"PRIMUM NON NOSCERE" continues to be one of the most important aphorisms—if not the most important of all—in contemporary medicine and anaesthetists should never ignore it. The use of elaborate anaesthetic technique entails correlated dangers, which can only be counteracted by minute and profound knowledge of the situation created.

Under this heading comes closed circuit respiration, which to-day is so commonly employed that its handicaps are often forgotten. Facilities in blood and plasma transfusion, which frequently accompany good anaesthetic organisation, are capable of disguising many misuses of carbon dioxide absorbers.

To ventilate a patient with oxygen is ordinarily a simple matter, but the adequate removal of carbon dioxide may be neglected. In fact, the criteria relied upon to assess the efficiency of carbon dioxide absorption are not entirely satisfactory for the following simple reasons:

1. The best brands of soda-lime when stale produce misleading results. For example, in the hospital stores, the container that was last bought can be incorrectly arranged in front of formerly acquired ones, so that the anaesthetists may later use a very stale soda-lime, supposing it to be fresh. This is more liable to occur in hospitals which buy in bulk. The situation is worse in many countries which must import soda-lime, a painfully long procedure,
currently taking many months; the result is that the soda-lime, when finally put in the canister, is no longer fresh, and fails to absorb efficiently from the very beginning of its use.

2. When the operating-room temperature is unusually low or high, or the anaesthesia is of short or medium duration, or the patient, owing to his metabolic peculiarities, produces too little or too much CO₂, the canister temperature, as judged by the hand, cannot be considered an accurate guide.

3. "Indicating" soda-lime is useful only in transparent containers, and even then gross mistakes can occur (Adriani and Rovenstine, 1941; Adriani, 1946).

4. Last and most important, it is neither consistent nor ethical to propose removing the exhaled CO₂ by means of a special technique, and afterwards await the appearance of evident clinical signs of CO₂ excess (or intoxication) before changing the soda-lime. In fact, when the patient himself exhibits respiratory and/or circulatory symptoms of CO₂ accumulation, the anaesthetist is definitely in the invidious position of correcting something which he formerly proposed to avoid. In other words, he used his patient as a biological test of the soda-lime! It is likely that if the patients were asked permission beforehand to allow themselves to be used in this way, many, if not all, would prefer some other less elaborate anaesthetic technique!

Most patients are very responsive in their natural reflexes and so the symptoms of CO₂ accumulation are very evident. On the contrary, other patients, such as those in pre-operative and anaesthetic pending or established shock, or in fluid imbalance, are partially incapable of exhibiting the normal respiratory and circulatory responses to CO₂ accumulation.
Many authors have demonstrated that the signs of CO\textsubscript{2} accumulation are less evident in the anaesthetized patient and diminish as the narcosis becomes more and more profound (Comroe and Schmidt, 1938; Leigh, 1942; Moyer and Beecher, 1942; Seevers, 1944; Draper, Whitehead, and Spencer, 1947; Dripps, 1947; Roth, Whitehead, and Draper, 1947), a point being reached when the three reflexes which act as a guide to the anaesthetist are not stimulated, even by high CO\textsubscript{2} tensions (Courville, 1941; Editorial, Anesthesiology, 1942; Guedel, 1944; Krichin and Shkurman, 1947; Evans, 1949).

At this point it is necessary to remember the well-established fact that CO\textsubscript{2}, above certain concentrations, acts as a depressant agent (Seevers, 1944).

Matters become more complicated when we take into consideration the techniques of controlled respiration, total curarization, and controlled hypotension: patients under these forms of anaesthesia can exhibit neither the respiratory nor the circulatory symptoms of CO\textsubscript{2} accumulation for obvious reasons and so, without warning, they pass into gaseous acidosis with all its consequences. An example is the so-called "cyclopropane-shock".

It would appear that the usual mistake concerning soda-lime is not to change it when necessary. The converse mistake, which has fortunately only economical consequences, is to discard absorbing material. This probably happens most often during painful interventions performed under light narcosis but not accompanied by regional block, since the signs which then appear resemble those of CO\textsubscript{2} accumulation.

On the whole, it can be said that concentrations of CO\textsubscript{2} under 0.5 per cent are innocuous and can be tolerated for long periods in spite of the fact that the normal content of fresh air is of the order of 0.04 per cent. This figure of
0.5 per cent was established by physiological, hygienic and pharmacological studies. Of course, for short periods, concentrations of CO₂ higher than 0.5 per cent may also be tolerated.

When using to-and-fro absorbers it is very difficult to measure the CO₂ content of the inhaled mixture, because there exists a fluctuating equilibrium between the CO₂ excretion by the patient and absorption by the soda-lime, approximately in the reverse manner to the equilibrium which exists between the fresh O₂ entering through the inlet and the oxygen absorbed by the patient. The exact conditions which exist in these circumstances remain obscure and very little more is known than that—as time goes on—the respiratory dead space (at least as far as CO₂ is concerned) increases at every moment.

In the circle absorber, on the other hand, it is possible to measure the CO₂ concentration of the inhaled mixture. For this purpose the writer has employed the “Carbon Dioxide Detector” developed by William B. Draper in 1939 and furnished by Ohio Chemical and Manufacturing Company under the name “Hi-CO Detector” (Draper, 1939).

This simple accessory consists of two ball valves, two bubble tubes, two test tubes (equipped with tightly fitting rubber connections) and a rubber bulb mounted in series with the inspiratory side of the circle absorber (figs. 1 and 2).

Squeezing the rubber bulb closes one of the valves, lifts the other and the air from the bulb passes into the respiratory circuit. When the bulb is released, its natural elasticity creates a negative pressure, which has a reverse effect on the valves, so that the final result is the bubbling of a sample of inhaled mixture through the test tubes. The first
FIG. 1

The Carbon Dioxide Detector connected to a circle filter.

FIG. 2

Semi-diagrammatic representation of the channels inside the Carbon Dioxide Detector.
Chemical Control of Soda-Lime Efficiency

test tube contains tap water to retain soda-lime dust, and the second one the chemical reagent used in the test.

This apparatus *per se* does not open the closed circuit nor increase the resistance to respiration.

The chemical reagents used for CO\textsubscript{2} estimation may be divided into two main groups:

1. Reagents which simply detect the presence of H\textsubscript{2}CO\textsubscript{3} by turbidity according to the following equations:

\[ \text{H}_2\text{CO}_3 + \text{Ca(OH)}_2 = 2\text{H}_2\text{O} + \text{CaCO}_3 \downarrow \]
\[ \text{H}_2\text{CO}_3 + \text{Ba(OH)}_2 = 2\text{H}_2\text{O} + \text{BaCO}_3 \downarrow \]

When gas containing low concentrations of CO\textsubscript{2} is bubbled through these reagents, the clear solution becomes milky.

2. Reagents which identify pH alterations caused by H\textsubscript{2}CO\textsubscript{3} by colour changes in chemical indicators.

Theoretically, since it is intended to estimate a weak acid, the only useful chemical indicators are those with a critical point near neutrality. A list of these appears in table I. A very weak alkaline solution containing any of the chemical indicators quoted may be used in the test.

The chemical reagent having been prepared, it is of the utmost importance to calibrate its sensitivity.

\begin{center}
\textbf{Table I}

*Colour changes in chemical indicators suitable for the estimation of CO\textsubscript{2}*
\end{center}

<table>
<thead>
<tr>
<th>pH indicator</th>
<th>Colour</th>
<th>pH</th>
<th>Colour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenosulphonphthalein</td>
<td>Yellow</td>
<td>6.8-8.4</td>
<td>Red</td>
</tr>
<tr>
<td>Rosolic Acid</td>
<td>&quot;</td>
<td>6.9-8.0</td>
<td>&quot;</td>
</tr>
<tr>
<td>Cresol Purple</td>
<td>&quot;</td>
<td>7.2-8.8</td>
<td>&quot;</td>
</tr>
<tr>
<td>Metacresol Purple</td>
<td>&quot;</td>
<td>7.4-9.0</td>
<td>Purple</td>
</tr>
<tr>
<td>Tropeolin 000</td>
<td>&quot;</td>
<td>7.6-8.9</td>
<td>Rose</td>
</tr>
<tr>
<td>Thymol Blue</td>
<td>&quot;</td>
<td>8.0-9.6</td>
<td>Blue</td>
</tr>
<tr>
<td>Cresolphthalein</td>
<td>No colour</td>
<td>8.2-9.8</td>
<td>Red</td>
</tr>
<tr>
<td>Phenolphthalein</td>
<td>&quot;</td>
<td>8.3-10.0</td>
<td>&quot;</td>
</tr>
</tbody>
</table>
SENSITIVITY TESTING

For this purpose the anaesthetic machine is used, with the CO₂ detector already connected, and various O₂-CO₂ flows are employed. If the flowmeters are correctly calibrated (some small variations are unimportant) a flow of, for instance, 50 ml of CO₂ and 10 litres of O₂ per minute will contain approximately 0.5 per cent of CO₂. With this O₂-CO₂ mixture flowing, the rubber bulb is squeezed a number of times, an interval being permitted between the successive squeezes. It is very simple to observe the characteristic changes which occur in the chemical reagent at the completion of a certain number of squeezes of the rubber bulb.

We have tried and tested the following reagents:

1. A clear filtered solution of 40 g. of Ca(OH)₂ in 500 ml. of distilled water. Weak but evident turbidity was considered the characteristic change of this reagent.

2. Saturated (at 15°C) clear filtered solution of Ba(OH)₂ in distilled water. Weak but evident turbidity was considered the characteristic change of this reagent.

3. NaOH 0.0005N with phenolphthalein quantum satis to a characteristic purple colour. Complete discolouring was considered the characteristic change.

4. 0.04 per cent solution of Bromothymol Blue with sufficient 0.01N NaOH added to develop the typical blue colour. A complete change to yellow was considered the characteristic end point.

In a number of sensitivity tests we obtained the results in table II.

The chemical reagents of the second group are, on the whole, difficult to manage because it is necessary to use laboratory accuracy (neutral glass, frequent re-testings, neutral washings of the test tubes, etc.).
TABLE II

Calibration of percentage of \( \text{CO}_2 \) against number of squeezes of the bulb with various indicators.

<table>
<thead>
<tr>
<th>( \text{CO}_2 ) %</th>
<th>( \text{Ca(OH)}_2 )</th>
<th>( \text{Ba(OH)}_2 )</th>
<th>Phenolphthalein</th>
<th>Bromothymol</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1 squeeze</td>
<td>1 squeeze</td>
<td>1 squeeze</td>
<td>1 squeeze</td>
</tr>
<tr>
<td>5</td>
<td>1 &quot;</td>
<td>1 &quot;</td>
<td>1 &quot;</td>
<td>1 &quot;</td>
</tr>
<tr>
<td>2</td>
<td>1 &quot;</td>
<td>1 &quot;</td>
<td>1 &quot;</td>
<td>1 &quot;</td>
</tr>
<tr>
<td>1</td>
<td>2 squeezes</td>
<td>1 &quot;</td>
<td>2 squeezes</td>
<td>3 squeezes</td>
</tr>
<tr>
<td>0.5</td>
<td>6 &quot;</td>
<td>1 &quot;</td>
<td>2 &quot;</td>
<td>10 &quot;</td>
</tr>
<tr>
<td>0.25</td>
<td>12 &quot;</td>
<td>2 squeezes</td>
<td>4 &quot;</td>
<td>7 &quot;</td>
</tr>
<tr>
<td>0.10</td>
<td>40 &quot;</td>
<td>4 &quot;</td>
<td>20 &quot;</td>
<td>? &quot;</td>
</tr>
</tbody>
</table>

In anaesthetic practice the writer uses only the \( \text{Ca(OH)}_2 \) solution which is less expensive, easily prepared and tested, and sufficiently accurate.

One condition for accuracy is always to put the same quantity of the same reagent in the same test tube, squeezing the rubber bulb with the same strength.

PROCEDURE DURING ANAESTHESIA

During the administration of an anaesthetic, from time to time we squeeze the rubber bulb of the carbon dioxide detector. If the soda-lime is absorbing well, some turbidity appears after many squeezes, because soda-lime does not absorb \( \text{CO}_2 \) completely (Adriani and Rovenstine, 1941). Each time that there appears turbidity, an equal quantity of fresh reagent is substituted in the test tube and the process begins again. As the soda-lime begins to absorb less efficiently the characteristic change appears after fewer squeezes. It thus becomes evident, beyond any doubt, that the \( \text{CO}_2 \) content of the inhaled mixture is increasing. Since the reagent has already been calibrated we know exactly how many squeezes correspond to 0.5 per cent of \( \text{CO}_2 \). By this means, the \( \text{CO}_2 \) content of the inhaled mixture is determined within an accuracy of one half per cent, an accuracy which is completely satisfactory for clinical purposes.

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We have, since 1946, performed tens of thousands of these estimations in circle filter apparatus and we are completely convinced that soda-lime absorption presents no problems with this type of chemical control.

REFERENCES