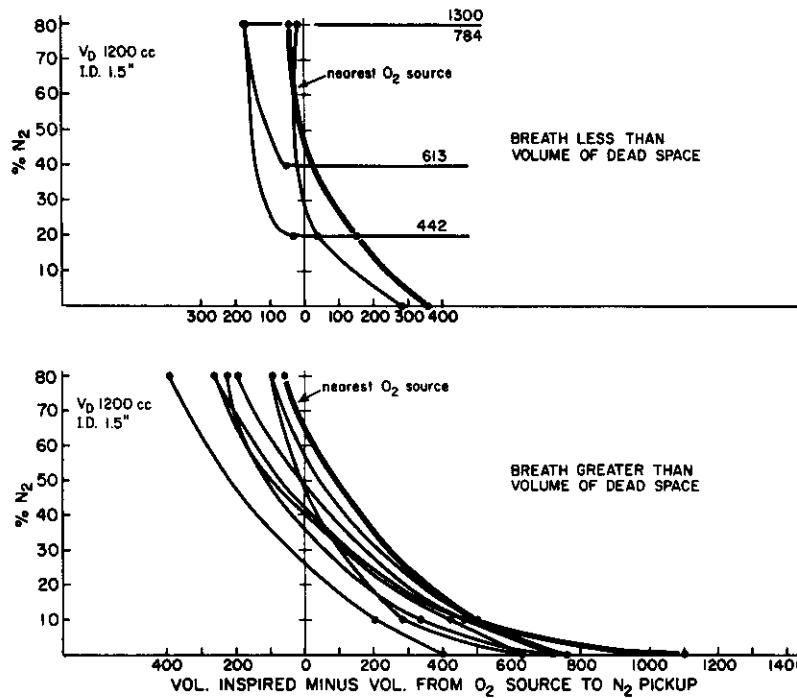


Figure 7. Graph of Gas Mixing, Tubing with 1.5-Inch Diameter and 1200-cc. Volume, in Human Subjects

B. EFFECTS OF ADDED RESPIRATORY DEAD SPACEMethod

Permanent tracheostomies were established in dogs by transecting the trachea and suturing it to the skin of the neck. In these dogs the effects of chronic additions to the respiratory dead space were investigated. Large volumes of external dead space were added by attaching various lengths of vinyl plastic tubing of 0.75-inch interior diameter to the airway (Figure 8). The ventilation could then be measured and arterial punctures performed while these dogs were awake. Four groups of experiments were carried out:

Group I - The control group had 2-5 cc./kg. of external dead space, an amount estimated to equal the natural dead space that was bypassed by the tracheostomy.

Group II - Dead space additions of 5-20 cc./kg. were maintained for 48 hours or less.

Group III - Volumes were of the same order as in the preceding group but were maintained for more than 48 hours (3-15 days).

Group IV - Dead space additions of 20-30 cc./kg. were maintained for 24 hours or less.

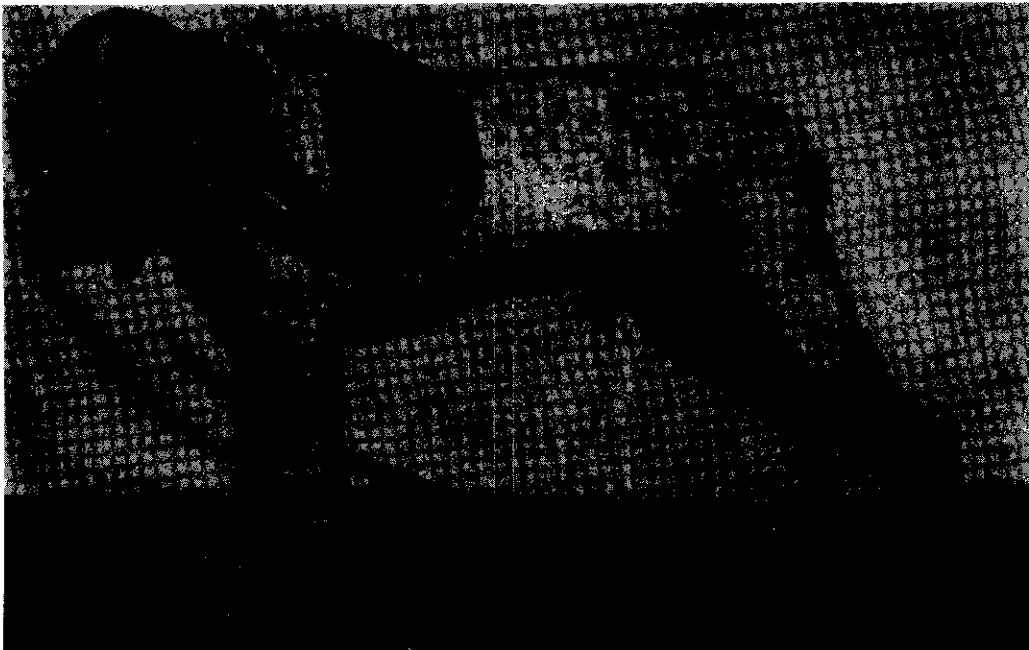


Figure 8. Dog with Tracheostomy in Place
and Dead Space Tubing Attached

In all studies the following observations were made: respiratory rate, minute ventilation, alveolar ventilation*, arterial carbon dioxide tension, and arterial oxygen saturation. Ventilation was measured by attaching the dead space tubing through a

* Barnett, T. B., and R. M. Peters, "Observations on Unanesthetized Dogs with Increased Respiratory Dead Space," Unpublished Data.

one-way valve to a Tissot spirometer with a recording kymograph. Arterial blood samples were collected anaerobically in heparinized syringes. Duplicate determinations were made of whole blood pH using a Beckman model GS pH meter and plasma CO₂ content using the Van Slyke-Neill manometric apparatus. Arterial CO₂ tensions were calculated by means of the Henderson-Hasselbach equation. Arterial oxygen content and capacity were determined either by spectrophotometer or by using the Van Slyke-Neill manometric apparatus.

Results and Discussion

As shown in figures 9-12, in those groups where extra dead space was added (II, III, and IV) the animals demonstrated an increase in minute ventilation which was accomplished mainly by increasing tidal volume. Respiratory rates varied considerably from one dog to another but did not show any significant increase with added dead space. By increasing tidal volume, the minute alveolar ventilation was maintained at normal levels even when very large dead space volumes were added. Marked fatigue occurred consistently in dogs with more than 20 cc./kg. of added dead space and this usually became apparent within 4 to 6 hours. A few animals were able to tolerate this large dead space volume for as long as 24 hours. Volumes of external dead space between 5 and 20 cc./kg. were usually well tolerated for periods up to 48 hours. Beyond this time interval, varying degrees of fatigue and labored breathing occurred. One dog was able to maintain a dead space volume of approximately 10 cc./kg. for 60 days. Evidence of fatigue was often associated with increased tracheobronchial secretions in most of the dogs with added dead space.

The effects of increased dead space on arterial pCO₂ are shown in Figure 13. The values in Group II did not differ significantly from the controls (Group I), but both Group III and Group IV showed a significant increase in arterial pCO₂. The mean values for arterial oxygen saturation in the four groups are shown in table I. In the range of values encountered in these dogs, the oxygen saturation would be expected to change relatively little with changes in oxygen tension. Nevertheless, the mean values in Groups III and IV were somewhat less than in the controls.

Table I

Group	Determinations	Dogs	Mean O ₂ Saturation
I	29	21	94.2%
II	10	8	94.6%
III	20	12	92.7%
IV	13	7	90.5%

Summary

Respiratory dead space in the form of 0.75-inch interior diameter vinyl plastic tubing added to permanent tracheostomies in dogs has been found to be well tolerated when volumes less than 20 cc./kg. are maintained up to 48 hours. Under these circumstances arterial carbon dioxide tension and oxygen saturations are not significantly different from those in control animals.

Dead space volumes between 20-30 cc./kg. produced labored breathing and fatigue within 4 to 6 hours. In these animals, hypercapnia and hypoxia occurred.

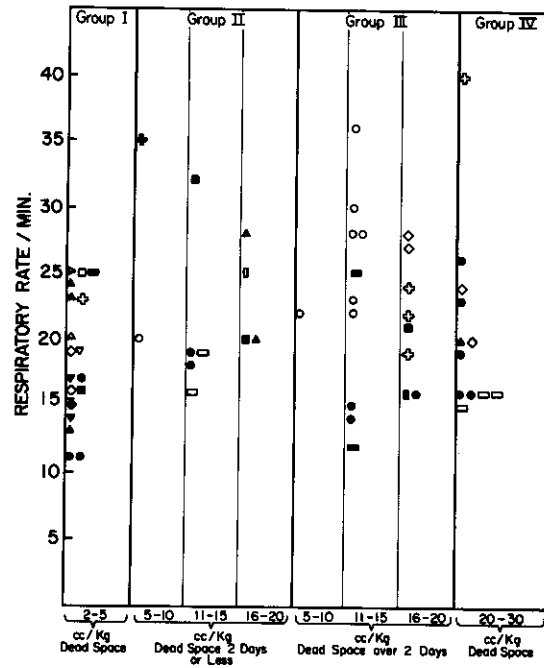


Figure 9. The Effect of the Amount and Duration of Dead Space on the Respiratory Rate

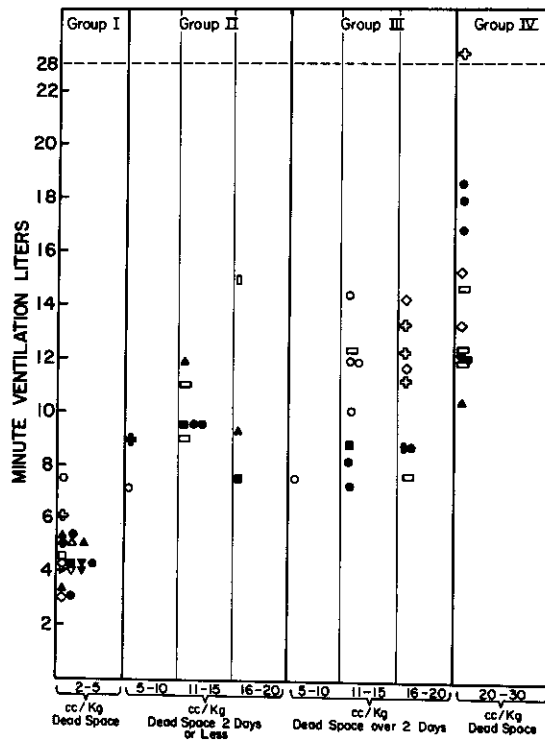


Figure 10. The Effect of the Amount and Duration of Dead Space on the Minute Ventilation

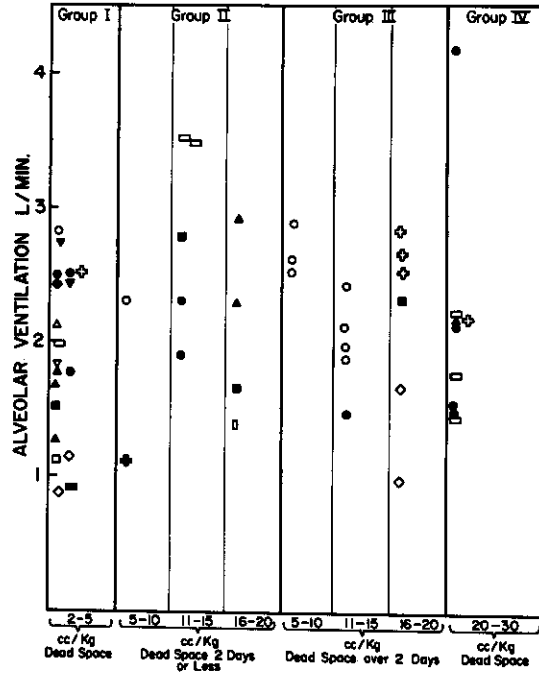


Figure 11. The Effect of the Amount and Duration of Dead Space on the Alveolar Ventilation

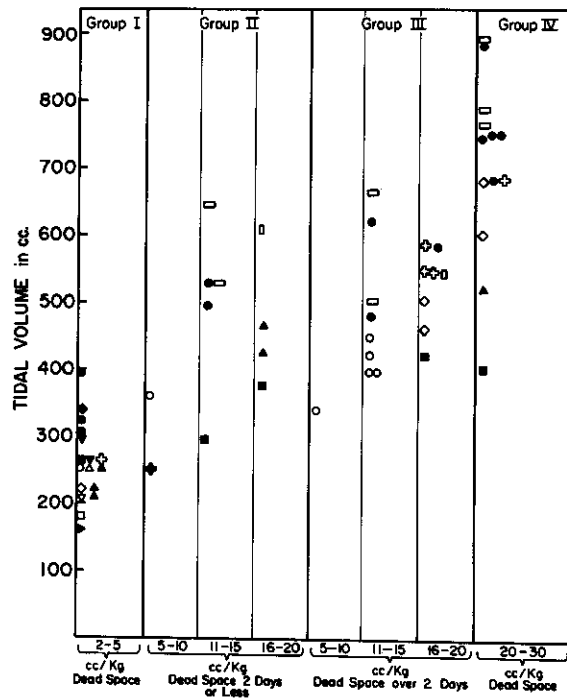


Figure 12. The Effect of the Amount and Duration of Dead Space on the Tidal Volume

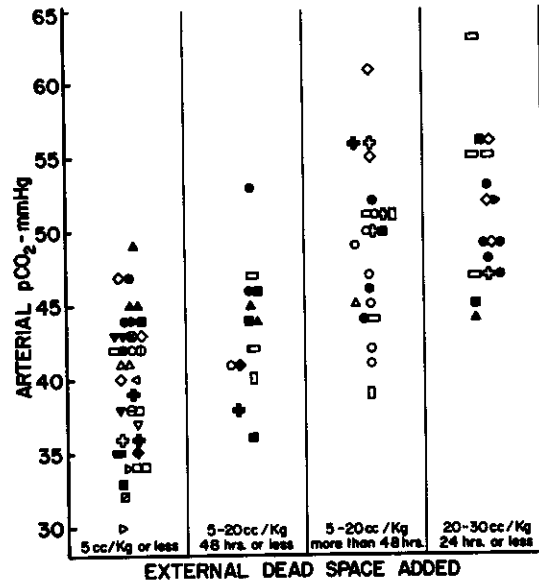


Figure 13. The Effects of Increased Dead Space on Arterial pCO₂