valves. The valves must be maintained in a vertical position to achieve the factory calibration.

In order to verify the accuracy of the device we measured the pressure in the spontaneous breathing circuit with an on-line manometer. The results were always very close to the preset PEEP (±1 cm H₂O), providing there was no leakage in the circuit. Using the PEEP valves, we avoid the hazard of tidal volume variations, prevent inaccurate readings on the spirometer, and provide a desired and constant pressure in the spontaneous breathing circuit.

We have also incorporated an oxygen–air mixing device, using two ordinary flowmeters for supplying the necessary flow to the spontaneous breathing circuit bag. With this system one can supply the desired inspired oxygen concentration to the circuit. When there is no oxygen–air blender available, the use of a wall nebulizer as a source of the mixture for an IMV assembly precludes the use of PEEP. In such a situation, our system provides a constant and known inspired oxygen concentration without leakage in the circuit.

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**Epidural Injection Pressures**

*To the Editor:*—Doctors Ward et al. provide a plausible explanation for their report of total spinal anesthesia occurring during the course of continuous epidural anesthesia with a double-orifice catheter. However, the experimental studies that they report in support of this explanation are, we believe, an oversimplified and inaccurate representation of pressure relationships during epidural injections. The authors represent the experimental epidural space pressure as zero (atmospheric pressure) in relation to the subarachnoid space pressure of 10 cm H₂O. This is erroneous, as it does not take account of changes in pressure within the space during an injection. Usobiaga et al. attempted to measure pressures within the epidural space during injections of local anesthetic but found inaccuracies due to artifacts, and they did not take account of pressure gradients across the needle.

Current studies of epidural injection pressures that we are carrying out in obstetric patients have provided data which may be relevant. We locate the epidural space at L2–3 or L3–4 with the patient in the
CORRESPONDENCE

Fig. 1. Pressure gradients recorded with the Tuohy needle in the epidural space (AX) and open to atmosphere (BY).

This is achieved by repeating the injection to the atmosphere at the same rate through the same circuit with the needle at the same level. From these measurements the initial injection pressure (A—B) and terminal injection pressure (X—Y) are easily calculated (fig. 1; table 1). The residual pressure after injection may also be measured. The highest initial and terminal injection pressures occurred with the most rapid injection (Injection 9). However, an equally high initial pressure occurred on one occasion at less than half that injection rate (Injection 3), and on two occasions slower injections resulted in terminal pressures approximately 100 per cent greater than the initial pressures (Injections 4 and 6). Pressure changes within the epidural space during local anesthetic injections are governed not only by the rate of injection but also by the compliance of the space and the rate of leakage through intervertebral foramina. If the pres-

Table 1. Epidural Injection Pressures at Different Injection Rates of Lidocaine, 10 ml, 1.5 Per Cent

<table>
<thead>
<tr>
<th>Injection</th>
<th>Time (Sec)</th>
<th>Rate (ml/Sec)</th>
<th>Initial Injection Pressure (cm H₂O)</th>
<th>Terminal Injection Pressure (cm H₂O)</th>
<th>Residual Pressure after 60 Sec (cm H₂O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection 1</td>
<td>68</td>
<td>0.147</td>
<td>7</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Injection 2</td>
<td>65</td>
<td>0.154</td>
<td>13</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>Injection 3</td>
<td>65</td>
<td>0.154</td>
<td>29</td>
<td>28</td>
<td>10</td>
</tr>
<tr>
<td>Injection 4</td>
<td>65</td>
<td>0.154</td>
<td>14</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Injection 5</td>
<td>65</td>
<td>0.154</td>
<td>21</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>Injection 6</td>
<td>58</td>
<td>0.172</td>
<td>15</td>
<td>24</td>
<td>21</td>
</tr>
<tr>
<td>Injection 7</td>
<td>56</td>
<td>0.179</td>
<td>9</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Injection 8</td>
<td>46</td>
<td>0.217</td>
<td>23</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>Injection 9</td>
<td>30</td>
<td>0.333</td>
<td>29</td>
<td>47</td>
<td>14</td>
</tr>
</tbody>
</table>

Flexed left lateral decubitus position. The hub of a Tuohy needle is then connected to a 10-ml syringe via a 100-cm-long nylon manometer tube, both of which have been prefilled with lidocaine, 1.5 per cent, solution. A three-way tap between syringe and manometer tube is connected to an electromanometer and pen recorder calibrated in cm H₂O to record continuously the pressure gradient across the circuit between the syringe and needle point during the injection. The syringe is driven at a preset constant rate by a pneumatic syringe pump.

From Poiseille's law, the pressure gradient, P₁, during an injection into the epidural space may be represented by the equation

\[ P₁ = \frac{8 \eta Q}{\pi r^4} + P_e \]  

(1)

where \( l \) is the length of the tube between syringe and needle point, \( \eta \) the coefficient of viscosity of lidocaine, 1.5 per cent, \( Q \) the volume of lidocaine delivered per second, \( r \) the radius of the tube, and \( P_e \) the instantaneous pressure within the epidural space.

When the Tuohy needle is open to the atmosphere the pressure gradient across the circuit, \( P₂ \), is represented as

\[ P₂ = \frac{8 \eta Q}{\pi r^4} \]  

(2)

Then, if \( l, \eta, Q \) and \( r \) are kept constant, the instantaneous pressure within the epidural space, \( P_e \), may be represented as

\[ P_e = P₁ - P₂ \]  

(1) − (2)
sure in the subarachnoid space remained approximately 10 cm H₂O during the epidural injection, then under the circumstances described by Ward et al. the gradient would frequently favor exit of local anesthetic solution through the distal orifice into the subarachnoid space even with slower injections. The balance is, however, further complicated by the fact that an increase in epidural pressure may be transmitted to the subarachnoid space.²

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Vaporizer Overflow a Preventable Hazard

To the Editor:—Sharrock and Gabel¹ described a death caused by halothane overdose due to a mechanical fault in an anesthesia machine equipped with a side-arm Vernitrol® vaporizer. The authors believe that if the machine had not been effectively scavenged, they might have been able to recognize the problem of liquid halothane delivered from the vaporizer to the patient breathing system. The equipment used suffers from an inherent design deficiency, in that when by coincidence a high flow of gas is passed through the side-arm Vernitrol vaporizer filled to the maximum level, liquid anesthetic may be displaced from the reservoir and into the patient breathing system of the anesthesia machine. This hazard was reported nine years previously from the same city.² If the anesthetists had considered gross overdose of anesthetic owing to delivery of liquid volatile anesthetic as a possible cause of the dysrhythmias, then disconnection of the scavenging transfer hose from the scavenged pop-off valve would have verified the cause of the problem. The difficulty is to keep in mind the ever-present possibility of equipment failure as the cause of unexpected happenings. Confirmation of the coincidental faults and subsequent patient condition is possible within the design of a proper scavenging system. The correct diagnosis of the problem was made by visual recognition of the abnormally located rotometer bobbin and the "missing" halothane. There also existed an audible warning, the "gurgling" sound as the halothane was being displaced from the reservoir downstream into the machine. The authors' emphasis on the scavenging system diverts one's attention from the basic cause, a design fault in the vaporizer. It is hoped that the manufacturer of this vaporizer will make known to every individual and institutional owner of such equipment that a retrofit device is available at a reasonable cost to correct the design fault and obviate the hazard.

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