The Problem of De-aeration
—Cause, Consequence, Cure

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In colder climates dissolved air in the dialysis fluid may pass across the
membrane into the blood compartment leading to excessive frothing of blood,
rapid falls in the blood level in the venous bubble trap and the consequent
risk of air embolism. In the winter this may mean the patient has to wake
every hour to draw up the level in the bubble trap if air embolism is to be
avoided. The use of blood level detectors and air embolism monitors in this
situation provides little reassurance as most are unreliable in the presence
of froth. In the dialysis fluid compartment the accumulation of bubbles may
interfere with dialyser performance by reducing effective membrane surface
area.

Suspecting that this problem had its origin in the relationship between
solubility of nitrogen and oxygen in water and temperature (Figure 1) we have
investigated the partial pressure of dissolved gas at different points in the
dialysis fluid and blood compartments of some commonly employed systems.
We have used the partial pressure of dissolved oxygen as an indicator of

![Graph showing volume of air dissolved in water versus temperature](image)

Figure 1. Volume of air dissolved in water

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dissolved air as oxygen tension is easily measured with an oxygen electrode, whereas nitrogen tension is more difficult to measure. Dissolved oxygen represents about one-third of the total volume of dissolved gas since the absorption coefficient of nitrogen is about half that of oxygen, but it exerts approximately four times the partial pressure of oxygen in atmospheric air.

**METHOD**

The partial pressure of dissolved oxygen in samples of water, dialysis fluid, and blood were measured at 37°C using a Radiometer oxygen electrode Type E5046. In the Lucas Mark I proportionating system dialysis fluid could be

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*Figure 2: Partial pressure of oxygen at different points within dialyser system*
readily obtained for measurement of air content at several points — tap water inlet, the heating compartment, the conductivity and monitoring compartment, the dialyser inlet and dialyser outlet.

Arterial and venous blood entering and leaving the dialyser was also readily available for analysis.

A comparison of different proportionating units was made by measuring the partial pressure of oxygen in the conductivity compartment and/or at the dialyser inlet under identical conditions. Samples were taken from a Lucas Mark I proportionating unit on every day on which measurements were made.

RESULTS

Figure 2 shows the partial pressure of oxygen at various points in the dialysis system. In the unmodified Mark I Lucas the average $P_{O_2}$ in the heating compartment was 230 mm Hg falling to 200 mm Hg in the conductivity compartment. As expected there is little change between conductivity compartment and dialyser inlet but an appreciable fall occurs across the dialyser. The $P_{O_2}$ of blood leaving the dialyser was found to be as much as 40 mm Hg above that of arterial blood; the mean arterial $P_{O_2}$ was 89 mm Hg and the venous $P_{O_2}$ was 116 mm Hg.

In the modified Lucas I system (Dylade modification) 350 ml of fluid is drawn each minute through a vacuum pump which develops a negative pressure of 600 mm Hg and returns to the conductivity compartment. The $P_{O_2}$ in the conductivity compartment was 150 mm Hg. The $P_{O_2}$ in the dialysis fluid fell from 145 to 125 mm Hg in its passage through the dialyser whilst the $P_{O_2}$ of blood rose from 89 to 97 mm Hg. Bubble formation in the dialyser (Figure 3) and frothing in the bubble trap were much reduced and dialyser performance was improved (Figure 4).

Table I compares the de-aeration achieved by the widely used proportionating units. Improved values for the Lucas modification shown in this table have been achieved by increasing flow to 500 ml/min through the pump under the same negative pressure gradient 600 mm Hg as used in the Dylade Mark IV system. The Drake Willock vacuum pump de-aeration system was the most effective, followed closely by the Lucas Mark II heat exchanger column, then the modified Lucas Mark I system and the Dylade Mark IV systems.

In addition to investigating the proportionating units we have observed the rate of fall of $P_{O_2}$ in water after warming from 4°C to 37°C. We have found it to be dependent upon the ratio of surface area to volume of water and upon the degree of agitation (Figure 5). The $P_{O_2}$ may be significantly above that of atmospheric air up to four hours after warming so that central tank dialysis fluid supply systems are not without de-aeration problems in winter, particularly if the fluid is not constantly agitated.
Figure 3. Bubble formation in the dialyser

Figure 4. Effect of de-aeration of dialysis fluid on performance of Cordis Dow Hollow Fibre kidney. Evaluations in first four hours of dialysis
Table I. Comparative de-aeration qualities of available proportionating units

<table>
<thead>
<tr>
<th>Proportionating unit</th>
<th>Method of de-aeration</th>
<th>Partial pressure oxygen in dialysis fluid at dialyser inlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lucas Mark I</td>
<td>Agitation and Mesh</td>
<td>183</td>
</tr>
<tr>
<td>Lucas Mark I (Dylade Modified)</td>
<td>500 ml/min circulating through vacuum pump at 600 mm Hg negative pressure</td>
<td>137</td>
</tr>
<tr>
<td>Lucas Mark II</td>
<td>Heat exchanger column to 68°C — cooled to 40°C</td>
<td>133</td>
</tr>
<tr>
<td>Drake Willock</td>
<td>Vacuum Pump</td>
<td>125</td>
</tr>
<tr>
<td>Dylade Mark IV</td>
<td>500 ml/min circulating through vacuum pump at 600 mm Hg negative pressure</td>
<td>146</td>
</tr>
</tbody>
</table>

Figure 5. Rate of loss of dissolved air from water as reflected by partial pressure of oxygen when warmed from 5°C-37°C

DISCUSSION

Our results support the following explanation of the phenomenon of bubble formation in winter. Thus tap water is normally fully saturated with dissolved atmospheric air at the temperature of the reservoir but the solubility of $O_2$ and $N_2$ falls to about half on warming the water from 0°C to 37°C. A variable amount of bubble formation results depending on the time elapsed and the degree of agitation but the bulk of gases may remain in solution exerting partial pressures up to twice that exerted in atmospheric air. A high gas tension gradient across the cuprophane membrane leads to uptake of $O_2$ and $N_2$ by the blood. The sum of the partial pressures of dissolved gases in the blood leaving the dialyser may be significantly in excess of barometric pres-
sure so that subsequent agitation of the blood, eg in a drip type bubble chamber, may result in bubble formation.

The solution to the problem is clearly adequate de-aeration. To date, there is no standard requirement but we would suggest on the basis of this investigation and experience of the use of dialysis in winter conditions that the dialysis fluid entering the dialyser should have a $P_{O_2}$ of not more than 150 mm Hg. All Lucas Mark I and possibly also Dylade Mark II and III systems will require modification if this standard is to be achieved when the tap water is at a temperature below 7°C, and exerts $P_{O_2}$ of over 250 mm Hg on warming to 37°C. The alleviation of a very real cause of air embolism is worth the expense involved. The efficiency of de-aeration systems can be easily monitored by measuring the $P_{O_2}$ of dialysis fluid entering the dialyser using the Clark-type polarographic $P_{O_2}$ electrode now widely available.