adjustment. Figure 3 shows the system during expiration. With the exhalation valve open, expired gas from the patient is cleared from the system by the continuous high flow of fresh gas. This prevents rebreathing and insures that dry gas from the respirator does not reach the patient on the subsequent inspiratory phase.

This system makes use of familiar equipment to provide a simple apparatus for efficient ventilation in the newborn infant. It insures well-humidified oxygen at adequate flow rates and cycles per minute, minimal dead space and resistance, readily controllable airway pressures, and minimal equipment near the patient.

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Pneumatic Monitor for Arterial Blood Pressure

B. Raymond Fink, M.B. *

Dr. Fink notes that arterial blood pressure measurements, though vital to the safety of many anesthetized patients, are seldom available continuously, mainly because the necessary instruments are too costly. Because of its simplicity, reliance continues to be placed on the sphygmonanometer, although its readings are at best intermittent, and at worst difficult or impossible to obtain in a crisis. It seems inescapable that for secure, uninterrupted observation of blood pressure, measurements must be made directly through an arterial cannula. Techniques of transcutaneous arterial puncture have been available for years,1,2,3 but have remained of limited clinical application because they require electrical transducers and amplifiers.1,4,5 Coupling the artery to a mercury2 or aneroid7 manometer has been suggested, but this yields only the mean arterial pressure and is plagued by clot and the possibility of false high readings.

The need for a simple, direct method of monitoring arterial pressure remains, a need to which the system described here is offered as a working answer. Comprising an air or "pneumatic" manometer8 connected to a teflon arterial cannula and maintained patent by a trickle of saline, it allows indefinitely continued measurement of systolic and diastolic pressures and serves at the same time as a monitor of the cardiac rhythm. A kindred device suitable only for brief observation has been developed independently by De Bono.*

Artificial Cannulation

The cannula consists of a tapered two-and-a-half inch, 18-gauge (for adults) or 20-gauge (for children) teflon catheter with Luer hub

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on a freely movable trocar-needle, rigid during introduction and flexible once inside the vessel. In adults, the target vessel is the brachial artery at the crease of the elbow, with forearm fully extended and in mid-pronation (fig. 1). In children, the femoral artery is preferred. Cannulation is easily performed through a local anesthetic skin wheal, and seldom needs more than one attempt.

**Pneumatic Manometer**

The manometer (fig. 2) is a piece of vinyl tubing 33.75 cm. long, sealed at one end and with 3.75 cm. of indicator fluid at the other. The fluid consists of indigo-carmine and is introduced from a syringe with a 1.5 inch (3.75 cm.), 22-gauge needle. Obeying Boyle’s law, the air column varies in length inversely with the pressure. The open end connects through an adapter, stopcock and T-junction: via a connecting tube to the arterial cannula, to an externally pressurized plastic bag containing 500 ml. of normal saline with 10 mg. of heparin.

The dimensions specified in the legend of figure 2 are the result of various tests carried out on 4 dogs and 6 human subjects. The main considerations may be briefly reviewed. The volume of the manometer between the diastolic and systolic graduations must not exceed the volume of blood entering or leaving the system in one pulsation, a quantity depending mainly on the pulse volume and the bore of the cannula. If the manometer is narrow, the sensitivity will be high, but below a certain width the viscous impedance of the fluid in the manometer becomes excessive. The manometer is temperature-sensitive, since the volume of the air column is proportional to the absolute temperature; in air-conditioned rooms, this factor is of no account. Hydrostatic pressure in the transmission system affects the readings; the zero of the manometer should, therefore, be at the same level as the tip of the cannula. In addition, the height of the indicator column diminishes the air pressure to the extent of 1 mm. of mercury for every 1.36 cm. of liquid; a correction for this can be conveniently incorporated into the scale (table 1). Correction for barometric pressure can be disregarded at sea-level; at other altitudes, direct calibration with a mercury manometer is desirable.

**Table 1. Scale Graduations for 30 cm. Pneumatic Manometer**

<table>
<thead>
<tr>
<th>Blood Pressure (mm. Hg)</th>
<th>Distance on Scale (mm.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>7.5</td>
</tr>
<tr>
<td>40</td>
<td>14.5</td>
</tr>
<tr>
<td>60</td>
<td>21.5</td>
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<tr>
<td>80</td>
<td>28.0</td>
</tr>
<tr>
<td>100</td>
<td>34.0</td>
</tr>
<tr>
<td>120</td>
<td>40.0</td>
</tr>
<tr>
<td>140</td>
<td>45.5</td>
</tr>
<tr>
<td>160</td>
<td>51.0</td>
</tr>
<tr>
<td>180</td>
<td>56.5</td>
</tr>
<tr>
<td>200</td>
<td>61.5</td>
</tr>
<tr>
<td>220</td>
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<td>240</td>
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<td>260</td>
<td>75.5</td>
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<tr>
<td>280</td>
<td>79.5</td>
</tr>
<tr>
<td>300</td>
<td>83.5</td>
</tr>
</tbody>
</table>

* Calculated from Boyle’s law, corrected for height of indicator column.
Fig. 2. Exploded diagram of pneumatic monitor system.

1. Teflon Cannula-Needle, 18-Gauge, 2.5 Inch ................................. B.D.: 91-0045
2. Three-way Stopcock .............................................................. B.D.: MS10-T
3. Vinyl Tubing Adapter, Male, Lock ........................................... B.D.: 617LA
4. Vinyl Tubing, 0.067 Inch I.D. ..................................................... B.D.: VX067
5. Vinyl Tubing Adapter, Female ................................................... B.D.: 617FA
6. T-Connector .............................................................................. B.D.: 1314A
7. Stopcock .................................................................................. B.D.: MS800-T
8. Tuohy Adapter .......................................................................... B.D.: 611A
9. Vinyl Tubing, 0.044 Inch I.D. ..................................................... B.D.: VX044
10. Indigo Carmine ......................................................................... M.K.: 108
11. Microdrip ................................................................................. A.: 4510
12. 250 ml Bottle ........................................................................... A.: 4124
13. Recipient Set ............................................................................ E.: HB-10
14. Plastic Bag, 500 ml ................................................................. E.: JH-1
15. Pressure Infuser ....................................................................... E.: BD-1

(B.D.: Becton Dickinson, East Rutherford, New Jersey;
M.K.: Moore Kirk Laboratories, Worcester, Massachusetts;
E.: Fenwal Laboratories, Morton Grove, Illinois)

Components 1–10 are heat-sterilizable.
In general, these errors are small and tend to remain constant, and do not detract from the usefulness of the manometer. The transmission system is designed for ease of handling but adds to both the inertial and viscous damping. The latter is much the larger of the two and is minimized by employing a wide connecting tube.

**Operation**

On connecting the arterial cannula to the transmission system and opening the stopcock, the indicator liquid enters the manometer and thereafter faithfully follows every systolic and diastolic variation of blood pressure. A very slow drip of saline through the connecting tube suffices to keep the cannula clear and has no perceptible effect on the pressure readings. Damping by the drip tubing is avoided by placing the drip control as close to the T-connector as possible. A microdrip rate of 10–20 droplets a minute is ample, amounting to 10–20 ml. of liquid and 0.25–0.5 mg. of heparin per hour, an insignificant quantity in adults.

The manometer oscillations may occasionally become damped from impending clot. This can be cleared by aspiration through the three-way stopcock, followed by a slight speed-up of the intra-arterial drip. Sudden release of pressure is likely to fragment the indicator column. The remedy is to remove the manometer tube from the adapter, empty it, and refill with fresh solution.

The apparatus has become a routine adjunct in operations at the Neurological Institute and has already been used throughout 115 craniotomies, the longest of which lasted over 9 hours. The youngest of these patients was 6 years old. Two minor hematomas, which occurred before proficiency at inserting the cannula was acquired, have been the only complications. The pressures observed with the pneumatic monitor were compared with sphygmomanometer readings in every patient. The pneumatic pulse pressure was usually 10–20 mm. of mercury greater, a difference which tended to increase when blood pressure rose.

The practical value of the monitor was most evident in hypotensive episodes and during operations with hypothermia, when determinations with the sphygmomanometer were inconveniently slow or unobtainable. The sight of the regular oscillations and exact readings of the pneumatic manometer at every beat provided welcome reassurance at such times. The apparatus has also been used on conscious patients in the radiology department, for monitoring changes in blood pressure incidental to carotid arteriograms and to changes of posture during pneumoencephalography. For the latter, the manometer can be strapped to the patient, since it functions quite satisfactorily upside-down.

**References**