THE RESISTANCE OF ENDOTRACHEAL CONNECTORS

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The added resistance to breathing offered by the various components of the anaesthetic circuit is a major problem facing the anaesthetist, particularly in paediatric anaesthesia, and yet one which has produced very little comment in the literature. Macintosh and Mushin (1947) deal briefly with the problem, and Macon and Bruner (1950) discuss the question of the flow of gases through endotracheal tubes. In 1954 Orkin et al. investigated the resistance of soda lime canisters, and endotracheal catheters and adapters, whilst Hunt (1955) described the resistance of disc valves and canisters.

All these writers used a steady flow of gas at varying rates to measure the resistance, but Hamilton and Eastwood (1956) used a pneumotachograph screen and an electromanometer (recording airway pressure readings) to show changes occurring in the volume and pattern of ventilation as the result of introducing resistance into the air flow, in the form of soda lime canisters and valves.

The only work mentioning endotracheal connectors apart from Macintosh and Mushin, is that of Orkin et al., and they, of course, were concerned with American fittings. They stress the fairly obvious fact that the narrowest part of the circuit, and therefore the part with the biggest resistance, is the endotracheal connector (or adapter, as they call it) and it was felt that actual measurements of the resistance of British connectors would be a useful addition to the knowledge of anaesthetists.

THE THEORY OF RESISTANCE

For a given volume of a gas to pass through a tube in a certain time, there must be a difference in pressure between the two ends of the tube; this pressure difference is a measure of the resistance to be overcome when a gas is forced or drawn through the tube, so that the resistance of a length of tubing may be defined as the pressure difference between the entry and exit ports, under certain conditions.

Where the outlet from the tube communicates with the open air, the pressure here is obviously atmospheric, so that a manometer placed in the position shown in figure 1 will give the pressure difference and thus the resistance of any tubing that may be connected to it.

The resistance of a length of tubing depends on:

1. The volume of gas flowing through in unit time. According to Macintosh and Mushin (1947), in an adult breathing 8 litres per minute quietly, the maximum flow rate of air during normal inspiration reaches 25 litres per minute, and they use this latter rate to measure experimentally the resistance of endotracheal connectors. This figure may be on the low side, however, as Proctor and Hardy (1949) found an average peak inspiratory velocity (in normal patients) of 35 litres per minute; similarly Cherniack et al. (1952) give a figure of 35.5 litres per minute, and Mead and Whittenberger (1953) 30–50 litres per minute for quiet breathing.

2. Viscosity of the gas. The flow rate is inversely proportional to the viscosity.

3. The diameter of the tube.

4. The length of the tube.

5. The nature of the flow. Osborn Reynolds (1883) was the first to demonstrate the two types of flow of a fluid or gas in a tube, the smooth orderly type known as laminar, and the disorderly type known as turbulent, which may be local or general.

In anaesthetic practice it can be shown that the volume flow rates of inspired gases are below those which result in general turbulence, but areas of local turbulence (and therefore increased resist-
THE RESISTANCE OF ENDOTRACHEAL CONNECTORS

Flow

Cylinder

Contents
gauge

Metal

Y-piece

Length of tubing
(or connector)
to be tested

Water

manometer

FIG. 1
Apparatus for measuring resistance experimentally.

ance) can occur at a flow rate well below the critical—these local areas are produced by the unavoidable irregularities, bends, corners and constrictions which make their appearance in any anaesthetic set-up.

With the almost universal acceptance of the principle of large bore corrugated breathing tubes, and the increasing tendency to pass an endotracheal tube on more and more patients, the narrowest part of the anaesthetic circuit has become the connector joining the endotracheal tube to the expiratory valve. It would seem that this narrowness, together with the often acute angle of the connector, is responsible for much of the local turbulence and therefore of the resistance of the circuit, and this investigation was undertaken to determine whether there was any difference in the resistance offered by various connectors.

METHOD

The arrangement shown in figure 1 was used to measure the resistance of the connectors, with a constant flow rate of gas of 25 litres per minute, the figure given by Macintosh and Mushin. Although, as pointed out before, this may be on the low side for peak rates of flow during the respiratory cycle, it was felt that this would not affect the final conclusions, which are concerned with a comparison of different connectors, rather than the absolute resistance of any particular connector.

The connectors tested were those in more common use in this country and table I gives a list of them.

The final figures given are the average of 5 individual readings taken on different occasions and table II is an example showing the constancy of the results obtained.
The minimum internal diameters of the connectors were measured by using high speed twist drills accurate to 1/64 inch (0.038 cm approx.) and all the connectors were new and therefore theoretically smooth inside and without any dents.

### RESULTS

Table III shows the minimum internal diameters found (the Magill nasal connectors are, of course, numbered from 7 to 12B but are placed under numbers 1 to 6B for convenience). From this it can be seen that there is considerable variation in diameter between the different types of connectors, and an attempt to compare the resistances of comparable numbers would be meaningless. Figure 2 and table IV show instead a comparison of those connectors which were found to have the same diameters. Numbers 3 and 4 Forrester and 2, 3 and 4 Nosworthy connectors were found to have no resistance at all (table IV) and are therefore not shown in the figure.

### DISCUSSION

It is obvious that a sharp bend will greatly increase the resistance to the flow of a gas, the extent of the increase being dependent on the sharpness of the bend. If the inner bend only is rounded, there is a drop in resistance to one fifth of the value when both bends are sharp, provided that the radius of the inner corner is not greater than 1/4 pipe diameters; if the radius is larger, the resistance increases again.

Where both inner and outer corners are rounded, the resistance will be minimal. As the radius of the bend increases, the resistance drops,

### Table I

List of endotracheal connections tested.

| Right-angled: | Rowbotham | Cobb suction | Magill suction |
| Curved: | Magill nasal | Magill oral | Magill universal |
| Straight: | Forrester | Nosworthy | Rendell-Baker |

### Table II

Resistance of Magill nasal connectors, measured on five separate occasions.

<table>
<thead>
<tr>
<th>No. of connector</th>
<th>Resistance in mm</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>127</td>
<td>128</td>
</tr>
<tr>
<td>8</td>
<td>61</td>
<td>62</td>
</tr>
<tr>
<td>9</td>
<td>33</td>
<td>32</td>
</tr>
<tr>
<td>10</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>11</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>12</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>12A</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>12B</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

### Table III

Minimum internal diameters of endotracheal connectors (in 64ths of an inch: 1 inch = 2.54 cm)

<table>
<thead>
<tr>
<th>Number of connector:</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>6A</th>
<th>6B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rowbotham</td>
<td>12</td>
<td>16</td>
<td>20</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cobb suction</td>
<td>15</td>
<td>17</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magill suction</td>
<td>12</td>
<td>14</td>
<td>20</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magill nasal</td>
<td>10</td>
<td>12</td>
<td>14</td>
<td>16</td>
<td>18</td>
<td>20</td>
<td>21</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Magill oral</td>
<td>10</td>
<td>12</td>
<td>14</td>
<td>16</td>
<td>18</td>
<td>20</td>
<td>21</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Magill universal</td>
<td>9</td>
<td>12</td>
<td>16</td>
<td>20</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forrester</td>
<td>12</td>
<td>16</td>
<td>20</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nosworthy</td>
<td>16</td>
<td>18</td>
<td>22</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rendell-Baker</td>
<td>11</td>
<td>16</td>
<td>18</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table IV

Internal diameters (in 64ths of an inch: 1 inch = 2.54 cm) and resistances (in mm) of endotracheal connections.

| Internal diameters: | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---------------------|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Rowbotham           | 69| 22 | 6   | 4  |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Cobb suction        | 71| 31 | 10  | 5  |    |    |    |    |    |    |    |    |    |    |    |    |
| Magill suction      | 128| 62| 32 | 18 | 12 | 8  | 6  | 4  |    |    |    |    |    |    |    |    |
| Magill nasal        | 108| 47| 26 | 12 | 8  | 4  | 3  | 2  |    |    |    |    |    |    |
| Magill oral         | 118| 42| 12 |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Magill universal    | 20 | 5  | 0  | 0  | 0  |    |    |    |    |    |    |    |    |    |    |
| Forrester           | 66 | 14 | 9  | 4  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Nosworthy           | 2  | 0  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Rendell-Baker       | 66 | 14 | 9  | 4  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
MINIMUM INTERNAL DIAMETER (INCHES)

FIG. 2
Resistance of Endotracheal Connectors.
but not indefinitely (fig. 3); the minimum resistance is offered when the mean radius of the bend is six or seven times the pipe radius (Owers, 1949).

The above theoretical considerations are fully borne out by the results obtained in practice (fig. 2); for a particular diameter the resistance offered to the flow of a gas would be (from lowest to highest):

1. Straight type of connector (such as Forrester).
2. Angled connector with rounded corners of 90° arc (such as Magill universal).
3. Angled connectors with rounded corners of more than a 90° arc (such as Magill nasal).
4. Right-angled connector with sharp corners (such as Rowbotham).

It is interesting to note that both the Cobb and the Magill suction connectors have a greater resistance than a comparable diameter Rowbotham connector, from which they were both adapted. This is presumably due to the increased local turbulence set up by the blind end of the suction entry.

**SUMMARY AND CONCLUSION**

A comparison has been made of the resistance offered to the flow of gas by the endotracheal connectors commonly used in this country, using a flow rate which would approximate to the maximum velocity of flow reached by an anaesthetized patient breathing quietly at 8 litres per minute.

The factors responsible for producing resistance in the anaesthetic circuit are briefly discussed (in nontechnical language).

The following conclusions may be drawn from the results obtained:

1. From the point of view of resistance, a straight type of connector should always be used if possible. Failing this, a curved connector is preferable to a right-angled one—this would appear to be contrary to the more usual practice.

2. There is a marked difference in the internal diameters of various types of connectors, and a plea could well be made for the laying down of standard minimum internal diameters for the varying sizes. Failing such standardization, every anaesthetist should at least be aware of the difference in internal diameter, and therefore in resistance, offered by, for example, a number 1 Magill oral as compared with a number 1 Rowbotham.

3. The ideal type of angled connector should have smooth rounded inner and outer bends forming a 90° arc, with the bend having a radius which is six or seven times that of the connector.
ACKNOWLEDGMENTS

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REFERENCES


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theatre. Local requirements should dictate whether it is large or small, just as they must be considered when deciding how long the patients will need to be retained. At one extreme, the recovery room is a special ward, large enough to accommodate all cases passing through the operation theatres of the hospital. It is merely a substitute, but often an essential one, for insufficient nursing staff—a place where a number of nurses highly skilled in the special problems of the postoperative period are always available and to which every patient must be transferred for several hours or days. Such an arrangement will deprive the surgical ward nurses of much of their interest in the patients. Alternatively, the recovery space may be small, sufficient for from three to six beds, but actually in the theatre block and within sight or sound of surgeon and anaesthetist. Into this room each patient can be placed until fully conscious and with a lastingly effective pulmonary ventilation—a relatively brief period of minutes rather than hours—and therefore free from the common immediate troubles of anaesthesia. When necessary, those exceptional patients who need special treatment or further observation can be kept for a far longer period, particularly at night. Competent nurses must be available, but perhaps—with a small recovery ward—they should be part of the theatre staff, who are best situated every day of the week to learn about the care of unconscious patients from those who know most about the subject. Such a system could be an advantage in a hospital with a nurses' training school, for all nurses spend some part of their training in the operating theatre, and presumably no one, for preference, wishes to remove all normal postoperative care from the supervision of the surgical ward sisters.

With good methods a return to a normal or near normal state usually quickly follows anaesthesia, but paradoxically the selective effect of some agents or techniques may persist well into the postoperative period. So long as this is the case special provision should be made for the patient's safety, and delegation of responsibility by surgeon and anaesthetist should only be countenanced when this has been accomplished.

REFERENCES
