POTENTIAL DEADSPACE IN AN ANAESTHETIC MASK AND CONNECTORS

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The volume of respiratory deadspace in an anaesthetic mask is an elusive quantity. At one extreme Gillespie (1948) suggests that the approximate content of most masks is 150 ml, whilst Swerdlow (1957) assumes a volume of 50 ml for both mask and connector.

In the present investigation the volume of gas contained between mask and face was measured on forty-five faces in the postmortem room, using a water displacement method. The volume of mask connectors as far as either the expiratory valve, or the T piece, was measured for a variety of connectors, using a similar method.

METHODS

Measurement of Mask Volume.

Control of both the volume of air in the rim pad, and the pressure with which the mask is applied to the face, are essential to obtain consistent results.

In the postmortem room the nose and mouth of the adult subject are sealed using waterproof adhesive strapping. To the air inlet of the rim pad of the mask is attached a tube leading to a Tycos pressure gauge, and through a three-way tap to a 20 ml all-glass syringe (fig. 1). Before

![Image of the apparatus used. The No. 4 McKesson mask contains 120 ml of air.](https://academic.oup.com/bja/article-abstract/30/4/176/355079)
use a known volume (V) of air is injected into the completely emptied rim pad. The mask is attached to the face of the subject using a Connell harness, the tension of which can be adjusted so that the rim pad pressure is readily controlled. From a measuring cylinder containing a known volume, water is poured into the entrance to the mask until it reaches level X in figure 2. If this level remains constant no leaks are assumed, and the volume of water poured from the cylinder is noted. The mask is removed from the face, both are dried, and the readings are repeated twice.

**Measurement of Volume of Mask Connectors.**

One end of each connector is occluded with waterproof adhesive strapping, water being added from a 20 ml syringe, until it reaches the level shown by the shading in figure 3. It is assumed that in each case the taper fitting to be attached to the mask extends exactly to the level X in figure 2.

**Accuracy of the Method.**

The Tycos pressure gauge was checked against a vertical mercury column before, during and after the investigation, and was then accurate to ±3 mm Hg. The maximum difference between any two of the three readings keeping subject, rim pad volume and rim pad pressure constant,
was 7 ml. Errors due to difference in barometric pressure and temperature were ignored.

RESULTS
The same initially new No. 4 McKesson mask was used throughout the investigation. Mean readings only were plotted (figs. 4, 5, 6 and 7). Figures 4 and 5 show respectively the effect of varying rim pad pressure (P) and rim pad volume (V). Figure 6 shows that, under standard conditions, mask volumes varied between 76 and 107 ml in 25 males. Figure 7 shows similar results in 20 females, in which mask volumes varied between 87 and 110 ml.

Approximate volumes for a variety of connectors are given in figure 3. These should be checked on the reader’s own apparatus.

DISCUSSION
The relationship between Mask Volume and Mask Deadspace.
Internal mask volume as measured by this method will probably be greater than mask deadspace, because during respiration gas currents presumably tend to travel between the points of entry and exit, i.e. channelling probably occurs to an unknown extent.

In addition, when tidal volume is small, even if we assume complete mixing of inspired gas with mask gas, only a proportion of the finally diluted mixture will be inhaled. With increasing tidal volumes, more of the diluted mask gas will be inhaled, and mask deadspace will approach internal mask volume in exponential fashion if mixing occurs.

Channelling will be opposed by gas currents set up inside the mask, which will be maximal at peak inspiratory and expiratory gas velocities, in which flowrates of 30–35 litres a minute occur during quiet breathing (Proctor and Hardy, 1949; Cherniack, 1952). These currents will be affected by facial contours and by the direction of the column of gas entering or leaving the patient’s airway.

Until the interaction of these factors has been studied, it would be wise to regard internal mask volume as potential deadspace.
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The effect on internal mask volume of varying the volume of air in the rimpad of the mask. Lines join readings where face and rimpad pressure (P), in mm Hg, remain constant.

The internal volume of a No. 4 McKesson mask in 25 males, under standard conditions, i.e. rimpad volume (V) = 120 ml, rimpad pressure controlled by adjusting the tension on the straps of a Connell harness = 90 mm Hg. At lower pressures a watertight seal became unreliable.
**The Effect of Added Deadspace in Patients who Breathe Spontaneously.**

This will depend upon the sensitivity of the anaesthetized subject's respiratory centre to slight changes in arterial CO$_2$ tension.

Let us first assume that the patient's respiratory centre is fully sensitive, and that it responds to an added deadspace in such a way as to restore the alveolar ventilation to its previous level.

This will probably be achieved mainly by an increase in depth, rather than in rate of breathing. In this case minute volume will be increased by the product of added deadspace and respiratory rate. If, as a result of added deadspace, respiratory rate is increased, the product of total deadspace and this increase must be added.

To give an example, suppose an anaesthetized female breathes from a No. 4 McKesson mask connected to a Magill attachment by an angle piece and expiratory valve (type A, fig. 3). Her tidal volume without added deadspace is 400 ml, and her respiratory rate is 16 a minute, i.e., respiratory minute volume = 6.4 litres.

Fresh gas flow to limit the percentage of CO$_2$ rebreathed to a satisfactory level has been shown by Woolmer and Lind (1954), to be 7 litres a minute for a patient having a respiratory minute volume of 6.4 litres, breathing from the Magill attachment without added deadspace. Any increase in minute volume due to an increase in deadspace must be added to this figure (Mapleson, 1954). Assuming added deadspace = potential deadspace of mask and connectors = 98 ml (mean for females in fig. 7) + 30 ml = 128 ml. Increase in minute volume due to added deadspace = (added deadspace \times respiratory rate) = (128 \times 16 = 2048 = 2 litres a minute. Therefore fresh gas flow should equal 7 + 2 = 9 litres a minute.

If in the same female respiratory rate increases from 16 to 24 breaths a minute as a result of added deadspace, it can be shown similarly that fresh gas flows should exceed 11 litres a minute. Thus it will be seen that a response to added deadspace which consists of an increase in rate calls for a larger augmentation of the flow of fresh gases than does a response consisting of an increase in depth.

The assumption that the patient's respiratory centre is fully sensitive to slight changes in carbon dioxide tension does not apply in a patient premedicated with or given narcotic drugs (Prescott et al., 1949; Eckenhoff et al., 1955; Dripps and
Severinghaus, 1955). Let us assume that, as a result of pre-operative narcotic drugs, carbon dioxide retention has already occurred, and that the respiratory centre can no longer respond to a further rise in arterial CO₂ tension. In these circumstances, if deadspace is added, the arterial CO₂ level will rise until the product of alveolar CO₂ concentration and alveolar minute volume equals the volume of CO₂ produced by the patient each minute.

To illustrate this assumption let us suppose:

CO₂ production = 200 ml each minute.
Respiratory rate = 12 a minute.
Tidal volume = 400 ml.
Normal deadspace = 150 ml.
Added deadspace = 125 ml.

Before added deadspace is introduced the effective alveolar ventilation

\[
= (400 - 150) \times 12 = 3000 \text{ ml/min.}
\]

Alveolar CO₂ concentration therefore

\[
= \frac{200}{3000} = 0.066 = 6.6 \text{ per cent}
\]

After added deadspace is introduced alveolar minute volume

\[
= (250 - 125) \times 12 = 1500 \text{ ml.}
\]

Alveolar CO₂ concentration therefore

\[
= \frac{200}{1500} = 0.133 = 13.3 \text{ per cent.}
\]

Unless inspired oxygen concentration is above 20 per cent a reduction in arterial oxygen saturation will also occur.

In practice, the result of added deadspace is shared between an increase in respiratory minute volume and an increase in alveolar CO₂ concentration to a level where the reduced alveolar minute volume is sufficient to expel metabolized CO₂. An increase in minute volume will be of little consequence in the healthy adult. In patients who are exhausted or suffering from any form of respiratory obstruction, the extra work imposed may be beyond the capabilities of the respiratory muscles.

The effects of a raised arterial carbon dioxide tension are beyond the scope of this paper.

**SUMMARY**

(1) A method of measuring the internal volume of an anaesthetic mask using cadavers is described.

(2) The internal mask volume of a No. 4 McKesson mask under standard conditions, varied from 76 ml to 107 ml in twenty-five males, and from 87 ml to 110 ml in twenty females.

(3) The internal volume of a series of facepiece connectors has been measured.

(4) The relationship between internal mask volume and mask deadspace is discussed.

(5) The physiological effects of added deadspace are discussed.

(a) An increase in respiratory minute volume may occur. The expected increase can be calculated if added deadspace is known.

(b) Carbon dioxide retention will follow unless the full increase in minute volume occurs. Hypercarbia would appear to be universal when patients premedicated with narcotics breathe spontaneously through the anaesthetic masks and connectors in current use.

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**REFERENCES**


