RESISTANCE OF HEIDBRINK-TYPE EXPIRATORY VALVES

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SUMMARY

The minimum resistance of expiratory Heidbrink-type valves has been assessed by determining the pressure decrease across the valves at a flow rate of 30 litre min⁻¹. The average resistance of 70 valves currently in clinical use was 318 Pa at that flow rate and about 44% had resistances greater than the limit of 294 Pa previously suggested. The resistances obtained in new valves were either similar or fractionally greater. Valves being introduced as parts of scavenging systems appeared, on the whole, to have lower resistances.

One-way valves of the Heidbrink pattern are used frequently in semi-closed anaesthetic circuits, in circle systems and in the "manual" circuits attached to ventilators. Proportional adjustment of the spring resistance allows the elimination of gas to be controlled by the anaesthetist; low settings are recommended for spontaneous breathing and higher settings are needed for intermittent positive pressure ventilation.

Whilst the detailed construction varies with each manufacturer, the design consists essentially of a circular disc resting on the valve seating against which it is held by a closely coiled helical spring. A pin fixed to the disc runs in a guide. The knurled screw allows the pressure applied by the spring to be varied (fig. 1).

The work of breathing in anaesthetic circuits has been reduced considerably by the use of large-bore tubing, by decreasing the number of bends and by using valves of low resistance (Cooper, 1961). The main source of resistance lies with the expiratory valve. Mushin and Mapleson (1954) described the properties of such valves and showed marked differences between six of the Heidbrink type. Sykes (1959) and Mehta and his colleagues (1977) found also variations in the resistances of valves in clinical use.

We report here a study of a number of expiratory valves in clinical use, of some newly delivered from the manufacturers and of some new types. Part of this work has been presented at the Royal Society of Medicine (Nott, 1977).

METHODS

Valves taken from those in clinical use in six operating theatres were examined. They were of the Heidbrink pattern and in use in Magill systems, or mounted in the E-piece of circle systems or as part of the carbon dioxide absorber system (B.O.C. Mk III). Not all were from the same supplier. New unused valves of the same type were examined also. In addition, one of each of four recently introduced "anti-pollution" valves were studied.

The pressure decrease across each valve when fully "open" was measured with an air flow rate of 30 litre min⁻¹ by the method of Gaensler, Maloney and Bjork (1952). Air from a calibrated Rotameter (GEC-Elliott, 2000) was passed into the anaesthetic circuit containing the valve and allowed to escape only through the valve. The Heidbrink and E-piece valves were mounted upright and the absorber valves horizontally. The pressure decrease was measured using an inclined manometer (Paul Pody, T.7). Readings were obtained to the nearest 5 Pa.
The addition of the anaesthetic tubing necessary for these tests did not add substantially to the pressure decrease measured and has been ignored.

To assess the variability of the spring used in the valves, 16 similar springs were tested independently in the loading space of a materials-testing machine (Instron, 1115) which gave a continuous record of load versus compression. The stiffness of each spring was then calculated in terms of mN mm\(^{-1}\).

The resistance of valves of each type was also measured when the springs were removed.

### RESULTS

The valves tested were classified as follows: Heidbrink valves were those used as independent components of Magill systems. E-piece valves were those from the patient end of circle systems and absorber valves those constructed as part of the absorber block.

**Resistance of valves in clinical use** (table I). The 40 Heidbrink valves tested showed an average pressure decrease of 294 Pa, but about 17 (43\%) had a greater resistance. The average value for E-piece valves was 361 Pa at this flow rate and about 329 Pa for the circle absorber valves. For these valves seven of 20 and seven of 10 respectively exceeded Nunn’s recommended limit (Nunn, 1969).

**Resistance of new valves.** New Heidbrink valves behaved worse than those in use, whilst the circle E-piece valves were marginally better (table I). The differences with the Heidbrink valves were statistically significant \((P<0.001)\).

**Resistance of valves without springs.** Removing the spring from 11 valves caused a decrease in resistance to values of about 100 Pa or less at 30 litre min\(^{-1}\) for each of the three types of valve (table II).

**Resistance of anti-pollution valves.** Four examples of shrouded exhaust valves (which have lighter springs than those in current use) were tested (table III); with each the pressure decrease at 30 litre min\(^{-1}\) was between 50 and 200 Pa.

### DISCUSSION

Any arrangement of tubing and valves used to deliver gas mixtures to patients will lead usually to an increase in the work of breathing by adding resistance to gas flow. With semi-closed circuits and circle systems most of the resistance to expiration now resides in the Heidbrink-type valve. Mushin and Mapleson (1954) suggested that, during spontaneous respiration, such valves should be set so that the pressure in the circuit should be of the order of 50 Pa (0.5 cm H\(_2\)O) to balance the need for sufficient pressure to maintain distension of the reservoir bag with the minimum addition to the

<table>
<thead>
<tr>
<th>Type</th>
<th>No.</th>
<th>Mean</th>
<th>Range</th>
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</thead>
<tbody>
<tr>
<td>Heidbrink valves</td>
<td>5</td>
<td>87</td>
<td>59–108</td>
</tr>
<tr>
<td>E-piece valves</td>
<td>5</td>
<td>63</td>
<td>59–69</td>
</tr>
<tr>
<td>Absorber</td>
<td>1</td>
<td>108</td>
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**Stiffness of springs.** The stiffness was assessed by changing the length of the spring at a constant rate of 2 cm min\(^{-1}\). The stiffness was expressed as mN mm\(^{-1}\) and varied from 14 to 48 mN mm\(^{-1}\) for the 16 valves tested. Remarkably, there was no correlation between the stiffness of the spring and the resistance of the valve.
work of breathing. Low resistances are achieved by using lightweight discs and suitably designed springs.

The assessment of the minimum resistance of these valves is made most easily by measuring the pressure decrease across the valve at a fixed flow rate. Nunn (1969), in considering resistance to breathing, suggested that, at a flow rate of 30 litre min$^{-1}$, the pressure decrease should not exceed 294 Pa (3 cm H$_{2}$O). This flow rate exceeds that normally seen in anaesthetized patients. At lower flow rates which might reproduce more exactly those seen in clinical practice, the pressure decrease is smaller, but there are still marked differences between individual valves (Nott, 1977). Testing at a steady flow rate ignores the problem that some of the pressure is used to overcome inertia in the valves to allow them to open. Further, testing with air will underestimate the resistance for exhaling nitrous oxide-oxygen mixtures. Nevertheless, the test using air at a constant flow of 30 litre min$^{-1}$ forms a convenient standard.

Sykes (1959) found that three Heidbrink valves showed a mean pressure decrease of 314 Pa at 30 litre min$^{-1}$. Mehta and his colleagues (1977) found 10 valves to have a mean pressure decrease of 265 Pa with a range of 196–373 Pa at this flow rate. Our results for 70 Heidbrink-type valves in clinical use show a mean value of 318 Pa with a range from 88 to 1138 Pa (table I). Thus, on average, the resistance is of the order suggested by Nunn (1969) but 31 of the 70 (44%) had higher values. The worst of the E-piece valves had a pressure decrease of 1138 Pa (11.6 cm H$_{2}$O) because the spring was inserted incorrectly.

New valves of the Heidbrink type were significantly worse in performance than those in clinical use (table I), whilst the E-piece valves showed no such difference. The increase with the Heidbrink valves was about one-third greater than for those in use.

The resistance of the valve lies principally in the behaviour of the spring. Removal of the spring is a not uncommon clinical practice and leads to a reduction in pressure decrease to values about one-third of those seen when the spring is in place (table II). The stiffness of 16 springs was measured and found to vary between 14 and 48 mN mm$^{-1}$, but with these springs there was no correlation between stiffness and the resistance of the valve. The mounting of the spring is much more important with distortion of the spring allowing non-uniform lifting of the valve (fig. 2).

Many Heidbrink valves have springs with an even finish at one end only; this end should be next to the disc. Such springs can be mounted upside down; four of 20 examined were so mounted, including one in a new valve.

The recent development of scavenging systems has led to a number of new types of expiratory valve that allow the expired gases to be ducted away. The U.K. Department of Health and Social Security (1976) suggested that such scavenging attachments should add no more resistance than 50 Pa at 30 litre min$^{-1}$ air. The scavenging valves we have tested (table III) all have values much less than that recommended by Nunn (1969) as a result of better design. The springs may be lightweight (M.I.E.) or relatively long with 15–16 turns instead of the usual 7–8 (Medishield, Penlon) and may have narrow bases. The pins and guides may be made of newer, synthetic, lower-friction materials.

These findings suggest that many standard expiratory valves have high resistances. Presumably, the increased resistance does not lead usually to any clinical ill-effect and, indeed, added expiratory resistance may be useful in improving the oxygenation of arterial blood, but it is reasonable to suggest that such resistance should be controllable and valves used should have a low minimum resistance which can then be varied at will. The newer types of valves being introduced with scavenging systems offer an improvement on those in current use.

**ACKNOWLEDGEMENT**

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REFERENCES


RESISTANCE DES SOUPAPES EXPIRATOIRES DU TYPE HEIDBRINK

**RESUME**

On a évalué la résistance minimale des soupapes expiratoires du type Heidbrink en déterminant la diminution de pression qui se produit sur l'ensemble des soupapes à un débit de 30 litre min⁻¹. La résistance moyenne de 70 soupapes en usage clinique effectif a été de 318 Pa à ce débit, et environ 44% d'entre elles ont eu une résistance plus grande que la limite de 294 Pa que l'on avait proposée antérieurement. Les résistances obtenues avec les nouvelles soupapes ont été soit similaires, soit marginalement supérieures. Les soupapes que l'on met actuellement en service comme pièces des systèmes de balayage ont semblé, dans l'ensemble, avoir des résistances plus faibles.

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