COMPARISON OF EFFICACIES OF VARIOUS TYPES OF ARTIFICIAL KIDNEY

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At the present time, a variety of haemodialysers is found in the world market, and it is difficult to decide which of them is best suited for practical application. An especially difficult problem is encountered in attempting to compare the efficacies of various types.

Usually either the clearance or the dialysance of urea is used as the basis of comparison (Wolf, Remp, Kiley, Currie, 1951). These values indicate the efficacy of the artificial kidney per time unit. They are not influenced by the initial concentration of urea; they are, however, dependent on the flow-rate of the dialysed fluid—'blood'—through the apparatus, and, moreover, their mutual relationship is not linear. These facts are a decided drawback to their use.

When characterizing the efficacy of a given apparatus, it is necessary to indicate not only the value of either the clearance or the dialysance and the dialysing-surface area, but also the flow-rate of the 'blood' at which the said values have been measured. Even then, however, it is not evident from which part of the curve the values have been read off. It is impossible to predict whether an increase of the flow-rate would produce any increase of the clearance or of the dialysance, and, if so, how great an increase would be achieved, or whether a maximum has been attained already.

A number of theoretical studies has been devoted to investigations of the conditions ensuring the maximum efficacy of artificial kidneys, and a variety of equations determining the efficacy of haemodialysers has been proposed. Unfortunately, such equations are so complicated that they are better suited to the needs of designers of the apparatuses than to the guidance of physicians entrusted with the practical use of artificial kidneys.

For these reasons we tried to find a measurement which would be dependent only on the dialysing capability of the apparatus, which could be determined by a simple process, and would be expressed by a single numerical value.

We think that such a suitable measurement is the permeability per 1 sq.m. of the dialysing-surface area.

**Theory**

Renkin (1955) expressed the diffusion of substances from the blood capillary by a simple mathematical formula:

\[ D_i = a(1 - e^{-t}) \]  

Equation (1)

where:

- \( D_i \) is the dialysance in ml/min
- \( a \) is the flow rate of the dialysed fluid ('blood') in ml/min.
- \( e \) is the base of natural logarithms

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P is the permeability in ml/min., determined by the expression \( P = D' \cdot \frac{A_p}{\Delta x} \), where \( D' \) is the limited diffusion of the substance examined, \( A_p \) is the total area of the pores, \( \Delta x \) is the length of the pores (i.e. the thickness of the membrane).

Dialysance can also be expressed as follows (Wolf et al., 1951):

\[
Di = a \frac{A - R}{A - U} = a \cdot E
\]

**Equation (2)**

Where:

- \( A \) is the concentration of the substance examined in the fluid entering the apparatus, in mg/100 ml
- \( R \) is the corresponding concentration in outflowing fluid
- \( U \) is the concentration of the same substance in the dialysing fluid in mg/100 ml
- \( E \) is the extraction of the substance in an apparatus with recirculation of dialysis fluid.

Combining equations (1) and (2):

\[
Di = a(1 - e^{-P}) = a \cdot E
\]

\[
E = 1 - e^{-P}
\]

\[
P = -\ln(1 - E) \cdot a
\]

Permeability per 1 sq.m. of the dialysing surface area will then be expressed by the formula:

\[
P_{m^2} = -\ln(1 - E) \cdot \frac{a}{S}
\]

where \( S \) is the total surface area of the dialysing membrane in sq. m.

**Methods**

The appropriate measurements were carried out (1) in an Alwall type artificial kidney with tube membrane 3 cm wide, 0.0027 cm thick, surface area 1.175 sq.m.; (2) in a Skeggs-Leonard type artificial kidney made in USSR with membrane 0.0020 cm thick and surface area 1.5 sq.m.; initial blood priming volume was 150 ml so that distance between cellophane foils was 0.1 mm.

Tap water was used as dialysis fluid, at 37°C. In the Soviet kidney water flow rate was 12-15 litres per minute without recirculation; in the Alwall kidney tap water was exchanged after each measurement so that bath water concentrations were negligible. Urea solution was pumped single pass through the blood compartment. Urea nitrogen concentrations were measured by microkjeldahlisation. Flow rate was measured with a rotameter. Our results were compared with those calculated from the literature.

**Results**

1. **Effect of blood urea concentration.** In both Alwall and Soviet kidneys permeability was constant over a range of urea nitrogen concentrations from 50 to 400 mg%.

2. **Effect of blood flow rate.** The permeability increases with flow rate to a maximum, then decreases (Figure 1).

3. **Effect of surface area and membrane thickness.** The maximum permeability is proportional to surface area and inversely proportional to membrane thickness. The permeability per sq.m. \( (P_{m^2}) \) is the same in all apparatuses of the same type having different surface areas (Table I; Figure 1). When membrane thickness is halved, maximum permeability increases by about 50% (Table I; Figure 1).

4. **Relation of permeability to clearance or dialysance.** Permeability reaches a maximum at a certain blood flow rate, whereas clearance goes on increasing with blood flow (Figure 2).
5. Comparison between artificial kidneys in terms of $P_m^2$. All machines studied had a maximum permeability per sq.m. between 100 and 300, the majority around 150. The Kiil gave the highest result (Fig. 3).

Discussion

Rate of dialysis is determined by diffusion, filtration and hydrodynamic conditions in the apparatus (Grimsrud and Babb, 1964; Cole et al., 1963; Sweeney and Galetti, 1964). Hence ‘permeability’ defined above is not the maximum permeability of the membrane but an integrative expression of machine efficiency. The dependence of permeability on blood flow rate presumably indicates that the whole membrane area is not efficiently utilised below a certain flow rate. The maximum permeability may be used to determine the optimum blood flow rate.

Renkin’s equation shows that dialysance increases with blood flow reaching its maximum only at infinite flow. We verified this relationship over the range of flows used in our experiments but it may not be valid at very high flows which induce changes in the hydrodynamic conditions in the apparatus. Moreover very high flows are difficult to obtain clinically and may cause haemolysis (Blackshear et al., 1965). Choice of blood flow rate is therefore
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A compromise between theoretical and practical considerations. Increasing flow rate to the point of maximum permeability yields a good return in increasing dialysance; beyond that point it is less profitable.

If maximum permeability is increased by expanding surface area, a higher blood flow is required to exploit it and priming volume rises. It is therefore preferable to increase permeability by use of better apparatus or more permeable membranes.

No comparison of the efficacies of artificial kidneys can be made on the basis of values for clearance, flow rate and dialysing surface area supplied by authors (Jørgensen and Balslev, 1962); these parameters cannot even be brought into a simple relationship between one another. No such objection applies if the maximum effective permeability per sq.m. is used as the basis for comparison.

### TABLE I

Comparison of maximum effective permeability in individual types of artificial kidneys

<table>
<thead>
<tr>
<th>Type of dialyser</th>
<th>No</th>
<th>References</th>
<th>MembraneSpecification</th>
<th>Thickness mm</th>
<th>S m²</th>
<th>a ml min.</th>
<th>Dml min.</th>
<th>P ml min.</th>
<th>Pm² ml min.</th>
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<td>420</td>
<td>580</td>
<td>290</td>
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<td>Du Pont P.D. 215</td>
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<td>310</td>
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<td>231</td>
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<td>108</td>
<td>140</td>
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* Present study.
Fig. 2. Relationship of permeability (P) to dialysance (Di) or clearance (C).

Fig. 3. Comparison of individual types of artificial kidneys based on the maximum effective permeability (P) related to a dialysing-surface area unit (S/P_m^2).

REFERENCES


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