DEADSPACE IN PAEDIATRIC ANAESTHETIC APPARATUS

BY

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SUMMARY

The effective apparatus deadspace of the Magill, Potter and Cape Town gas circuits has been investigated using a model system simulating 3- and 8-year-old children.

1. The Cape Town system is more suitable for smaller children.
2. The Potter system is more suitable for larger children.
3. A generous fresh gas flow will decrease the deadspace of the Potter and the Cape Town systems. A flow of double the minute volume is suggested.
4. There is no place for the Magill system in anaesthesia of children, and it might be better to supplant it with the Potter system in adults too.

Deadspace is the part of the ventilation which does not partake in the equilibration of gases with pulmonary blood. It includes any part of a breathing system in which unchanged expiration remains to be inspired by the next breath. During anaesthesia when a gas circuit is in use, the deadspace will consist of:

Anaesthetic apparatus deadspace: this is the volume of expiration in the apparatus remaining to be inspired in the next breath.

Physiological deadspace consisting of: (i) Anatomical deadspace: this is the space from the nose or mouth down to, but not including, the alveoli; it measures approximately 1 ml/lb. (0.45 kg) body weight (Radford, 1955). (ii) Alveolar deadspace: this is the part of the gases ventilating the alveoli which under certain conditions are not perfused.

Effective deadspace is not a constant volume. In anaesthetized man, both effective anatomical deadspace and effective alveolar deadspace increase with tidal volume (Nunn and Hill, 1960).

Deadspace is increased when a facemask, with angle piece and expiratory valve, is applied to the face (fig. 1). This additional deadspace was measured, using water, by Clarke (1958), and by Harrison, Ozinsky and Jones (1959), and was found in adults approximately to double the deadspace. Hall (1955) reported that the facepieces used for anaesthetizing children up to 1 year old had a capacity of 50 ml and, in the case of those up to 4 years old, of 80 ml. Using such masks and a semiclosed system, he reported figures for respiratory parameters far in excess of those accepted by Mushin, Mapleson and Lunn (1962) as representing physiological respiratory requirements (see table I). This marked difference is very likely due, in part at least, to the large additional deadspace imposed by the masks and angle pieces.

The ventilatory requirements of patients have been estimated (Radford, 1955), and shown overall to be accurate under anaesthesia for intubated patients during artificial ventilation (Nunn, 1960). Other circumstances must be considered
TABLE I
Comparison between respiratory parameters of Hall (1955) and Mushin, Mapleson and Lunn (1962). It is suggested that apparatus deadspace contributed towards the differences.

<table>
<thead>
<tr>
<th></th>
<th>Age (years)</th>
<th>Minute volume (L.)</th>
<th>Rate/minute</th>
<th>Tidal volume (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hall</td>
<td>1</td>
<td>3.7</td>
<td>45</td>
<td>79</td>
</tr>
<tr>
<td>Mushin, Mapleson and Lunn</td>
<td>1</td>
<td>1.5</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>Hall</td>
<td>8</td>
<td>6.2</td>
<td>25</td>
<td>228</td>
</tr>
<tr>
<td>Mushin, Mapleson and Lunn</td>
<td>8</td>
<td>4.0</td>
<td>20</td>
<td>200</td>
</tr>
</tbody>
</table>

in the patient who is breathing spontaneously from a facepiece attached to a standard Magill arrangement (fig. 1). These are as follows:

(1) Spontaneous ventilation is increased in the presence of added deadspace in the conscious patient (Clappison and Hamilton, 1956), and in the anaesthetized patient (Jones and Harrison, 1958). This increase in ventilation will only compensate for the added deadspace if the fresh gas flow is at least as big as the patient's increased minute volume (Molyneux and Pask, 1951; Mapleson, 1954; Lowe, 1956; Davies, Verner and Bracken, 1956).

(2) Even this increase in ventilation cannot fully compensate for the added deadspace. Clappison and Hamilton (1956) showed that increasing the deadspace in normal unmedicated subjects led to increases in tidal volume and rate, which were not sufficient completely to correct the end-expiratory carbon dioxide tension.

(3) This ability to compensate for added deadspace is probably reduced by respiratory depression from premedication and anaesthesia, and in some patients by a small reserve of muscular energy for the additional work.

(4) Children, with relatively larger facepiece deadspace, might be expected to be even more affected (Pask, 1958)

Therefore it would be good to reduce the apparatus deadspace as much as possible, especially in children.

METHOD
Two ways (fig. 2, the Potter system, and fig. 3, the Cape Town system) of reducing apparatus deadspace are suggested, and the object of this study is to compare these two ways with the commonly used Magill system (fig. 1). The three systems were compared experimentally on models of a 3-year-old child and an 8-year-old child, whose physiological parameters are given in table II.

The effective deadspace of the different systems can be determined from their effect on the alveolar ventilation. Alveolar ventilation = (tidal air – total deadspace) × respiratory frequency.

\[ V_A = (V_T - V_D) f \] (1)

Alveolar carbon dioxide concentration =

\[ \frac{\text{carbon dioxide production}}{\text{alveolar ventilation}} \]

\[ \frac{F_A_{CO_2}}{V_A} \] (2)

Solving (1) and (2) for \( V_D \)

\[ V_D = V_T - \frac{V_{CO_2}}{F_A_{CO_2}} \] (3)

TABLE II
Physiological parameters regarded as normal for this investigation. (Figures from Mushin, Mapleson and Lunn (1962) except for those for carbon dioxide production, which are estimations based on metabolic rates quoted by Smith (1959)).

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Body weight (lb)</th>
<th>Anatomical deadspace (ml)</th>
<th>Minute volume (L.)</th>
<th>Rate/minute</th>
<th>Tidal volume</th>
<th>Carbon dioxide production (ml/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>55</td>
<td>55</td>
<td>4.0</td>
<td>20</td>
<td>200</td>
<td>130</td>
</tr>
<tr>
<td>3</td>
<td>31</td>
<td>31</td>
<td>2.2</td>
<td>26</td>
<td>85</td>
<td>70</td>
</tr>
</tbody>
</table>
Therefore if $V_t$, $V_{CO_2}$, $F_aCO_2$, and $f$ are known, $V_d$ may be calculated.

It is convenient to do this on a mechanical model in the laboratory where the conditions may be held constant. The model is shown in figure 4. A Starling Ideal pump (1) provided the ventilation. A steady flow of carbon dioxide into the pump represented the patient's carbon dioxide production. If the pump had been connected by a single tube to the mask, there would have been large fluctuations in the carbon dioxide concentration in the "alveoli" from moment to moment during the respiratory cycle, and these fluctuations might have been wrongly averaged by the sampling process. Therefore a miniature circle system was constructed incorporating a mixing chamber (3) of about 500 ml capacity to smooth out these fluctuations. The one-way valves (4) ensured that this circle system formed no part of the "dead-space" of the "patient". This deadspace (stippled area fig. 4) was represented by the tube connecting the one-way valve unit (4) to the facepiece, and made equal to the "normal" anatomical dead-space given in table II.

A BOC No. 3 facepiece with inflatable detachable rim was used for the "8-year-old" experiments, and an Everseal No. 1 facepiece was used for the "3-year-old" experiments. The mask was glued to a rubber hemisphere (12 cm diameter) which partially projected into the mask. An oral airway was glued into a hole not directly opposite the aperture in the mask. The anatomical deadspace was made to equal the expected deadspace for the given child, taking 1 ml of deadspace/pound body weight.

For both the "3-year-old" and the "8-year-old" investigations, each of the three systems was tested in turn, with fresh gas flows of 4 and 8 l./min. For the "8-year-old" this represented first the minute volume of the patient, and then double the minute volume. For the "3-year-old", this should have been 2 l./min and 4 l./min. Since it was felt that 2 l./min would not be used clinically, it was more useful to see whether a relatively large flow of four times the minute volume (8 l./min) would still further decrease the deadspace.
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Carbon dioxide flow ($V_{\text{CO}_2}$) was measured by a Parkinson Cowan wet gas meter, and thereafter dried by passage through anhydrous copper sulphate. The meter readings were therefore reduced by 2.2 per cent to allow for the vapour pressure of water at room temperature. Before readings were taken, carbon dioxide was run through the meter for several hours to ensure that there was negligible loss of carbon dioxide into solution in the water.

Respiratory rate ($f$) was checked during each experiment but never varied.

Measurement of minute ventilation ($V$) was by a Wright respirometer calibrated, for the experimental conditions of use, against a Parkinson Cowan dry gas meter. The correction factor for the “8-year-old” was small. For the “3-year-old” it was large but consistent. It was found that the dry gas meter could not be directly incorporated in the circuit because its large compliance led to differences between the tidal volume it recorded within the circle part of the system and the functioning tidal volume between the circle system and the mask. In the “8-year-old” the respirometer formed part of the anatomical deadspace (2 in figure 4). In the “3-year-old”, because of the small anatomical deadspace, it had to be incorporated within the circle part of the system. The inspiratory flow rate of the Starling pump is substantially faster than the expiratory flow rate. With the small tidal volume of the “3-year-old” it was found essential to connect the Wright respirometer to measure inspiratory volumes in order to get consistent readings. It happened to be mechanically convenient to measure inspiratory volumes in the “8-year-old” also. Therefore, in both cases it was necessary to add the flow of carbon dioxide ($V_{\text{CO}_2}$) to the measured inspiratory total ventilation to obtain the expiratory total ventilation ($V$) required in the calculation.

Measurement of alveolar carbon dioxide concentration ($P_{\text{A}^{-}\text{CO}_2}$) was made by passing a continuous sampling stream (500 ml/min) from the mixing bottle through a katharometer and back to the mixing bottle. The katharometer was calibrated at the start and finish of each set of readings with oxygen and 5.25 per cent carbon dioxide in oxygen (determined on an Aimer simplified Haldane apparatus). All other gases had to be excluded from the system. This was achieved by eliminating air leaks, and by using oxygen for the fresh gas flow into the anaesthetic circuit.

RESULTS

The results are given in tables III and IV. Tidal volume has been calculated from total ventilation and respiratory rate. Total effective deadspace has been calculated according to equation (3).

Total effective deadspace includes the internal deadspace of the “patient” (the stippled area in fig. 4). Not all of this will be effective. An estimate of the effective part of this deadspace can be obtained from the equation of Rohrer quoted by Gray, Grodins and Carter (1956):

$$V_{\text{D}_{\text{eff}}} = V_D (1 - 0.25 \cdot \frac{V_D}{V_T})$$

where $V_D$ is the internal deadspace of the “patient” (53 ml for the “8-year-old” and 31 ml for the “3-year-old” from the volume of water they would contain), and $V_{D_{\text{eff}}}$ is the effective part of this

<table>
<thead>
<tr>
<th>Table III</th>
<th>Results of 8-year-old experiments. The estimated effective anatomical deadspace was 50 ml.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fresh gas flow (l./min)</td>
</tr>
<tr>
<td>Magill system</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Potter system</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Cape Town system</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>8</td>
</tr>
</tbody>
</table>
## TABLE IV

<table>
<thead>
<tr>
<th></th>
<th>Fresh gas flow (l./min)</th>
<th>Minute volume (l.)</th>
<th>Rate/min</th>
<th>Tidal volume (ml)</th>
<th>Carbon dioxide production (ml/min)</th>
<th>Alveolar carbon dioxide percentage</th>
<th>Total effective deadspace (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magill system</td>
<td>4</td>
<td>2.09</td>
<td>25</td>
<td>83.4</td>
<td>72.5</td>
<td>9.30</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>2.09</td>
<td>25</td>
<td>83.7</td>
<td>72.5</td>
<td>8.95</td>
<td>51</td>
</tr>
<tr>
<td>Potter system</td>
<td>4</td>
<td>2.08</td>
<td>25</td>
<td>83.2</td>
<td>72.5</td>
<td>5.50</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>2.07</td>
<td>25</td>
<td>82.8</td>
<td>72.5</td>
<td>5.40</td>
<td>29</td>
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<tr>
<td>Cape Town system</td>
<td>4</td>
<td>2.09</td>
<td>25</td>
<td>83.5</td>
<td>73.0</td>
<td>6.35</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>2.08</td>
<td>25</td>
<td>83.0</td>
<td>73.5</td>
<td>5.55</td>
<td>30</td>
</tr>
</tbody>
</table>

## DISCUSSION

The Magill system was investigated by Molyneux and Pask (1951), theoretically analyzed by Mepson (1954), tested in the laboratory by Woolmer and Lind (1954), and Bracken and Sanderson (1955), and in the operating theatre by Lowe (1956), and Davies, Verner and Bracken (1956). These all showed that, provided the fresh gas flow is at least equal to the minute volume of the patient, no significant rebreathing will occur beyond the expiratory valve during spontaneous respiration.

The Potter system (fig. 2) (Potter, 1961) con-

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**internal deadspace (50 ml for the "8-year-old" and 28 ml for the "3-year-old" at the tidal volumes used in these experiments).

If these effective internal deadspaces are subtracted from the total effective deadspaces in tables III and IV, the effective external deadspace is obtained, and these values are listed in table V. These represent the deadspace imposed on the patients by the three systems. The apparatus deadspace of the systems (the cross-hatched areas in figs. 1, 2, and 3) as measured from the volume of water they would contain, are also listed for comparison.
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sists of a standard angle piece modified by the insertion of a septum and the addition of a rubber flap valve for expiration. Due to the septum, fresh gas must pass through the facepiece before leaving via the expiratory valve, thus flushing the deadspace.

The Cape Town system (fig. 3) was evolved in 1954 by the Department of Anaesthetics of the University of Cape Town and has since been used there as the standard apparatus for small children and neonates. It consists of a standard angle piece with a tube of 6 mm internal diameter soldered in the position shown. A 575-ml soft latex rubber bag with an open tail is fitted over the open limb of the angle piece. Somewhat similar arrangements had been described by Rees (1950), and in 1945 by Nesi (1951). Since it is a form of T-piece, it has in the past been used with a fresh gas flow of at least double the minute volume of the patient (Mapleson, 1954; Inkster, 1956). The fresh gas entering the mask might be expected to flush out the mask deadspace.

The values of the various parameters achieved in the experiments are sufficiently close to the "normals" given in table II to be representative of 3-year-old and 8-year-old children.

From tables III and IV it will be seen that all the values calculated for the effective external deadspace are considerably smaller than the apparatus deadspace as measured by filling with water. This is partly because the expiratory tidal volume does not wash out the entire apparatus deadspace and, partly in the Potter and the Cape Town systems, because of the flushing action of the fresh gas in expiration. This explains why the effective external deadspace is so much smaller in these two systems than in the Magill system and also why it is lower at the higher fresh gas flows. In the Magill system a fresh gas flow equal to the minute volume is sufficient to eliminate rebreathing, beyond the expiratory valve, and increases in the fresh gas flow beyond this have a negligible flushing effect.

The figures for alveolar carbon dioxide concentration in tables III and IV should be interpreted with caution because they are directly proportional to the carbon dioxide production assumed (whereas the calculated effective deadspace is independent of this). However, they provide a dramatic illustration of the difference between the Potter and the Cape Town systems on the one hand and the Magill system on the other.

While the Potter system gave slightly lower readings than did the Cape Town system, there are other factors to be considered in deciding which system to adopt. A given small effective external deadspace can be achieved at lower fresh gas flows in the Potter system than in the Cape Town system. For example, 4 l./min in the former system in the 8-year-old gives an effective external deadspace of 34 ml. To achieve this with the latter system might require about 6 l./min fresh gas flow. This sort of result is to be expected from the similarity of the Potter system to the Magill attachment, and of the Cape Town system to a T-piece system (Mapleson, 1954). Thus the Potter system is more economical, and this is more significant in bigger children.

The Cape Town system has no expiratory valve, and so imposes less resistance to expiration than do the other two—the Magill and the Potter systems, which have expiratory valves. Because of this, the Magill and the Potter systems might reduce the tidal volume and increase the venous pressure slightly. This is probably more important for smaller children.

The small thin bag of the Cape Town system makes it easier to assess an infant's respiration than it is with the Potter system.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the guidance and encouragement I have received from Professor W. W. Mushin, Professor of Anaesthetics, Welsh National School of Medicine. Dr. W. W. Mapleson, PH.D., also contributed greatly to the conduct of the experiments and to their evaluation. Mr. E. K. Hillard, L.I.B.S.T., rendered technical assistance of the highest order. Dr. S. Galloon gave help in the reading of the manuscript. To all these people, and to Mrs. Trelevas for typing so willingly, I record my grateful thanks.

REFERENCES


BRITISH JOURNAL OF ANAESTHESIA

L'ESPACE MORT DANS LES APPAREILS D'ANESTHESIE EMPLOYES EN PEDIATRIE

SOUMAIRE

L'espace mort reel dans le circuit des gaz des appareils "Magill", "Potter" et "Cape Town" a ete etudie a l'aide d'un phantome representant des enfants ages de 3 et de 8 ans. L'auteur estime:

1° Que le systeme "Cape Town" est le mieux approprie pour les enfants en bas age.

2° Que le systeme "Potter" est le mieux approprie pour les enfants plus grands et plus ages.

3° Que l'admission d'une quantite generouse de gaz frais diminuera l'espace mort des systemes "Potter" et "Cape Town". Il recommande donc de regler le flux initial au double du volume/minute normal.

4° Que le systeme "Magill" n'est pas utilisable pour l'anesthesie des enfants et qu'il serait meme prefere de le remplacer par la systeme "Potter" egalement pour les adultes.

TOTER RAUM IN PÄDIATRISCHEN ANAESTHESIEAPPARATEN

ZUSAMMENFASSUNG

Mit einem Modellsystem, das 3- und 8jährige Kinder nachahmt, wurde der effektive tote Raum der Gas-Anaesthesie-Apparate von Magill, Potter und Cape Town untersucht.

1. Das Cape Town-System ist für kleinere Kinder besser geeignet.

2. Das Potter-System ist für größere Kinder besser geeignet.
