Guide for treating patients by chronic dialyses with the twin-coil artificial kidney

ARTHUR SHIMIZU, M.D.,*
SATORU NAKAMOTO, M.D.,
WILLEM J. KOLFF, M.D., PH.D.
Department of Artificial Organs

THE number of patients in need of maintenance dialysis is large, but the number actually treated is small. Maintenance dialysis with the twin-coil artificial kidney is not difficult. The patient and an adult relative can be taught the technical procedure and the patient can dialyze himself at home. The family physician or internist not trained in the use of the artificial kidney does not have to know the technical details. This guide, we hope, will help him and the intelligent patient to anticipate and to prevent common causes of difficulties, and to meet with understanding the problems that may arise.

I. Initial period.

A. Diagnosis. A definitive diagnosis of the primary disease of the patient in chronic renal failure may or may not be possible. However, in regard to the patients in need of maintenance dialysis, the diagnosis often is merely an academic matter.

B. Improvement of uremic syndrome and complications. These conditions can be dealt with by repeated short dialyses while the patient is undergoing the initial diagnostic workup.

C. One should obtain base line assessments of:

1. Calcium and phosphorus metabolisms
2. Peripheral neuropathy
3. Cardiac status
4. Liver function
5. Carbohydrate and protein metabolisms

II. Maintaining the patient on chronic or intermittent dialyses. The outline covers five aspects:

A. Maintenance of "ideal" predialysis weight and "ideal" predialysis standing blood pressure. A rationale of consequences of excessive losses.

---

* *Fellow, Department of Artificial Organs.*
Supported by a grant from The John A. Hartford Foundation to The Cleveland Clinic Foundation with Willem J. Kolff, M.D., Ph.D., as principal investigator.

B. Mobilization at the earliest possible time.

C. Surveillance of the patient's clinical state and prevention of complications.

D. Education of the patient and his family.

E. Complications of chronic dialyses.

A. Maintenance of "ideal" predialysis weight and "ideal" predialysis standing blood pressure.

1. The rationale for the maintenance of the ideal predialysis weight and standing blood pressure.

a. The ideal weight and blood pressure are the predialysis weight and the predialysis standing blood pressure at which the individual patient feels well and which permits him maximal activity and mobilization. Usually the diastolic blood pressure is between 90 and 100 mm Hg. In this range of diastolic blood pressures the patient is probably slightly overhydrated.

b. Because uremic patients are rarely in positive nitrogen balance, true weight gain of tissue, if it occurs, develops gradually over a long period. Thus, if weight gain occurs suddenly, within a few days or weeks, this is invariably due to overhydration and increased salt intake.

c. Excessive intake of fluid beyond the intake of sodium causes increase in weight; thus, weight is the best factor to observe in respect to the fluid intake.

d. With 135 mEq of sodium intake there is a gain of 1 liter in the extracellular fluid (ECF) volume whether the person does or does not gain weight.

e. The ideal standing blood pressure is determined by the cardiac output, peripheral resistance, blood viscosity, and blood volume. Blood volume, which is a relatively insignificant factor in hypertension of most clinical states, becomes of paramount importance in patients on maintenance dialysis. When the ECF volume is expanded, then the blood volume also is expanded. When the patient takes excessive sodium, the ECF volume becomes expanded, since to maintain an osmotic equilibrium the water shifts from the intracellular fluid (ICF) volume, which constitutes two thirds of the body water, into the ECF.

f. To maintain the ideal predialysis standing blood pressure, restricted intake of sodium is essential, since serum sodium content determines the volume of the ECF, because, generally, sodium is restricted to the ECF space.

2. Consequences of excessive intake of sodium and water.

a. One of the main problems of patients on maintenance dialysis is the development of hypertension and/or overhydration.

b. Excessive sodium intake results in hypertension because of gross expansion of the ECF volume and, thus, the blood volume.

c. Excessive water intake results in overhydration, with heart failure and possibly hyponatremia. Usually the patient who becomes hypertensive is

also the one who becomes overhydrated, since excessive intake of sodium accompanies excessive intake of fluids.

d. Since the twin-coil kidney is efficient in ultrafiltering fluids and sodium, up to 6 kg of isotonic fluid can be removed over the 6-hour period; however, such large changes in fluid and in volume are extremely undesirable, since gross postdialysis hypotension will result, leading to weakness, and inability to stand, which may last as long as 24 hours. This syndrome, known as "'postdialysis fatigue," negates the purpose of chronic dialyses to keep the patient comfortable, happy, and useful to his family and to society. To be immobilized for 24 hours because of orthostatic hypotension prevents rehabilitation of the patient. Postdialysis hypotension also results in clotting of the arteriovenous shunt, with the threat of shunt failure.

e. The ideal patient is the one who does not require removal of fluid and sodium during dialysis because he limits his fluid and sodium intake. Thus, his predialysis and his postdialysis weight and blood pressure will be respectively similar or the same. This avoids the great changes between predialysis hypertension and postdialysis hypotension and ill health. The blood pressure and weight changes are aggravated by the use of antihypertensive agents, particularly before dialysis, which tends to cause a greater fall in blood pressure after dialysis. Thus, antihypertensive agents should not be used if it is at all possible to avoid them.

Comment

To avoid the necessity of removing fluid and electrolytes from the patient during dialysis, and to maintain equality of his predialysis and postdialysis weight and blood pressure, his sodium and fluid intake should be restricted during periods between dialyses.

Patients vary in their ability to withstand fluid and electrolyte removal during dialysis. Some patients can tolerate 3 or 4 pounds of weight loss without much difficulty during the postdialysis period. These patients are usually young men with good vasomotor control. But a 2-pound loss of weight in a middle-aged woman may result in a severe orthostatic hypotension immediately after dialysis. Those who can withstand considerable weight loss during dialysis, are permitted a certain degree of freedom in regard to salt intake; but the patients who are sensitive to weight and sodium removal must adhere strictly to limitations in dietary salt and fluid intake. Some medical centers have tried to solve this problem of liberal sodium intake by more frequent dialyses, such as three dialyses per week, or by interposing sauna baths to remove sodium and fluid.

When the physician is faced with the necessity of removing fluid and sodium during dialysis, he should remove them slowly over the 6-hour period of dialysis, remove an extra 250 to 500 g, and rapidly reinfuse from 250 to

500 ml of blood from the coils of the artificial kidney at the end of the dialysis. This procedure expands the blood volume over a period of a few minutes and minimizes the orthostatic hypotensive episodes.

3. The problem of excessive salt or sodium loss. Not all patients have the problem of hypertension due to excessive salt or sodium intake; some have the opposite problem of excessive salt or sodium loss, with contraction of the ECF volume, including the blood volume, leading to orthostatic hypotension.

a. The patient who has relatively good residual urine output who is a "salt loser" such as the one who has polycystic kidneys, pyelonephritis, or hydronephrosis, can lose daily from 50 to 70 mEq of the sodium in the urine; however, when the patient has been having chronic dialyses for some time, the urine output tends to diminish, with the result that serum sodium content also diminishes. Thus, the sodium intake must be concurrently reduced to avoid hypertension.

b. During the summer months, when the patient perspires excessively, sodium and fluid are lost excessively. Under this condition, supplemental sodium is necessary. The amount of time the patient spends out of doors during the summer months, or whether or not he lives in the tropics, and whether or not he works in an air-conditioned environment, all must be taken into account in reference to adjusting the patient's sodium intake. Living in a city apartment, without an air conditioner during the summer months may produce the effect of a sauna bath.

When extra sodium must be provided, it is probably best to continue the restricted sodium diet and add sodium bicarbonate supplements according to the individual sodium loss per day. This can be calculated by determining the 24-hour urinary sodium loss the day before dialysis and the day after dialysis and taking the average of the two amounts as the daily urinary sodium output.

B. Mobilization at the earliest possible time. Mobilization at the earliest possible time during the initial assessment period is mandatory to prevent muscle wasting. Once the muscle mass is lost it is most difficult to regain it, because it is hard to achieve any degree of positive nitrogen balance. The patient who remains in bed for the initial few weeks to a month is subject to considerable muscle wasting, sometimes even to a cachectic extent. Chronic dialyses can improve this cachectic condition only slowly and with great difficulty. The patient usually does poorly. By contrast, the patient who is mobilized as soon as he is able to tolerate being ambulatory, and is made to do everything for himself, starts off on chronic dialyses with a larger muscle mass and is in much better clinical condition than that of the inert patient, and he usually does well. The concern of the patient's relatives tends to be detrimental; they try to do everything for him instead of forcing him to take

care of himself. Educating relatives in regard to the importance of mobilization is an important part of chronic dialyses. Furthermore, exercise permits maximal use of muscles when peripheral neuropathy has contributed to loss of function and wasting of muscles.

C. Surveillance of the patient's clinical state and prevention of complications.

1. Pattern of predialysis weight and predialysis standing blood pressure.

a. The pattern of predialysis weight and standing blood pressure taken at home and recorded in the patient's notebook* should be examined before dialysis or during the early part of dialysis to estimate the amount of fluid and sodium that must be removed or added. When the blood pressure and weight increase, fluid removal is necessary. Usually these two conditions are correlated. When the blood pressure and weight are ideal for the patient, then no fluid should be removed during dialysis. On the contrary, it is mandatory to maintain the weight and blood pressure during dialysis so that the patient will not have orthostatic hypotension after dialysis.

b. It is important to ascertain how much weight loss the patient is able to withstand without the development of orthostatic hypotension. When the patient is able to withstand a considerable amount of fluid and sodium removal, there is no need to reinfuse blood at the end of dialysis. However, when the patient is highly sensitive to fluid removal, an extra 250 to 500 g of fluid and electrolytes can be removed and from 250 to 500 ml of blood can be rapidly reinfused at the end of the dialysis from the dialyzer, thus mitigating the hypotensive effects. The predialysis and postdialysis weight and blood pressures are recorded in the patient's notebook.

2. Progress studies of the patient in relation to the clinical and laboratory evaluation.

a. General examination is necessary only about once a month.

b. If the patient is not doing well and rehabilitation is not satisfactory, more frequent review of the clinical and blood studies must be made.

c. Electrolytes, blood urea, serum creatinine, and blood hemoglobin, blood flow through the artificial kidney during dialysis, a pattern of changes of the blood urea, serum creatinine, and serum electrolytes should be determined. The predialysis values will become stabilized at a particular level, and this is also true with the postdialysis values. This pattern will continue, provided the blood flow through the artificial kidney does not change, intake of protein, sodium, potassium, etc., is constant, and the urine output is constant. Once the pattern of these factors is known to the physician, only monthly determinations of electrolytes and other blood elements are necessary. However, if there is a change in the dietary input of protein, sodium, or

* *Each patient is given a notebook in which to record data, as taught while in training (see Section D).*

potassium, or there is a decrease in the blood flow or in the urine output, the pattern of these blood values will change, and closer monitoring of them becomes necessary.

Other situations may result in a gradual increase in blood urea and serum creatinine values in the presence of good blood flow, constant input, and constant output. Consideration must be given to possible infection, gastrointestinal bleeding, or ingestion of drugs such as prednisone or tetracycline. Other factors that may result in worsening of the above-mentioned blood values can be caused by technical problems. When, for example, there is poor recirculation of dialysate fluid, such changes as impaired clearance of creatinine, and increase in blood urea content, will follow.

d. Physicians should always be on the lookout for complications (see section *E*).

D. Education of the patient and his family. Each patient is given a notebook and is taught to keep a record of all important data in it. It is best to start with the book immediately after the patient's admission to the program so that he has practice in record-keeping before he goes home.

1. Diet. The importance of following the restricted protein, sodium, and potassium diet is something that must be constantly emphasized to the patient, since in this one aspect lies the greatest difficulty for a patient on a program of chronic dialyses. In addition to the above restrictions, a high-carbohydrate diet is encouraged, to spare protein maximally. The patient who does not do well on chronic dialyses is usually the one who is not able or not willing to adhere to the prescribed diet.

2. Recording blood pressure, weight, temperature, fluid intake, and urine output in the notebook. These records are important because the physician must be familiar with the pattern of changes in the factors recorded, so that he can order dialysis to be performed in a manner that is particularly suited to the individual patient.

3. Shunt care and reporting of complications. In view of the fact that the patient's life depends on shunt survival, the greater care that the patient takes of his shunt, the longer he survives. The aseptic technic for cleaning the shunt tube, and taking care not to injure it, should be emphasized. We are convinced that when possible it is best that the patient take care of his own shunt tube. Sometimes a member of the family will have to do it. It should not be done by a nurse or a technician or physician; they can carry infection from one patient to another.

The patient should be encouraged to report any change in his clinical state no matter how minor it may be, and certainly record them in his notebook.

E. Complications of chronic dialyses.

1. Cardiovascular complications. Overhydration and hypertension have been discussed in section *A*.

2. Pericarditis. A patient may have pericarditis at the beginning of a program of maintenance dialysis. Pericarditis may also occur during the first weeks of dialyses. Despite regional heparinization, a slow pericardial effusion and bleeding into the pericardial sac may occur with a resultant low cardiac output and possible pericardial tamponade, when this continues for some time. A surgically constructed pleuropericardial window leads to recovery in most cases; rarely does constriction occur. When this occurs, pericardiectomy probably is indicated.

3. Pulmonary embolism. Embolism in the lung rarely occurs from a clotted shunt, unless the shunt is infected. Shunts in the leg only are likely to be associated with pulmonary embolism.

4. Shunt infections. These infections are the most common to occur in the patient on chronic dialyses. Immediate and vigorous treatment of shunt infection is mandatory to prevent seeding into the blood, with serious sequelae and shunt failure. Usually the infectious organism is coagulase-positive *Staphylococcus,* though gram-negative organisms occur in about 20 percent of the lesions.

5. Subacute bacterial endocarditis and septic embolism have occurred and probably are due to the blood-borne infection resulting from a shunt-site infection.

6. Hematologic complications.

a. Bleeding. Hemorrhage, especially from the gastrointestinal tract, is a frequent complication of chronic renal failure. Chronic ulcers, acute stress ulcers, and diffuse hemorrhagic gastritis may occur. Regional heparinization during dialysis may be required.

b. Anemia. It is necessary to maintain blood hemoglobin at about from 7 to 8 g per 100 ml, and blood cell volume at about 22 to 25 percent, but not greater. When blood cell volume and blood hemoglobin are maintained at higher values, more blood is necessary each month, since the bone marrow then does not regenerate erythrocytes. Hemosiderosis may go on to hemochromatosis, but experience has indicated that this is not such a serious complication as was initially feared. But it is an additional reason not to give the patient frequent blood transfusions.

7. Serum hepatitis. This complication occurs in many patients on chronic dialyses and has been seen in an alarming number of attendant personnel. Through and through perforation with an injection needle through a plastic tube and into the attendant's finger or even leg has been the apparent mode of infection in some instances. Prophylactic intramuscular γ-globulin injections every three months have been recommended; however, there is some doubt that they help to prevent serum hepatitis, in contradistinction to their certain benefit in infectious hepatitis.

8. Incompatible blood transfusions. Incompatible blood transfusions constitute a rare complication, but are a hazard that must be watched. Errors are

always clerical and never due to mismatching; the labels should be checked and rechecked, especially when a patient has a chill.

9. Neurologic complications. Peripheral neuropathy is usually present when the serum creatinine content is more than 5 mg per 100 ml. The polyneuritis may regress or be aggravated by dialysis, particularly during the early stages of maintenance dialysis. It is believed by some clinicians that more frequent dialyses will improve the peripheral neuropathy; however, this has not been proved. Vitamin B-12 in large doses, and vitamin B complex have been given and perhaps are justified. Little is known about the cause of peripheral neuropathy in regard to uremia.

10. Calcium metabolism. Renal osteodystrophy may include osteosclerosis, or secondary hyperparathyroidism. All three conditions can occur individually, together, or in various combinations. In the diet that the patient is following, there is 400 mg of calcium per day. In the patient with uremia, calcium is not all absorbed. Thus, in patients on maintenance dialysis, osteomalacia is common, occurring generally in from 6 to 18 months after commencement of chronic dialyses. Various treatments have been recommended, such as increased calcium intake and high doses of vitamin D, starting with about 50,000 units and increasing if necessary, provided the serum calcium content is low. The dialyzing fluid contains about 5 mg per 100 ml of calcium, which is the physiologic concentration that the patient should have. If 1 liter of fluid is ultrafiltrated, since there is 5 mg of ionizable calcium in 100 ml of plasma, 1 liter of ultrafiltration will result in the loss of 50 mg of calcium. Metastatic calcification seems to be related to the amount of the phosphorus in the plasma or in the phosphorous calcium product. In any case, diminishing absorption of phosphorus from the blood by the administration of aluminum hydroxide, which binds the phosphorus in the intestine, seems to prevent metastatic calcification. All patients should be given aluminum hydroxide medication indefinitely. Secondary hyperparathyroidism may become autonomous and may necessitate removal of the parathyroid glands.

11. Endocrine complications.

a. Frequently menstruation stops in the woman who is on maintenance dialysis. If not, menstrual periods should be stopped with the aid of contraceptive pills.

b. Sexual impotence. This has occurred, but chronic dialyses generally do not interfere with sexual activity. Male patients, who were on chronic dialyses, have sired children.

c. Gynecomastia. This occurs in about 50 percent of uremic patients.

12. General wasting. The patient on long-term chronic dialyses may undergo generalized wasting and cachexia. This wasting may be related to prolonged negative protein balance, immobilization, and secondary hyperparathyroidism, probably the latter. Early and continued mobilization of the patient is a most important aspect in forestalling general wasting.

13. Care of the shunt catheter.

a. Summation of survival times of the shunt determines the survival of the patient. With current technics the patient has only 10 shunt sites, two in each lower limb and three in each upper limb, if he has good blood vessels. The importance of care of the shunt is obvious. Common causes of clotting of shunts and eventual failure of them are as follows. (1) Postdialysis fall in blood pressure; this frequently results in clotting. When this occurs repeatedly, the shunt eventually fails to function. (2) Infection around the shunt frequently causes shunt failure. When infection is at the shunt site and extends beyond, it cannot be cured without its removal. (3) Allergic manifestation to antibiotic ointment or powder around the shunt, cleansing soaps, or tapes, may result in clotting of the shunt. (4) Infection of the shunt can produce false aneurysms and rupture or erosion of the blood vessels.

Care must be taken that episodes of postdialysis hypotension do not develop. When the shunt becomes obstructed with a clot, the following procedure should be followed. (1) Remove the clot from the shunt as soon as possible. (2) Heparinize the patient for at least 10 days, with from 100 to 150 mg of heparin subcutaneously injected into the abdominal wall every 12 hours. Blood-flow rates through the artificial kidney should be observed closely during each dialysis to see whether or not decrease in the flow rate has occurred after the clotting episode. When the flow rate decreases to less than 100 ml per minute, it may be necessary to make a new shunt.

b. When a patient has repeated clotting of the shunt, continuous anticoagulant therapy should be considered; a sodium warfarin preparation may be used.