

REPORT ON THE UNITED KINGDOM ARTIFICIAL
KIDNEY UNITS

for

THE ROYAL INFIRMARY, EDINBURGH.

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By

J.S.Robson and H.A.F.Dudley

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REPORT ON VISITS TO THE ARTIFICIAL KIDNEY UNITS
IN THE UNITED KINGDOM

INTRODUCTION

The purpose of the visits to the three Artificial Kidney Units in the U.K. was to obtain as much information as possible about the design and operation of the artificial kidneys in use in this country, to discover the nature of the Units in which the kidneys were located and the staff used in their operation. In addition, as a secondary aim, it was hoped to gain some information of a more general nature regarding the value of this form of therapy. The centres visited were the Unit in Leeds General Infirmary, the R.A.F. Renal Unit at Halton and the Unit in the Postgraduate Medical School, Hammersmith, London.

THE LEEDS UNIT

1. The Machine.

The machine in operation at Leeds is of the original Kolff-Brigham design. It is purely a dialysis instrument involving arterial and venous cannulation. The blood flows from the patient through the coils of cellophane by the Archimedean screw action of the rotating drum which carries the cellophane tubing. The blood is then scavenged from the tubing by a pump and passed back to the patient through a clot catcher. The pump is modified from the original design by a fine "bleed" adjuster which varies the amount of suction applied. The machine is fitted with one flowmeter of the ball type. Frequent re-adjustments of the pump seem necessary and are carried out according to the state of fullness of the last two cellophane coils of the kidney. This appears a crude method of estimating alternations in the volume of blood in the instrument and demands very careful watch by the responsible doctor. In our view this method of control is a drawback. If blood is not returned to the patient for any reason it is possible for him to be exsanguinated into the machine in a very short space of time. The efficiency of this model in terms of blood flow and urea clearance is high, being 400 - 600ml. and 100 - 300ml. per minute respectively. A priming volume of blood of 1 pint is required. The machine costs about £3,000 and each dialysis involves expenditure of £4 - £5.

2. The location of the machine & staff.

The instrument itself is based in a 6-bedded metabolic unit and Professor Tunbridge (medicine) and Mr. Pyrah (surgery) are in charge of it. Patients who require dialysis are admitted to the wards of one of these two persons but the greater part of the running of the unit and the dialysis and after care is delegated to Dr. McCracken (lecturer in medicine) and Mr. Parsons (External Staff M.R.C. research fellow in surgery). The dialysis is carried out by either Dr. McCracken or Mr. Parsons and there are one to two other doctors (registrars) who have experience of the instrument. The nursing care of the patient during dialysis is the duty of the Metabolic Ward and one of the two Sisters in this Unit is responsible for day to day care and sterilisation of the Unit. Fluids for the bath are made up to order by the hospital pharmacy. Initially, hourly biochemical monitoring with determination of the blood concentration of Na, K, Ca, HCO₃ and urea

was done during the six hour dialysis period, but at the present time the members of the Unit feel they have gained sufficient experience with the machine to dispense with this in the great majority of patients. Blood sampling is carried out before and after dialysis.

For the actual performance of the dialysis two doctors set up the instrument, prepared and sterilised under the care of the sister. This procedure, with the aid of a nurse, takes 1 - 2 hours. A full time technician for the care and maintenance of the machine has just been allocated but not yet appointed. The dialysis procedure takes 6 hours. There is always at least one doctor and a nurse in attendance.

3. Results etc.

The Unit has carried out about 140 dialyses in 121 patients, some from as far afield as Glasgow, in eighteen months. Their experience is considerable. It is of interest that in the last twelve months all of their 17 patients with obstetrical anuria have survived. Mortality in other groups has of course been higher but their overall clinical results are impressive. Post-operative acute renal failure comprise their next largest group (14 patients in twelve months). Experience with poisons is limited (3 patients) but treatment was successful in all cases.

A programme of "operational" research is under way to assess the capabilities of the machine but more basic research is precluded by the extensive clinical commitments of both machine and staff.

Part of the good clinical results obtained by the Unit are attributed by them to the modifications carried out to increase the blood flow through the machine and its urea clearance. Flow through most artificial kidneys is about 350 ml./min. but by boosting the efficiency of the pump this has been increased to approximately 600 ml./min. By this means and by a slight increase in length of the cellophane tubing very high urea clearances have been obtained (300ml./min.). By argument from analogy it is thought that the movement of other substances across the membrane is probably increased and that this may contribute to the good results. In spite of these high rates of flow no haemo-dynamic difficulties have been encountered; this is probably attributable more to the excellence of the care of the patients and control of the machine than to any other factors.

R.A.F. RENAL UNIT HALTON.

1. The Machine.

The Renal Unit at Halton has an artificial kidney of the Kolff-Travenol type. This instrument is based upon a disposal coil of cellophane supported by nylon through which blood is bathed in an internally circulating bath fluid. Blood is removed from an artery and supplied to a Sigma pump which circulates it through the coil and returns it to a clot catcher and then to the patient's vein. Vein to vein operation is also possible on this machine but has been used by the unit only once in 22 dialyses. Unlike the Leeds machine, the blood circulates under predetermined pressure generated by the pump and the instrument, therefore,

Flow rate recording on this and the other machines was rudimentary (Leeds) or non-existent (Halton)

performs ultra filtration as well as dialysis. The volume of blood in the machine depends on the tension pressure attained by the priming operation before the patient is connected to the circuit and this pressure is maintained throughout therapy. The possibility of the patient bleeding into the machine is therefore minimal and the operational control necessary to maintain a given pressure small. In this respect the machine impressed us as being simple to operate, of great safety, and in these respects superior to the Leeds apparatus. A priming volume of blood of 2-3 pints is necessary.

The flow rate of this machine is estimated to be 300ml./min. with a urea clearance of 150ml./min. Considerable fluid (up to 10L) can be removed from the patient by increasing the pressure in the cellophane. In the Unit's experience a net fluid loss of 1-2L is obtained on average but the Unit has no experience of clinical situations where larger amounts of fluid loss might be desirable or indicated. The machine costs about £750 and, using the disposable coil, each dialysis involves an expenditure of £25.

2. Location of Kidney & Staff.

This machine is under the charge of Group-Captain Jackson, medical specialist, and is located near Captain Jackson's medical beds. It is hoped in the near future to move it to a smaller unit of some six beds which will then comprise a self-contained renal unit.

Four doctors can use the machine and two are on duty during a dialysis with two nursing sisters, the one attending the patient (recording 1/4-hourly B.P.'s, pulse rate, etc.) the other helping one of the doctors with the machine. Very little operational attention is needed in the great majority of instances, but alteration in pressure during a run may indicate, for example, blocked inflow tubes or leak in the cellophane coils, and rapid correction of these would demand all available assistance at a moment's notice. One doctor and one nurse can set up the machine in 50 minutes and this is conveniently done immediately before a run, while the patient is being prepared and undergoing arterial and venous cannulation.

As in Leeds, biochemical analysis is being reduced with experience, and blood determinations are being done only before and after dialysis in the majority of cases. Blood clotting time, however, is routinely performed every hour. Captain Jackson believes this to be important, especially in traumatic cases where bleeding from other sources is likely.

3. Results.

22 patients have been treated in the 10 months during which the machine has been in operation, and this rate is steadily increasing. The machine has been in use as often as three times in one week. No oedematous patients have been treated. The patients dialyzed include some suffering from obstetrical anuria, traumatic oliguria, acute nephritis, and post-operative states with acute renal failure. The majority of these have survived and no deaths have occurred on the machine or have been ascribed to its use.

Captain Jackson is conscious of the susceptibility of uraemic patients to infection and has grown *Proteus pyocyaneus* from the bath water in the machine. The significance of this is at present uncertain. The operation

of dialysis is regarded as a surgical procedure demanding surgical asepsis and he is presently investigating the value of an ultra-violet light attachment in the bath.

POST GRADUATE MEDICAL SCHOOL, HAMMERSMITH.

1. The Machine.

The instrument here is a developed version of the Kolff-Brigham dialyses manufactured in France by Usifroid. This instrument is a vein to vein dialyser, the circulation of blood being attained by both an inflow and an outflow pump, as well as by the screw like action of the rotating drum. The pumps, driven by the same motor, minimise the risk of bleeding into the machine, and the control of this is clearly superior to the Leeds instrument. It possesses some further detailed refinements including mechanical means for emptying the bath.

The vein to vein nature of the apparatus accounts for the flow rate of 250-300 ml./min., but the Unit was strongly of the opinion that adequate extraction could be carried out by this technique and the argument advanced by the Leeds group for the advantages of higher rates are considered by them to be rather academic.

The machine costs £2,800 with an expenditure of £4 - £5 for each dialysis.

2. Location of Kidney & Staff.

The machine is under the charge of a surgical and a medical consultant (Mr. Shackman and Dr. Milne) and is operated with the assistance of a medical and a surgical registrar, a staff nurse and two biochemical technicians. At the moment patients requiring dialysis are kept in either Mr. Shackman's or Dr. Milne's beds but a full Renal Insufficiency Unit is being planned with its own beds.

3. Results.

40 patients have been treated in 17 months and the number of patients is steadily increasing. The great majority suffered from acute renal failure of obstetric or traumatic origin. It is of interest that we saw two patients at the Post Graduate School and heard of one other at Halton, neither of whom would have been dialysed if the limited criterion of established tubular necrosis had been employed. In these patients uraemia was the result of a combination of urinary tract infection, post-operative catabolism and vomiting with water and salt depletion. High blood urea concentration and other electrolyte abnormalities were corrected within 6 hours, and in one of the patients at Hammersmith a second dialysis was performed six days later. Although the ultimate prognosis of these patients is likely to be determined by factors other than their renal function, the Units were convinced that these individuals would have died of uraemia and "toxaemia" soon after operation, if dialysis had not been available. In the patient dialyzed twice, Mr. Shackman believed that the patient would have died twice without dialysis! This experience provides some indication of the extended usefulness of the therapeutic measure beyond that classically accepted.

The facts relating to the type of instruments used in the three units, their mechanism of action, flow rates, efficiency, approximate cost and staff required for their operation are summarised in Appendix 1.

GENERAL CONSIDERATIONS APPLYING TO ALL THREE UNITS VISITED.

1. Water Supplies. All units are agreed that an adequate supply of thermostatically controlled warm water greatly simplifies the making up of the bath fluid. A local supply independent of the variable hospital supply is obtained in London and Halton by a Gas or Electric heating unit in the Artificial Kidney room. This may be regarded as essential to any artificial kidney unit. The variability of the Ca^{++} and Mg^{++} content of the Halton water supply has necessitated the fitting of ion exchange resins to the delivery tap, but this would seem unnecessary in Edinburgh.

2. Chemicals. Liaison with a biochemical or pharmacy Department for the supply of chemicals for the bath is essential.

3. Sterilisation. Some means of sterilising cutting-down equipment is required. If a Kolff-Brigham kidney is used special equipment is needed to boil and sterilise the cellophane coil. This is avoided by the use of the disposable coil kidney.

4. Comparison of Ultra filtration and Dialysis. Theoretically a dialysis instrument of the Kolff-Brigham rotating drum type does not remove water from the patient. This is possible, however, by the production of pressure filtration, with the use of an inflow pump, as is fitted on the Kolff-Travenol machine and was borne out in practice by the observation that the patients in Leeds rarely lost weight, whereas a loss of up to 3 Kg has been recorded at Halton in 6 hours. Some fluid extraction, however, can be obtained with dialysing machines by making the bath fluid hypertonic with dextrose, and water extraction has been achieved at Hammersmith by this technique. The extent to which this is possible is unknown, since the Hammersmith Unit did not possess adequate weighing facilities. There seems little doubt that a continuous accurate record of weight is of great value in the control of patients on the artificial kidney. In Leeds this is achieved by an Avery bed weighing scale at a cost of about £200. Similar instruments are on order for Halton and Hammersmith.

5. Flow Rates. Some remarks about flow rates have already been made. Dr McCracken at Leeds is convinced that high rates of flow are necessary, but the clinical results at the other centres suggest that the lower clearances do not significantly or necessarily detract from the therapeutic efficacy of the machine. The theoretical advantages to be gained from high rates of flow must be set against the increased difficulties of control which arise when a large arterio-venous fistula is present.

6. Artery to Vein versus Vein to Vein Machines. On a priori grounds it might be supposed that vein to vein machines would be preferable to those which necessitate arterial cannulation. This view, however, is not accepted by the two Units (Leeds and Halton) using artery to vein machines. Little difficulty is experienced in arterial cannulation and no complications have arisen. Furthermore, if a patient requires dialysis more than twice, arterial cannulation for the outflow track offers certain advantages. The radial artery may be cannulised at three sites in one limb

and there is little difficulty in finding three veins for the return of the blood. In similar circumstances, vein to vein use would involve the destruction of six veins and in these circumstances the jugular vein sometimes has to be used. In some subjects there has been considerable difficulty in obtaining channels for return of the blood. It would seem therefore that the disadvantages of artery to vein operation are more apparent than real.

7. Infection. It is the opinion of all three units that infection plays a considerable part in the death of the uraemic patient. Ideally, barrier nursing should be applied and to some extent this need is a strong argument in favour of the housing of candidates for dialysis and dialysed patients in a separate ward unit. All units regard dialysis as a surgical procedure and the dialysis room as an operating theatre. Reference has already been made to the Halton device of sterilising the bath water and the result of this experiment will be of some interest.

8. Reactions. The Leeds experience is that haemo-dynamic disturbances are very rare and they have not seen the development of hypertension reported by Merrill in Boston using a similar machine. At Halton, because of the large priming volume of the instrument, hypotension of a mild degree has been a not uncommon feature but has never caused alarm. Hypertension during dialysis has occurred at Hammersmith. Infective hepatitis has not been noted anywhere.

CONCLUSIONS AND RECOMMENDATIONS.

In general the recommendations regarding the function of and facilities for an Artificial Kidney Unit as expressed in the Memorandum submitted to the South Eastern Regional Hospital Board by the Artificial Kidney Subcommittee of the medical, surgical and obstetrical staff (March 1958) have been largely confirmed by our visit to these centres. In our opinion more precise conclusions may now be reached for the proposed Unit in The Royal Infirmary, Edinburgh.

1. The Type of Machine.

An ideal artificial kidney should possess the following qualities:-

- (a) Compactness and ease of assembly.
- (b) Minimum number of moving parts.
- (c) Easy sterilisation, or alternatively disposability of coil.
- (d) Adaptation to dialysis or filtration.
- (e) Small pumping volume.
- (f) Build-in control to prevent exsanguination into the machine.
- (g) Ease of maintenance.
- (h) Sufficiently high flow rates and efficiency to correct severe degrees of uraemia in a reasonable period of time.
- (i) Design which results in economy in capital cost.

It is certain that the limits of development in Artificial Kidneys have not been reached and that progress will continue to be made. Considering the history of the development of such machines over the last 20 years, however, it seems unlikely that any dramatic innovation will be commercially available within the next five years. Of the three machines seen, all fulfil their therapeutic demands in a period of some six hours

and all machines are capable of reducing concentrations of blood urea from levels of 500 - 700 mg. per 100 ml. blood to levels around 50 to 100 mg. per 100 ml. in this time.

The Kolff-Travenol pressure-dialyser possesses material advantages over the other two in respect of ease in sterilisation (i.e. disposable coil) ease of setting up and running, adaptation to ultra filtration and dialysis and, in our opinion, safety in the method and accuracy of the control of the blood volume in the machine. It is as efficient, in terms of its urea clearance, as the Hammersmith Usifroid model and the original Kolff-Brigham machine still used by Merrill in Boston, though its efficiency is significantly less than the "boosted" Kolff-Brigham machine at Leeds. We are of the opinion however that this lesser efficiency is not a material disadvantage to the patient and its doubtful value is to be set against the potential dangers of the Leeds apparatus which demands a degree of operational control considerably greater than that required for either of the other two models. The Kolff-Travenol machine is more compactly made and more easily maintained than the other two. It is very considerably cheaper in capital cost, though more expense is involved in each dialysis. We understand that it is possible to introduce new cellophane into the disposable unit by hand, a process which reduces the running cost to near the level of the other two models at the expense of time and simplicity. If this procedure were adopted the "disposable" unit would require to be sterilised as in the case of the cellophane in the other two models.

In so far as the removal of water from the patient is concerned, the Leeds unit provided no evidence that water could be removed by their machine and the weights of the patients before and after dialysis were not significantly different. The Hammersmith Unit (modified Kolff-Brigham) have the clinical impression that some water may be removed by increasing the concentration of glucose in the bath. The Halton Unit have not considered the problem systematically as their clinical material so far has not demanded such therapy. However, the data on weighings before and after treatment at Halton appear to leave little doubt that the claims of the makers of the instrument in this respect are correct.

2. Requirements for the Operation of an Artificial Kidney.

(A) The room in the Clinical Laboratory of The Royal Infirmary suggested for the location of the kidney is adequate in size, and on the basis of the experience of the three Units, would require to be fitted with:-

- (i) Electrical power.
- (ii) Sinks etc.
- (iii) A heater of sufficient capacity to deliver water (100L) at controlled temperature (102°F) within two hours.
- (iv) Sterilisers.
- (v) Surgical equipment for arterial and venous cannulation and blood sampling.
- (vi) Facilities for continuous recording of the patients' weight during dialysis e.g. an Avery bed.

(B) Medical Staff. The Units at Leeds and London are under the joint control of a physician and surgeon while the one at Halton is under control of a physician. We would recommend control by a physician and a surgeon

both capable of operating the machine independently and that one other member of the Staff should be able to do so.

(C) Nursing Staff. The machine and its ancillaries should be under the care of a Senior Nurse or Sister, preferably with operating theatre training. During a dialysis she and one other more junior nurse would be required. It would further simplify the use of the instrument if the Senior Nurse or Sister is attached to an operating theatre.

(D) Technical Staff. One full time biochemical technician under the supervision of a graduate biochemist of the Clinical Laboratory would be needed for the biochemical analyses and to help in the setting up of the machine.

The artificial kidney is a therapeutic instrument which is likely to be required intermittently, and because of this these centres have not appointed full time medical or nursing staff to run it. In all of them, the persons involved have other duties in the hospital. We are of the opinion that this is a desirable practice but it means that the persons involved must be able to relinquish these duties from time to time, at a notice which may be only 12 hours. This does not appear to have raised insuperable problems in the three Units.

3. The After Care of the Patients.

At the present time it is the practice of all three Units to care for the patients in the surgical and medical beds of the surgeon and physician responsible for the dialysis. Two of the three Units however (London and Halton) are making plans to locate their kidney near a self-contained unit which would form the Renal Ward and which would be under joint surgical and medical care. Although this may not be immediately practicable in the Royal Infirmary, there would seem to be little doubt that it should be the ultimate aim.

As presently envisaged it is proposed that some of the beds in Ward 21 are to be made available for patients who have undergone dialysis. While this arrangement would appear to be satisfactory for these patients dialysed for medical or obstetrical reasons the nursing staff of Ward 21 would be unable to deal with traumatic or other surgical patients in whom dialysis might represent only a small part of their treatment. This aspect of the problem requires further discussion. An immediate, if temporary solution would consist of using beds in Wards 7 and 8 for this type of case.

S U M M A R Y

1) On the basis of our visit to the three Artificial Kidney Units in the United Kingdom, we are of the opinion that the Kolff-Travenol Artificial Kidney with disposable coils and incorporating ultra filtration and dialysis is the machine which combines most advantages. Its simplicity of preparation and operation and its intrinsic safety are outstanding. It has the additional advantage of relative cheapness.

2) For the operation of dialysis two doctors and two nurses are required. One of the nurses should be senior and preferably have operating

theatre experience. One other member of the medical staff should be able to run the machine.

3) A full time biochemical technician is necessary.

4) The room in the Clinical Laboratory suggested for the artificial kidney when suitably equipped, would be adequate for the purpose.

5) The Artificial Kidney should ultimately form the basis of a Renal Unit (already envisaged in London and Halton) which would house patients of both surgical and medical nature, and which should be under the joint control of a physician and a surgeon. While Ward 21 is suitable for post-dialysis care of obstetrical and medical patients, the location of beds for the after care of patients with anuria of traumatic origin requires further consideration.

ADDENDUM ON OTHER TYPES OF ARTIFICIAL KIDNEYS

We have not had the opportunity of comparing the three machines in operation in England with the other three commercially available types. These are:-

The Alwall Kidney.

The Skeggs-Leonard Kidney.

Nephra II manufactured in Berlin

These kidneys are in current use in Scandinavia and in Germany. They all involve the principle of ultra filtration combined with dialysis and are therefore comparable with the Kolff-Travenol machine. From information available about the Alwall and the Skeggs-Leonard kidneys, it seems unlikely that they are superior to the Kolff-Travenol type. Information about Nephra II is promised by the manufacturers in Germany within two weeks. Although in some respects a final choice of machine for Edinburgh might best be made after obtaining comparable information on these machines, we do not think that a serious error in judgement would be made by the purchase of a Kolff-Travenol machine without further enquiry.

Appendix 1.

Instrument	Type.	Mechanism of action.	Number of pumps	Blood Priming Volume.	Flow rate.	"Efficiency".	Price**	Operators.
Leeds	Kolff-Brigham	Dialysis Artery-Vein	1	1 pint	400-600 ml./min.	High.	£3000 +£4-£5 per Dialysis	2 doctors. 1 nurse. 1 technician.
Hammersmith	Kolff-Brigham (Usifroid)	Dialysis	2	1 pint	300 ml./min.	Moderate.	£2800 +£4-£5 per Dialysis	2 doctors. 1 nurse. 2 technicians.
Halton	Kolff-Travenol disposable coil.	Dialysis + ultra filter artery to vein or vein to vein.	1	2-3 pints	300-400 ml./min. (? can be increased)	Moderate.	£750 +£25 per Dialysis*	2 doctors. 2 nurses. 1 technician.

* likely to decrease.

** prices are approximate.