An Evaluation of the Efficiency and Transfusion Requirements of Four Coil Haemodialyzers in a Home Haemodialysis Programme

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The disposable twin coil dialyzer, initially available to our dialysis unit was the 1.9 $\text{M}^2$ fibreglass mesh wrapped cellulose coil developed in 1955 (Kolff & Watschinger, 1956). This coil had an internal volume of approximately 1200 ml, a very significant disadvantage since blood was necessary for priming. This coil was replaced several years ago by another fibreglass-cellulose coil of similar design but with a 0.9 $\text{M}^2$ membrane surface. The smaller coil proved adequate in regard to urea and creatinine dialysance if the number of hours of dialysis was increased from 12 to 20 hours per week. Ultrafiltration with the smaller coil, however, was extremely difficult even when dialysate osmolality was increased to 325 m0sm/kg and outflow pressure to 200 mm Hg. The 0.9 $\text{M}^2$ fibreglass-cellulose coil was soon replaced by a 1.45 $\text{M}^2$ coil of the same material. This coil proved at least equal to the larger twin coil in regard to urea and creatinine dialysance and despite the 25% less membrane surface there was little, if any, sacrifice in ultrafiltration. The coil, however, has an internal volume of 700 - 800 ml and although in select patients it can be primed without blood, it proved to be necessary in many cases to prime with the blood stored from the patient’s previous dialysis (Patel et al, 1967). To avoid blood storage in a home haemodialysis programme, coil dialyzers offering a reduced priming volume and high erythrocyte recovery without sacrifice of efficiency or ultrafiltration were evaluated to replace the previously used dialyzers.

METHOD AND MATERIAL

Fourteen patients participated in this study while being trained for home haemodialysis. All had similar degrees of renal insufficiency, i.e. they were functionally anephric with creatinine clearances below 2 ml/min and all excreted between 50 and 250 ml of urine per day.

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The numbers and types of disposable dialyzers used in this study were:

a) 36 1.45 M² polypropylene wrapped cellulose (Ultra-flo 145)*  
b) 36 1 M² polypropylene wrapped Cuprophane (Ultra-flo 100)*  
c) 36 1 M² polypropylene wrapped cellulose (LTX 299)*  
d) 36 0.7 M² polypropylene wrapped Cuprophane cartridge (EX-01)**

All haemodialyses were performed on the commercially available recirculating single-pass machines using a roller blood pump at complete occlusion. The disposable dialyzers were used in the 14 patients on a randomly selected basis. In all studies the dialysate flow rate was maintained at 325 ml/min at a temperature of 38 - 40°C. Blood flow rate was determined from calibration of the roller blood pumps. The pump calibrations were performed using whole blood at 38 - 40°C by volumetric collection of the blood during five minute periods at pump speeds to deliver flows of 130, 220 and 300 ml/min. The calibrations were checked in triplicate. With the roller pump head at complete occlusion blood flow rates were independent of coil pressure. At the time of initial calibration the accuracy of the blood flow rate was confirmed by a Döppler ultrasonic flowmeter. Blood pumps were checked weekly for complete occlusion and calibration was also re-checked monthly with the Döppler ultrasonic flowmeter. Dialysance data were calculated at 130, 220 and 300 ml/min allowing a minimum of 30 minutes equilibration time between changes in blood flow rate. Coil pressure was determined by measuring pressures in aneroid gauges connected to the side arm of the bubble trap on the venous outlet set. Ultrafiltration was determined during dialysis using a constant monitoring bed scale with corrections for body weight changes from intake and output volumes as well as for food ingested during dialysis. In the coil dialyzers requiring an inflatable cuff, the cuff pressure was maintained at a constant pressure of 150 mm Hg. Urea and creatinine dialysance were calculated using the formula of Wolf et al, 1951, as follows:

\[
D = \frac{A - V}{A - B} \times Q_b
\]

Where:

- \(D\) = dialysance in ml/min  
- \(A\) = concentration (mg/100 ml) in blood entering dialyzer  
- \(V\) = concentration (mg/100 ml) in blood leaving dialyzer  
- \(B\) = dialysate concentration (mg/100 ml)  
- \(Q_b\) = blood flow rate in ml/min

*Kindly supplied by Travenol Laboratories, Inc., Morton Grove, Illinois  
**Kindly supplied by Extracorporeal & Medical Specialties, Inc., Mount Laurel Township, New Jersey
The coils were primed with 0.9% saline at a maximum outflow pressure of 20 mm Hg. After priming the coils the arterial and venous lines were then filled. Erythrocyte recovery was determined following dialysis as follows: 0.9% saline in the same volume used to prime the dialyzer plus an additional 100 ml was used to wash the coil blood into the patient. 300 ml of 0.9% saline was then washed through the coil and blood lines and the haematocrit was determined in duplicate on this wash using a microhaematocrit centrifuge. The microhaematocrit capillary tubes were examined by two observers under 3 x magnification and the result was rounded to the nearest whole number which, in our experience, is the limit of accuracy of this method. In order to test the reliability of this method random coils were unwrapped after dialysis and emptied with a roller and random coils were rinsed with gradually increasing rinse volumes to 800 ml. The latter two procedures did not significantly increase the recovered erythrocyte mass. The trapped erythrocyte mass was also determined in vitro using radioactive Cr$^{51}$. The results of

<table>
<thead>
<tr>
<th>TABLE I. Urea dialysance</th>
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<tbody>
<tr>
<td><strong>Coil type</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>1.45 M$^2$ cellulose (Ultra-flo 145)</td>
</tr>
<tr>
<td>1 M$^2$ Cuprophane (Ultra-flo 100)</td>
</tr>
<tr>
<td>1 M$^2$ cellulose (LTX 299)</td>
</tr>
<tr>
<td>0.7 M$^2$ Cuprophane (EX-01)</td>
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<tr>
<td><strong>n = 36</strong></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE II. Creatinine dialysance</th>
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</thead>
<tbody>
<tr>
<td><strong>Coil type</strong></td>
</tr>
<tr>
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</tr>
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</tbody>
</table>
TABLE III. Comparative ultrafiltration

<table>
<thead>
<tr>
<th>Coil type</th>
<th>Coarse pressure (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20 mean ± sd</td>
</tr>
<tr>
<td>1.45 M² cellulose (Ultra-flo 145)</td>
<td>289.1 ± 124.3</td>
</tr>
<tr>
<td>1 M² Cuprophone (Ultra-flo 100)</td>
<td>243.0 ± 21.9</td>
</tr>
<tr>
<td>1 M² cellulose (LTX 299)</td>
<td>99.0 ± 93.2</td>
</tr>
<tr>
<td>0.7 M² Cuprophone (EX-01)</td>
<td>211.1 ± 18.4</td>
</tr>
</tbody>
</table>

n = 30

TABLE IV. Retained red blood cell mass and priming volume

<table>
<thead>
<tr>
<th>Coil type</th>
<th>Retained red cell mass (ml)</th>
<th>Priming volume (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean ± sd</td>
<td>mean ± sd</td>
</tr>
<tr>
<td>1.45 M² cellulose (Ultra-flo 145)</td>
<td>1.13 ± 0.73</td>
<td>491.0 ± 11.9</td>
</tr>
<tr>
<td>1 M² Cuprophone (Ultra-flo 100)</td>
<td>0.83 ± 0.61</td>
<td>402.1 ± 18.3</td>
</tr>
<tr>
<td>1 M² cellulose (LTX 299)</td>
<td>0.89 ± 0.75</td>
<td>394.0 ± 24.0</td>
</tr>
<tr>
<td>0.7 M² Cuprophone (EX-01)</td>
<td>0.67 ± 0.63</td>
<td>215.3 ± 12.3</td>
</tr>
</tbody>
</table>

n = 36

this method agreed within 3% with the results obtained using the wash haematocrit method.

The dialysance, ultrafiltration and erythrocyte recovery data were statistically analyzed using the Analysis of Variance and Degrees of Freedom Test at 5% significance level as described by Li in 1966. In Tables I and II the mean represents the results of 36 individual coils of each type (n = 36) in randomly selected patients. Each coil was tested at the three flow rates noted. In Table III the sample size was 30 for each coil. In Table IV the sample size was 36 for each type coil.

RESULTS

DIALYSANCE

In Tables I and II we see the urea and creatinine dialysance (D_u and D_cr) at the three selected blood flow rates. The blood flow rate of 300 ml/min is
the flow used in all of our routine clinical dialyses.

In Table I, Urea dialysance, the 1 M² Cuprophane coil has statistically significant superiority over the other three coils at blood flow rates of 300 and 130 ml/min. At 220 ml/min the 1 M² Cuprophane and 1.45 M² cellulose coils are not statistically significantly different. The 1 M² cellulose and 0.7 M² Cuprophane coils are not different at blood flows of 300 and 130 ml/min but at 220 ml/min the 1 M² cellulose coil is superior to the 0.7 M² Cuprophane coil.

In Table II showing Creatinine dialysance, the 1 M² Cuprophane coil has statistically significant superiority over the other coils at all three blood flow rates. The 1.45 M² cellulose coil ranks second at the three flow rates. The 0.7 M² Cuprophane coil is superior to the 1 M² cellulose coil at a blood flow rate of 300 ml/min but not at 220 and 130 ml/min.

ULTRAFILTRATION
During the ultrafiltration studies the dialysate osmolality was maintained between 260 and 275 m0sm/kg. Statistical analysis of the data in Table III shows that at 20 mm Hg pressure the 1.45 M² cellulose is superior followed by the 1 M² Cuprophane, 0.7 M² Cuprophane and 1 M² cellulose coils. At 100 mm Hg coil pressure the 1.45 M² cellulose and 1 M² Cuprophane coils are the same followed by the 0.7 M² Cuprophane and 1 M² cellulose. The lack of uniformity of the ultrafiltration capacity of cellulose acetate may be seen in the high standard deviations in the 1.45 and 1 M² cellulose coils. This wide range of ultrafiltration capacity noted in the 1.45 M² cellulose coil has produced hypotensive episodes rather frequently. Patients just beginning dialysis training may experience symptoms of hypovolaemia such as tachycardia, nausea, dizziness, muscle cramping, etc. As training progresses most of these patients easily recognize the early signs of hypovolaemia and avoid hypotension and more hazardous symptoms by the prompt infusion of saline. Certain patients, however, maintain an extremely brittle correlation between vascular volume and blood pressure and these patients are far safer dialyzed on a constant weight monitoring bed scale. We feel that the use of 1 M² Cuprophane coils with their very predictable ultrafiltration has allowed asymptomatic dialysis without a bed scale. Moreover, the anxiety produced by hypotensive episodes seriously prolongs the training period and may produce an extreme dependence upon the back-up dialysis person at home because of fear of developing frightening symptoms while left unattended.

PRIMING VOLUME AND ERYTHROCYTE RECOVERY
Table IV shows the erythrocyte recovery and priming volume of the four dialyzers. The 1.45 M² cellulose coil has the largest priming volume. The priming volumes of 1 M² Cuprophane and 1 M² cellulose coils are statistically the same and the 0.7 M² Cuprophane coil has the smallest
priming volume. An analysis of the trapped erythrocyte mass in the coils shows that there is no statistically significant difference.

DISCUSSION

As the development of long term intermittent dialysis has progressed during the past eight years the parallel flow dialyzers have enjoyed increasing popularity. In some centres coil dialyzers have been considered best suited for acute haemodialysis. This attitude is not without foundation. Until rather recently commercially available coils had a few significant advantages: disposability, ease of assembly, and high efficiency. The very significant disadvantage of a high internal volume with the associated blood priming and blood recovery problems certainly outweighed the advantages. Initially, the cost differential of the two types of dialyzers was also strongly in favour of the parallel flow system. The blood pump requirement of the coil is considered a disadvantage by some centres. We prefer blood pumping, however, even with parallel flow dialyzers, in order to obtain reproducible data and to guarantee optimal blood flow.

This study demonstrates that all four coils are very efficient, have low internal volumes, do not require blood for priming and have a very small erythrocyte loss. Only two coils (1 M² and 0.7 M² Cuprophone) have adequate and predictable ultrafiltration properties. Of these two coils, however, the 1 M² Cuprophone coil (Ultra-flo 100) has significantly superior dialysance properties. It becomes obvious that the 1 M² Cuprophone twin coil offers the most satisfactory combination of efficiency, ultrafiltration, low internal volume and high erythrocyte recovery. Even with the less satisfactory 1.45 M² cellulose coil we are able to achieve complete patient rehabilitation with two six hour dialyses per week. Home dialysis may be done one evening per week and once over the weekend, not interfering with the patient's employment.

It is our current practice to allow patients to select their own diet according to taste and we particularly encourage at least 1 g of protein per kilogram of body weight. Hyperkalaemia has not been a problem since we are using potassium-free dialysate. Our only restrictions are sodium in the hypertensive patients and fluids in all patients. We attempt to limit interdialysis weight gain to four pounds. Patients sufficiently cooperative to follow this instruction require only four pounds of ultrafiltration during a six hour dialysis. This degree of ultrafiltration, in our experience, usually does not induce muscle cramping, nausea, headache, or hypotension. It is accomplished safely without a bed scale in well trained patients. The use of Cuprophone coils should allow even the 'brittle patient' safe and asymptomatic dialysis at home.

One of the most significant advantages of the Kiil dialyzers has been
the ability to return all of the blood from the dialyzer to the patient leaving a
residual of 40 to 50 ml (Thomson et al., 1967). A recently described technique
has reduced red cell losses to less than 5 ml (Pollard et al., 1967). Indeed it
has been mentioned that complete recovery of all blood from the coils is al-
most impossible and that blood loss with coils is higher than with other types
of equipment (Tsaltas, 1967). Our own technique of returning coil blood to
the patient indicates that this advantage no longer exists. Even the coil with
the largest internal volume (1.45 M² cellulose) has a mean trapped erythro-
ocyte mass of 1.13 ml.

Until September, 1968, the 1.45 M² cellulose coil had been the primary
coil used in our Dialysis Training Centre. In September, 1968, it was re-
placed by the 1 M² Cuprophane coil (Ultra-flo 100). We have given only twelve
blood transfusions including five for the initial dialyzer priming since October,
1967. In February, 1968, it was decided to stop the previous routine blood
transfusion when the haematocrit fell below 17%. Since that time we have had
150 patient months experience and have performed 1,366 dialyses with this
coil without a blood transfusion for priming and only four transfusions for
maintaining the haematocrit. These four transfusions were given when the
haematocrit fell to 13% and was associated with severe weakness and dys-
pnoea on exertion. The mean post dialysis haematocrit has increased from
19.94 to 23.02% since discontinuing routine transfusions and initial blood
priming.

Our transfusion requirements are in close agreement with those in other
studies where routine transfusion was withdrawn (Comty et al., 1968; Verroust
et al., 1968; Crockett et al., 1968) and thus far we have not recognized a case
of hepatitis in our Dialysis Training Centre either in patients or in training
personnel.

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