OBSERVATIONS ON THE USE OF THE ARTIFICIAL KIDNEY*

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still a hazardous occupation. In our experience over the past 7 years, many severely traumatized patients, especially burned cases and those who incurred prolonged periods of

is nevertheless sometimes fatal. It was therefore decided to acquire a Kolff-type of 'artificial kidney', the use of which might tide the patient over reversible kidney lesions.

This Travenol 'disposable twin-coil kidney'[1,2] has been used so far on 3 occasions in this hospital. It is intended to

* Paper presented at a clinical meeting at the Ernest Oppenheimer Hospital, 20 November 1958.

describe its use in our metabolic unit, some practical points, and some difficulties that have arisen.

The Principle of the Coil Kidney

The coil kidney consists of two lengths of cellulose tubing enveloped in fibre glass screens which are wrapped around a central cylinder. This tubing acts as a semi-permeable membrane. The heparinized blood is pumped through it at the rate of 200-400 c.c. per minute.

Dialysing fluid, the composition of which can be altered to suit each case, circulates around these tubes, and by processes of osmosis, hydrostatic pressure and simple filtration the blood is brought into equilibrium with the surrounding dialysing fluid. When this stage is reached further dialysis of the blood can be obtained only by renewing the dialysing fluid. The composition of this fluid, which is almost standardized, is as follows:

mEq. per litre		*g. per* 100 *litres*	
Sodium	133	NaCl	570
Potassium	5	$NaHCO_3$	300
Calcium	5	KCl	40
Magnesium	3	$CaCl_2$	28
Chloride	110	$MgCl_2$	15
Bicarbonate	36	invert sugar	0·4%

A built-in thermostat maintains the dialysing fluid at a constant temperature (39°C), and the pH of the fluid must be kept at approximately 7·4 in order that no haemolysis of the blood shall occur.

The average urea clearance obtained during dialysis is from 100 to 300 c.c. per minute,[3] depending on the rate of flow through the coils.

Team-work in the use of the artificial kidney is of the greatest importance, for the procedure occupies several hours. In the early stages good team-work enables the preparation of the patient and the priming of the 'kidney' to be completed simultaneously.

Routine pre-operative skin preparation of the arms and legs from the knees to the umbilicus is performed by the nursing staff in the general ward. The patient is then transferred to the metabolic ward, where the selected blood-vessels are exposed by the surgeon.

The priming of the 'kidney' is under the control of the physician and an assistant; it entails the assembly and testing of the apparatus, the preparation of the required dialysing fluid, and the filling of the inflow tubes, the coil and the outflow tubes with 2-3 units of inter-matched heparinized blood. Each unit must also be individually cross-matched with the patient's blood.

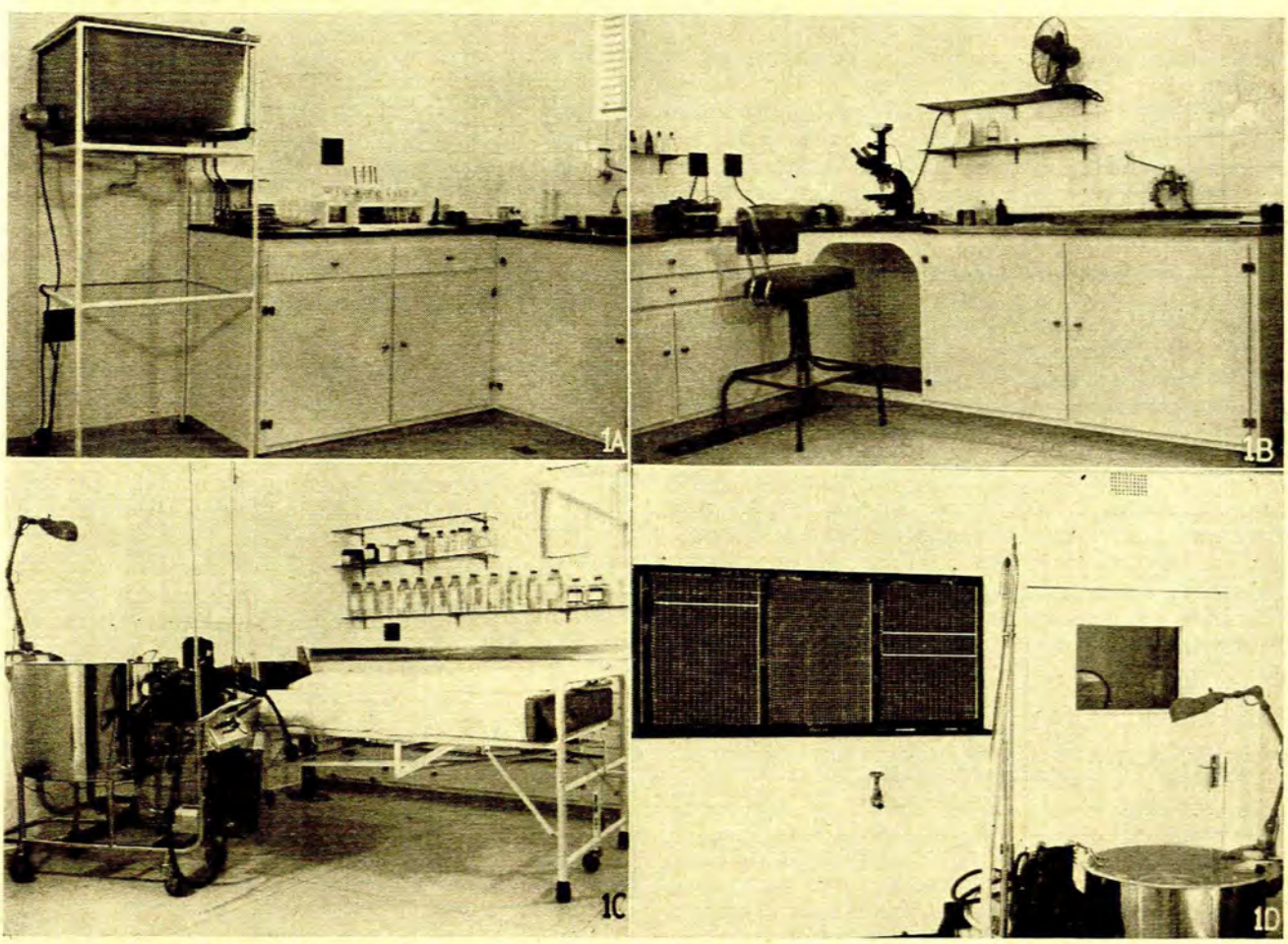

Fig. 1. A and B are views of the preparation room showing separate tank for preparation of new dialysing solutions, etc. C and D are views of the dialysis room showing the 'artificial kidney' etc. Beneath the blackboard is the tap which allows fresh dialysing solution to be run from the tank shown in A into the 'kidney' when change-over of the solution is necessary.

At this stage the patient is heparinized, the cannulae are inserted into the exposed vessels, which are then attached to the input and output tubes on the 'kidney', and the machine is switched on. It should be possible to accomplish this 30-45 minutes after beginning the preparation.

There is constant supervision of the patient by a nursing sister throughout the haemodialysis. She records the pulse rate and the blood pressure every 5 minutes, and informs the house-surgeon of any change. This is particularly important during the first 30 minutes after the operation commences.

The house-surgeon watches the apparatus for any dangerous rise in pressure in the coil and any leak that may occur through it. If either happens the machine is switched off until the fault is corrected. Samples of blood are taken from the circuit half-hourly for estimation of the serum electrolytes and blood urea, and to check on the clotting time. These investigations are carried out by the technician in the clinical laboratory, and the results are charted. The pH of the dialysing solution is checked hourly by the laboratory technician and is adjusted by altering the rate of flow of carbogen through the solution.

In this hospital a metabolic ward is set aside for artificial-kidney procedures. It consists of two adjoining rooms each about 13 × 12 feet in size (Fig. 1). Their floors, made of terrazzo, are sloped to drain any spill of old dialysing solution that may occur during replacement with the fresh solution.

One room is the 'preparation room', which is used for the initial priming of the machine and for the subsequent preparation of fresh dialysing solutions during haemodialysis. It is therefore fitted with cupboards for the storage of chemicals, intravenous solutions and drugs that may be required for the 'priming' and during haemodialysis. A spare 'disposable coil' must always be available as a replacement in the event of a fault occurring in the one being used. The preparation room is also used during haemodialysis for the half-hourly estimation of the serum electrolytes and the hourly pH of the dialysing solution.

Haemodialysis takes place in the second or 'dialysis room', when the vessels have been exposed and the primed artificial kidney has been wheeled through. It is equipped with a Fowler bed fitted with soft dunlopillo mattress, and a surgeon's hand-basin. Blackboards are fixed to the wall to chart graphically the levels of the serum electrolytes and blood urea and the blood pressure of the patient.

Carbogen, oxygen and nitrous oxide are piped through to the dialysis room. Carbogen is constantly bubbled through the dialysing solution to assist the maintenance of the pH, and oxygen and nitrous oxide are immediately available should they be required.

An operating-table type of anaesthetic screen is fitted to the side of the patient's bed, so that the actual artificial kidney is obscured from the patient's view.

The efficiency of the dialysis depends on the relative electrolytic and metabolic differences between the dialysing fluid and the patient's serum and after dialysis has continued for 1½ - 2 hours it is usually advisable to renew the dialysing solution according to the patient's requirements. To hasten this change-over a separate tank (also thermostatically controlled at a temperature of 39°C) is provided, so that the new solution can be prepared immediately before the change-over is effected. By this means 'lost' dialysing time is reduced to a maximum of 10 minutes, which is the time required to drain and refill the tank.

CASE REPORTS

Case 1

The first case treated with the artificial kidney was one of chronic renal insufficiency. The indications for dialysis in chronic renal insufficiency are not well defined. Merrill[4] suggests 3 indications, viz. (1) when intercurrent stress overtaxes the renal reserve, (2) to relieve the nausea, vomiting and anorexia of patients whose course has been gradually downhill, (3) to prepare patients with chronic nephritis and renal failure for necessary operation, or when renal decompensation has occurred after surgery. This patient was a case of uraemia, thought to have been precipitated by an intercurrent pulmonary infection, in a young tropical Native with previously compensated chronic renal disease. A severe normochromic anaemia attributable to the renal condition was also present.

The immediate treatment given included the use of (*a*) antibiotics to combat infection, (*b*) the restriction of fluid intake (protein-free) with adequate calories in the form of glucose, and (*c*) blood transfusion. The initial response was good, with improvement in the urinary output, and the infection appeared to be under control. However, about 2 weeks later, while he was still on restricted fluids, deterioration commenced. Oliguria developed and a pericardial friction rub and a protodiastolic gallop were heard. There was a slight diarrhoea and the patient gradually began to show signs of mental involvement. On 4 June 1959 he was mentally clouded and drowsy, and in addition the serum potassium had risen to 9·12 mEq. per litre.

As it was still hoped that compensated renal function would return to the extent that the patient could be sent home, it was decided to apply haemodialysis immediately. However, 3 hours elapsed before the dialysis began, owing firstly to the time necessary for the 4 units of blood to be crossed and inter-matched, and secondly to precipitation occurring in the dialysing solutions when the calcium and magnesium chloride were added. It became evident that the pH of the solution must be brought to 7·4 *before* the calcium and magnesium chloride are added.

Thirty minutes after dialysis began, back-pressure on the output side of the coil developed owing to an obstruction in the 'venous'

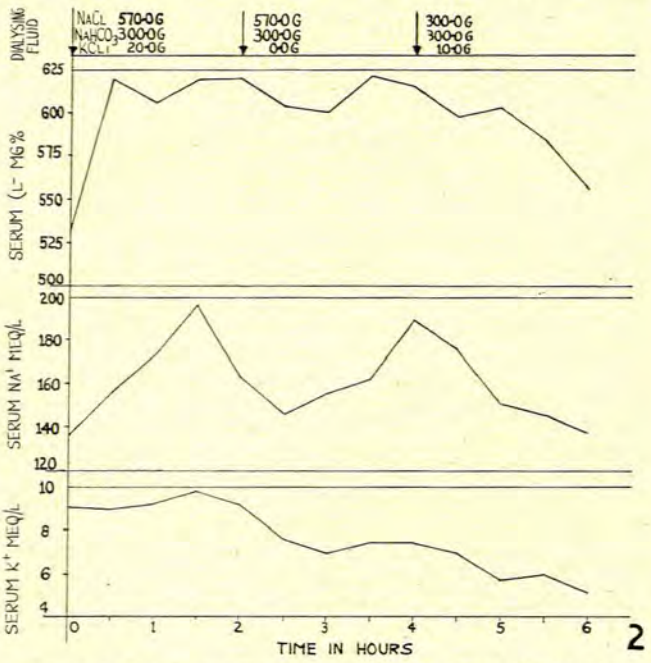

Fig. 2. Graph showing the biochemical results during haemodialysis in case 1. The arrows indicate the time of renewal of the dialysing solutions and the weights of NaCl, $NaHCO_3$ and KCl per 100 litres used in each solution are shown.

cannula. This necessitated replacement of the polythene cannula and change in the cutdown. In spite of this the pressure again built up, and remained high throughout the procedure. The use of a Martin's blood pump on the output tubing reduced the back-pressure sufficiently to prevent a dangerous rise in pressure in the coil. Haemodialysis continued for 6 hours, and the results of the serum electrolytes are shown in Fig. 2.

By the end of dialysis there was an obvious improvement in the patient's condition—he was no longer drowsy, and the proto-diastolic gallop had disappeared. There was, however, no improvement in the renal function and the patient's condition became worse about 4 days later. Death from uraemia occurred on the 8th day after dialysis.

Post-mortem examination showed small contracted kidneys with granular surfaces and reduced cortico-medullary ratio. The heart was enlarged, and there was a moderate straw-coloured pericardial effusion. Terminal broncho-pneumonia was present. Histological examination confirmed the diagnosis of chronic glomerulonephritis.

Case 2

A Shangaan male, aged 25, was admitted to hospital on 1 September 1958 with severe second-degree burns after an explosion of methane gas underground; 60% of the body surface was involved.

Routine treatment was instituted and for the first 2 days the urinary output was satisfactory, with good concentration. On the 3rd day his general condition had deteriorated, and although the urinary output was still good, the specific gravity varied between 1,012 and 1,014. There had been a slow rise in serum potassium with a falling blood pressure. On the 4th day the serum potassium was 7·25 mEq. per litre, and in spite of a good urinary output it was decided to perform haemodialysis.

Dyspnoea and cyanosis came on suddenly 2½ hours after dialysis was begun, and the blood pressure dropped. In spite of resuscitative measures the patient died, and at autopsy a massive pulmonary infarction was found, due to embolism from deep-vein thrombosis in the calf. The effects of haemodialysis in this case are shown in Fig. 3. During the procedure it was again noticed that there was a moderate rise in back-pressure on the output side of the coil, but no active measures to counteract this were necessary.

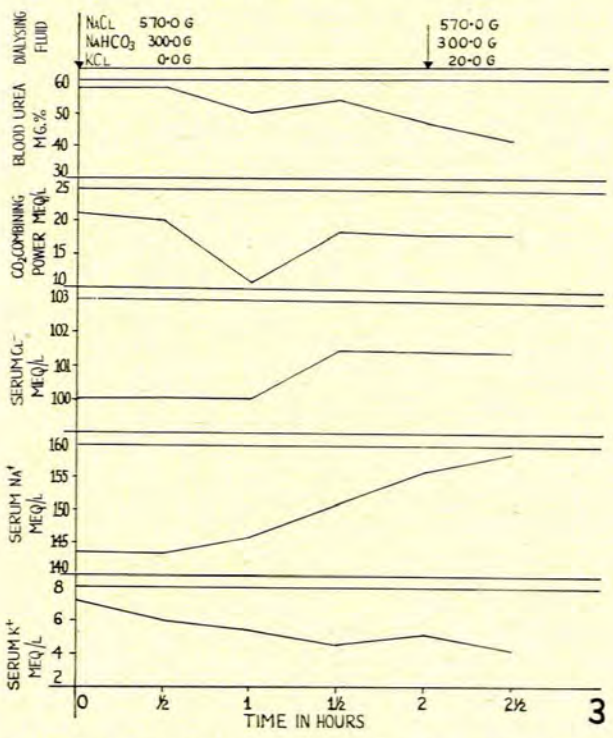

Fig. 3. Graph showing the biochemical results during haemodialysis in case 2.

Case 3

A 29-year-old Native from the Northern Transvaal, suffering from tuberculous osteitis of the spine, underwent a spinal fusion on 24 October 1958. The operation was uneventful, 2 units of blood being given as routine. A few hours after the operation he became restless, and there was severe bleeding from the operation wound. He was severely shocked, and for 6 hours the systolic blood pressure fluctuated between 80 and 90 mm. Hg.

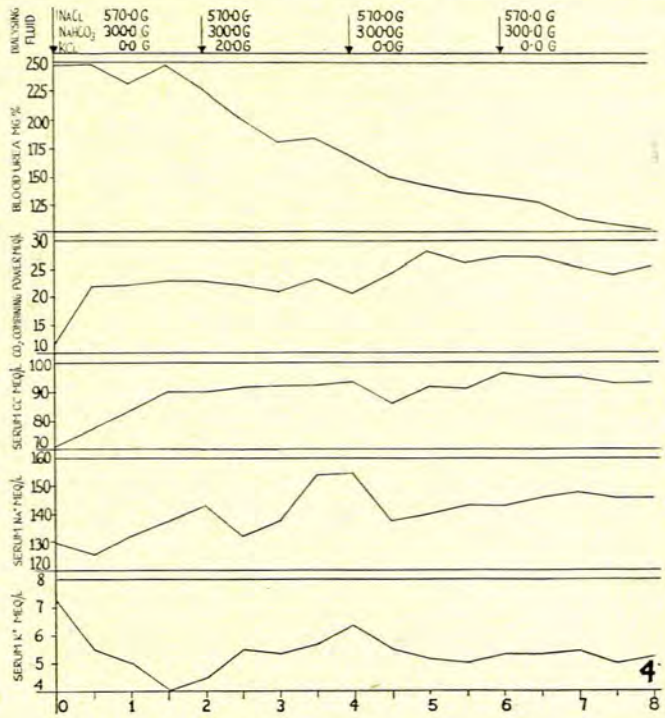

Fig. 4. Graph showing the biochemical results during haemodialysis in case 3.

It was subsequently proved that a major blood-transfusion incompatibility had occurred. The patient was Group O Rh-positive, and owing to an error in interpretation of the cross-match he had received 500 c.c. of blood from a Group-A Rh-positive donor. A coagulation defect occurred as a result of the transfusion reaction, and oozing continued for 12 hours.[5]

Treatment consisted of transfusion of further carefully cross-matched blood, with intravenous cortisone and noradrenaline to maintain the blood pressure, and subsequently restriction of the fluid intake. For the first 4 days there was complete anuria. On the 5th day the patient passed 200 c.c. of dark urine but his general condition was worse. The serum potassium was 5·5 mEq. per litre and the blood urea 250 mg.%. On the 7th day he was severely acidotic (CO_2 combining power 12·0 mEq. per litre), the blood urea was 320 mg.%, and the serum potassium was 7·0 mEq. per litre, with early ECG changes of hyperpotassaemia. The urinary output had fallen to 60 c.c.

Haemodialysis was performed and continued for 8 hours. Although electrolytic improvement was noted during the procedure (Fig. 4), clinical improvement was not apparent until 6 hours later. (Note: No back pressure on the coil developed during haemodialysis in this case. This was attributed to the larger polythene cannulae used, and to the fact that they were carefully rinsed with heparin before use.)

Subsequently the patient made good progress. The urinary output increased daily, and by the 16th day after dialysis he was passing 2,000 c.c. of dilute urine daily. Unfortunately he died suddenly on the 21st day as the result of a large pulmonary embolus lodged at the bifurcation of the pulmonary artery.

At post-mortem the kidneys were slightly pale in appearance but were otherwise normal.

DISCUSSION

Notwithstanding the fatal outcome in these first 3 cases, their favourable response to haemodialysis confirms the usefulness of the artificial kidney as part of the management of renal insufficiency.

The operation of the Kolff 'disposable coil' type of artificial kidney is not difficult,[6] but it must be stressed that an experienced team of operators with a well-equipped metabolic unit is essential for the efficiency of the whole procedure with the minimum of danger to the patient. It is also considered important to record the electrolyte and urea levels and the CO_2 combining power half-hourly. This not only ensures that effective dialysis is taking place and that the machine is operating properly, but also enables one to gauge better when to renew the dialysing fluid and to adjust its composition. A few other points have merged during our experience with the 'kidney'.

Choice of Blood Vessels for Cannulization

In all 3 cases the most effective combination of vessels used was that of the radial artery and the inferior vena cava. A blood flow of at least 200 c.c. per minute is available through the radial artery,[3] and at this rate the urea clearance is approximately 140 c.c. per minute. The inferior vena cava, cannulated *via* the saphenous vein, is used on the output side. It has been our experience that back-pressure may develop at this place, but this danger is minimized by using well-heparinized large-bore cannulae (size 3-5 mm. internal diameter).

For cases that may require repeated dialyses it is suggested that the Seldinger technique[7] can be used on the femoral artery at the input side in cases where both radial arteries have already been used.

Heparinization of the Patient

8,000 – 10,000 units of heparin has been recommended for patients of approximately 75 kg. weight. It is our experience that this dosage increases the coagulation time to more than 60 minutes, and it would seem that 5,000 units is sufficient for the average patient. In cases 1 and 3 a further 2,000 units was required halfway through the procedure to maintain an adequate coagulation time.

pH of the Dialysing Solution

Once haemodialysis was started it was noticed in all cases that the solution rapidly became more alkaline and that in order to maintain the pH at a reasonably constant level, it was necessary to bubble the carbogen through the solution very rapidly. Carbogen consists of 10% carbon dioxide and 90% oxygen, and it may well prove better to use 20% carbon dioxide and 80% oxygen.

Citrate Intoxication[8]

Citrated blood which is also heparinized (2,000 units to each unit of blood) was used for the 'priming' of the kidney. In cases 1 and 3 citrate intoxication tended to occur during haemodialysis, in spite of the intravenous administration of 10 c.c. of 10% calcium gluconate for every unit of blood used. As soon as any fall in blood pressure was noticed a further 10 c.c. of calcium gluconate was given, and this dramatically restored the blood pressure to normal (Fig. 5). It is therefore suggested that on the occurrence of hypotensive episodes, besides ensuring the proper functioning of the machine, further calcium should be given before other resuscitative measures are applied.

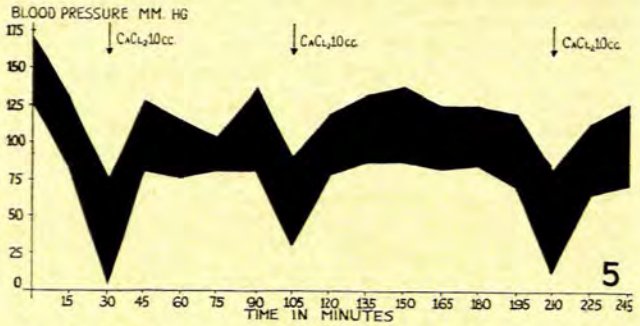

Fig. 5. The blood-pressure chart in case 3, showing the response to intravenous calcium chloride in hypotension due to citrate intoxication.

Time of Dialysis

Although the duration of haemodialysis should be sufficient for elimination of most of the toxic metabolites and renal toxins, and for correction of the electrolytes, it is nevertheless desirable that the time should be as short as possible, because the procedure is extremely exhausting to the patient. For this reason the use of a separate tank is recommended, in which the new dialysing fluid can be prepared shortly before the change-over. It has been found that the time necessary for 8 hours of haemodialysis is thereby reduced by at least 1 hour.

Pulmonary Embolism

Although in cases 2 and 3 the cause of death was pulmonary embolism, the emboli cannot be attributed to the use of the artificial kidney. In case 2, not only was the time of haemodialysis too short for the dialysis to be implicated, but there was post-mortem evidence of pre-existing deep-vein thrombosis in the leg. In case 3 the embolus had originated from a large thrombus in the right iliac vein; this thrombus is thought to have occurred as the result of the preceding 50%-dextrose infusions which had been given through a polythene cannula in this region.

During the oliguric phase it is necessary to maintain a certain intake of basic fluid and calories until diuresis begins, and 50%-dextrose infusions *via* polythene cannulae into large veins are frequently used. However, the risk of thrombosis around the cannula is great,[9] and although embolization from this site is uncommon, it is probable that prolonged anticoagulant therapy would be beneficial in preventing the occurrence of thrombosis.

Haemodialysis for renal insufficiency does not increase the risk of thrombosis and subsequent embolization.

SUMMARY

1. The principle of the 'artificial kidney' and the constitution of a metabolic unit for the purpose of haemodialysis are described.

2. Three cases who underwent haemodialysis are reported. One was a case of chronic renal insufficiency and the other two were cases of acute renal insufficiency. Although these cases died ultimately, the beneficial effect of haemodialysis was apparent.

3. The ease of operation of the Travenol 'disposable twin-coil kidney' is stressed, and the methods used in countering the few practical difficulties that arose are described.

I wish to thank the Medical Superintendent of the Ernest Oppenheimer Hospital, Dr. T. Leontsinis, for helpful suggestions and criticism in the preparation of this paper, and am indebted to him and to the Medical Consultant of the Anglo American Corporation for permission to publish these cases. My thanks are also due to the medical staff and the laboratory technologists of the hospital for their cooperation and assistance.

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