Polymethylmethacrylate Capillary Kidney Highly Permeable to Middle Molecules

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Introduction

Recent advances in polymer science have made high quality plastic polymers available, one of which is polymethylmethacrylate. We have tried to develop a capillary artificial kidney using this material.

This report is an experimental and clinical evaluation of the new dialyser along with the comparative studies on other dialysers commercially available at present.

MATERIALS AND METHODS

The Capillary Kidney The polymethylmethacrylate (PMMA) capillary kidney (Toray M-1A) is composed of 8,000 PMMA capillaries, potted with polyurethane and encased in a cylindrical container measuring 247 mm in length and 77 mm in diameter. Each capillary has an internal diameter of 240μ and a wall thickness of 50μ. Total effective dialysis area is about 1.1 m².

In Vitro Tests The in vitro dialysance tests were carried out using a test solution of normal saline containing urea, creatinine, vitamin B₁₂ and inulin. Deionised water served as dialysate.

Samples were taken from the arterial, venous and dialysate lines for the calculation of dialysance. Weight of the reservoir, inlet and outlet pressures of the dialyser, and flow of the test solution were measured during dialysis. Two other artificial kidneys, namely standard Kiil and Cordis Dow Model-4, were examined simultaneously for comparison.
Clinical Applications  Ten patients were selected for dialysis. For nine of them it was used for a short time only, and for the remaining one dialysis was continued for 3 months. Heparin was administered at a rate of 2,000 u/hour using an infusion pump.

Before starting dialysis, the blood compartment was rinsed with normal saline at a flow rate of 200 ml/min and the dialysate compartment with dialysate at a flow rate of 500 ml/min. During the procedure, transmembrane pressure was maintained at 100 mmHg. Samples were taken at intervals from the venous line to measure the concentration of formaldehyde.

Dialysance in clinical cases was calculated at $Q_B$ of 50, 100, 150, 200 ml/min and $Q_D$ of 500 ml/min using Wolff’s equation. During dialysis the weight of the patient was continuously monitored using a Datex bed scale. Transmembrane pressure was measured when indicated.

After dialysis, blood was washed with 150 ml of normal saline and the residual blood volume measured using a $^{51}$Cr labelled red blood cell method.

Motor nerve conduction velocity was measured in one chronically dialysed patient.

RESULTS

In Vitro Studies  The logarithmic expression of dialysance spectrum is illustrated in Figure 1. The curve at the top is for Toray M-1A, and the two others are for the standard Kiil and Cordis Dow HFAK Model-4. The dialysance of Toray M-1A

![Dialysance spectrum of Toray M-1A](image)

Figure 1. Dialysance spectrum of Toray M-1A
Figure 2. Formalin washout test
at $Q_B$ of 200 ml/min and $Q_D$ of 500 ml/min was as follows; NaCl 150 ml/min, urea 148 ml/min, creatinine 125 ml/min, vitamin $B_{12}$ 58 ml/min, and inulin 36 ml/min (Figure 1). Ultrafiltration rate was 20 ml/min at transmembrane pressure of 100 mmHg.

Elimination of formalin from the dialyser is shown in Figure 2. The curve at the bottom is for Toray M-1A. Clinitest, which is sensitive above 300 ppm, was negative after washing with 300 ml of normal saline. Only 1 ppm formaldehyde was detected in the effluent 40 minutes after the start of rinsing (Figure 2).

Clinical application was carried out successfully without any untoward effect.

Dialysance in the clinical situation is depicted in Figure 3. At $Q_B$ of 200 ml/min and $Q_D$ of 500 ml/min, urea dialysance was $144 \pm 9$ ml/min, creatinine dialysance $118 \pm 7$ ml/min and uric acid dialysance $103 \pm 10$ ml/min (Figure 4).

The clinical course of the chronically dialysed patient has been uneventful. The pre-dialysis level of the waste metabolites although fluctuating, show an obvious tendency to decrease. The reduction rate of urea in a five-hour dialysis is $53 \pm 3\%$, creatinine is $47 \pm 4\%$ and uric acid is $55 \pm 5\%$ (Figure 5).

Serum enzymes have remained within the normal range and the haematocrit has risen from 21% to 27%. Other clinical data including white blood cell and platelet count and serum protein electrophoresis have been kept within normal limits. Ulnar motor nerve conduction velocity has been improved from 38 m/sec to 41 m/sec.

Residual blood volume is only 1.6 ml measured by using a $^{51}$Cr-labelled red blood cell method. No blood leak was observed during the course of the experiments.

![Figure 3. Dialysance of Toray M-1A in clinical situation](image1)

![Figure 4. Ultrafiltration of Toray M-1A in clinical situation](image2)
Figure 5. Urea, creatinine and uric acid level of chronically dialysed patient
DISCUSSION

The hypothesis that middle molecular substances play an important role in the pathogenesis of uraemia, especially in uraemic neuropathy, was introduced by Babb et al (1971). The dialysability of commercially available cellulose dialysers, however, is very poor for middle molecules. It is for this reason that we have made effort to develop the PMMA capillary kidney.

Experimental and clinical results were satisfactory. In vitro dialysance of inulin at Q_B 200 and Q_D 500 was as much as 36 ml/min.

As is well known, one of the accompanying characteristics of a membrane highly permeable to middle molecules, is a too high flux of water which may lead to hypovolaemic shock. Man et al (1973), contrived a closed batch type artificial kidney in which the volume of dialysate was fixed at 75:1, thus avoiding excess water removal. This method was also used for the Rp 6, a new high flux type dialyser using a polyacrylonitrile membrane.

The PMMA dialyser is also a high flux type, (Okazawa et al, 1975), with an in vitro ultrafiltration rate of 20 ml/min/100 mmHg. It decreases, however, to 7 ml/min/100 mmHg in the clinical situation, making it usable in a single pass system.

Clinical observation of 3 times weekly, 5 hour dialysis has been enough to assure the well being of an anuric patient.

As for removal of middle molecules, no adequate assay system has been provided as yet. It is, however, noteworthy that the recovery of ulnar motor nerve conduction velocity and normalisation of abnormal cutaneous pigmentation have been observed in one patient chronically treated with the dailyser.

CONCLUSION

The polymethylmethacrylate capillary kidney has the following advantages:
1) the membrane is more permeable to middle molecules; 2) the ultrafiltration rate is 4-5 times greater; 3) the residual blood volume is much less, and 4) wash-out of formalin is much easier than in other commercially available cellulose kidneys.

References