Technique of Refrigerated Coil Preservation Haemodialysis with Femoral Venous Catheterization

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The use of daily haemodialysis in the treatment of severe acute renal failure has resulted in a significant improvement in mortality rates: 75% of patients with acute "hypercatabolic" renal failure survived (Teschan *et al.*, 1960). More recently Murray *et al.* (1961), using continuous haemodialysis, obtained 80% survival rates in similar patients. However, these results were obtained with MacNeill-Collins (MacNeill *et al.*, 1959), Skeggs-Leonards (Skeggs and Leonards, 1948), or modified Kiil (1960) dialyser, which require considerable technician-time in assembling and are not available in most haemodialysis units. To overcome these problems, and to provide an efficient dialyser for daily haemodialysis at an economic rate which would be available in most renal centres, we have modified the Kolff twin-coil kidney (Kolff and Watschinger, 1956) and disposable circuit to permit repeated use of the disposable dialyser without extra blood requirements. In addition, the entire assembly and running of the dialyser can now be performed by trained nursing staff without any supervision by a physician.

Modifications of the Kolff Twin-coil Kidney

1. Refrigeration (Fig. 1)

To permit repeated use of the twin-coil disposable unit, refrigeration of the bath water has been required to reduce bacterial growth in untreated tap-water used for rinsing. Attempts to reuse the coils for dialysis without refrigerating the bath water resulted in disintegration of the fibre-glass supports to the cellophane coil. Lagging of the stainless-steel tank with a cellulose fibre-glass blanket and the addition of commercial ice (7 kg. of ice was added to 100 litres of tap-water) have kept the bath water at between 0 to 7° C. for periods of up to four hours with blood-flow rates of 200 ml./minute.

With cooling the *p*H of the bath water does not rise above 6.3; calcium was not precipitated and it has not been necessary to use lactic acid or to bubble CO_2 into the bath water. As the ice melts in the bath water a dilution effect occurs which produces a 7% reduction in electrolyte concentration gradually over the four-hour period. Sodium concentrations have fallen from 135 to 125 mEq/l. over a four-hour period. This dilution effect has not produced any complications during or after haemodialysis.

2. Rewarming System

To rewarm the blood after its cooling in the dialyser a coil of PVC tubing (8 in. (20 cm.) long, 0.5 mm. wall thickness, and 4 mm. lumen) was included in the return circuit between the bubble-catchers and the patient. The coil was immersed in a constant-temperature water-bath[1] kept at 40° C. (Fig. 1). Rewarming of blood to 37–37.5° C. was produced at blood-flow rates of 150–250 ml./minute with the temperature of the water rinsing the twin-coil dialyser varying from 0–7° C.

3. Blood Pump

The standard outflow circuit was modified for use with an occlusive twin-roller pump.[2] Two 30-cm. lengths of silicone-rubber tubing (4.5 mm. lumen; 1.6 mm. wall-thickness) were used in the roller pump[3] instead of the thin-walled Tygon tubing used in the Sigma pump. The mean rise in plasma haemoglobin (Crosby and Furth, 1956) was 4.3 mg./100 ml. with daily haemodialysis using the roller pump.[2] This was significantly lower ($P<0.001$) than the rise in plasma haemoglobin of 8.7 mg./100 ml. with the use of a Sigma finger-pump. This comparison was made on the same patients at identical blood-flow rates using an electromagnetic flow-meter[4] after equal periods of dialysing time (four to six hours) (Aye *et al.*, 1964).

4. Alarm System for Automatic Cut-out of Blood Pump

An automatic cut-out device for the blood pump operated by the air-pressure level in the bubble-catchers on the venous return line was used to facilitate nurse-operation of the kidney and prevent bursting of the coil (Bienenstock and Shaldon, 1963).

5. Regional Heparinization (Fig. 1)

Improvements in the standard technique of regional heparinization previously described from this laboratory (Shaldon *et al.*, 1961) included the use of a twin occlusive roller pump[2] instead of a sigma pump for delivery of the solutions. The roller pump gave more accurate balance of small twin infusions without any creeping of the silicone-rubber tubing (0.5 mm. lumen; 1.5 mm. wall thickness) used in the pump. The heparin and hexadimethrine bromide or protamine sulphate requirements were reduced because of the refrigeration of the blood in the dialyser. Heparin and hexadimethrine or protamine were each delivered at a constant rate (0.2 mg./ml./minute) with blood-flow rates of 150 to 250 ml./minute. The infusions were delivered by No. 12 disposable needles into 3-cm. lengths of rubber tubing (4 mm. lumen; 1.5 mm. wall thickness) included in both the outflow and return circuits. Repeated sampling from those rubber tubes with needle punctures did not produce any leakage from the circuit. Clotting-time control was monitored by half-hourly whole-blood clotting-times and the patient's clotting-time kept at under 20 minutes.

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[1] Thermostatic heater and stirrer (Temp unit) obtainable from Techne (Cambridge) Ltd., Duxford, Cambridge.
[2] Occlusive twin-roller blood pump obtainable from the Watson-Marlow Air Pump Co., Marlow, Bucks.
[3] Supplied by Capon Heaton & Co. Ltd., with the complete circuit (see below).
[4] Electromagnetic flow-meter obtainable from Medelec Ltd., Woking, Surrey.

6. Coil Container and Clamp (Fig. 2)

The coil container was modified so as to prevent unwinding of the coil during repeated use. A straight-walled can[5] (20.5 cm. internal diameter; 16.5 cm. height) was made without ridges into which a standard twin-coil dialyser could be placed without difficulty. To prevent leakage of rinsing-water around the side of the twin coil, a rubber inflatable girdle[6] (2.5 cm. width) was placed between the two cellophane coils, and when the dialyser was in the can the girdle was inflated. In addition, an adjustable screw clamp[6] was used to hold the coil in the can. This allowed for variations in the height of the manufactured dialyser and enabled the dialyser to be set above the level of the floor of the can, thus offering less resistance to the flow of rinsing-fluid through the coil.

7. Technique of Coil Preservation

At the end of the dialysis the inflow and outflow tubing to and from the kidney were joined together and the blood content was recirculated for 10 to 15 minutes after adding 20,000 units of heparin. The circulating-pump was switched off during this time to avoid removal by dialysis of the added heparin. All side-arms and air-vents were then capped with sterile plastic plugs. The coil was carefully removed from the can and the roller tubes from their attachments to the blood pump. The coil and circuit were then placed in a sterile container and stored in a refrigerator at 4° C. During recirculation, ultrafiltration occurred and the coil contents were not under positive pressure during storage. Alternatively, if the coil was not reused its blood content could be transfused into the patient at the end of the dialysis.

8. Technique of Reutilization of the Coil

Daily Reuse.—Prior to reuse, the coil and circuit were reassembled on the kidney with the bath solution already made up. Any leakage of blood from the circuit during storage could be detected, after the coil was reintroduced into the can, by rinsing the coil with refrigerated bath water. Before attaching the circuit to the patient it was necessary to add saline to the circuit to increase the pressure in the twin coil to 200 mm. Hg (air pressure measured in the bubble-catchers by a Tycos manometer). This extra priming volume replaced the fluid removed by ultrafiltration during the recirculation technique at the end of the previous dialysis. The bubble-catchers were manufactured without filters, as the accumulation of fibrin around the filters tended to obstruct the circuit with reuse of the coil.[7] Routine blood cultures were obtained from the reused coils and no significant growths were obtained with daily reuse up to 10 days. No antibiotics were added to the coil circuit routinely during storage. Febrile reactions were uncommon with daily reuse up to 10 days. However, when coils were not reused daily the incidence of febrile reactions increased. This was associated with the growth of cold bacteria in the coil during storage.

Twice-weekly Haemodialysis.—For periodic haemodialysis in the long-term treatment of chronic renal failure, where only twice-weekly haemodialysis is performed (Shaldon *et al.*, 1963), the technique of coil reutilization has been modified. The circuit and coil are primed with saline and haemodialysis is performed without added blood. At the end of the dialysis the coil contents are washed back into the patient and the coil and circuit stored in the usual manner. Before commencing the next haemodialysis, the coil contents are washed out with 6 litres of saline. Using this technique for "periodic" haemodialysis, febrile reactions during haemodialysis have been reduced to a minimum, and it has been possible to reuse the same coil four or five times over 12 to 14 days without growth of cold bacteria from soil cultures.

Efficiency of Dialysis (Fig. 3).—Average bath-water temperatures ranged from 1 to 5° C. and there was an average reduction in urea dialysance (Wolf *et al.*, 1951) of 30% compared with urea dialysance measured at 37° C. However, no loss of efficiency occurred with reuse of the cellophane twin coil on as many as 10 occasions. Exhaustion of the cellophane membrane did not occur with refrigeration.

Cleaning of the Tank.—Because of the frequent number of dialyses performed on one day with the same tank efficient scrubbing of the tank with benzalkonium was done between consecutive dialyses.

Twin Femoral Venous Catheterization

A further requirement for daily haemodialysis was repeated easy access to the patient's vascular bed. Although the silastic Teflon arterio-venous shunt (Quinton *et al.*, 1962) usually functions without difficulty, it is time-consuming to insert, and poor flow-rates may result in some patients because of arterial spasm. Accordingly we have developed an alternative technique for prolonged femoral venous catheterization (Shaldon *et al.*, 1963) which has functioned without difficulty in patients with acute renal failure. The catheters can be inserted and be ready for use within 10 minutes.

[5] Straight-walled can available from V. J. Millard, 12 Springcroft Avenue, London N.2.
[6] Rubber inflatable girdle and adjustable screw clamp available from V. J. Millard, 12 Springcroft Avenue, London N.2.
[7] The complete circuit and twin-coil dialyzer, including siliconized rubber roller tubing, rewarming coil, and sterile plastic plugs, may be obtained from Capon Heaton and Co. Ltd., Hazelwell Mills, Stirchley, Birmingham 30.

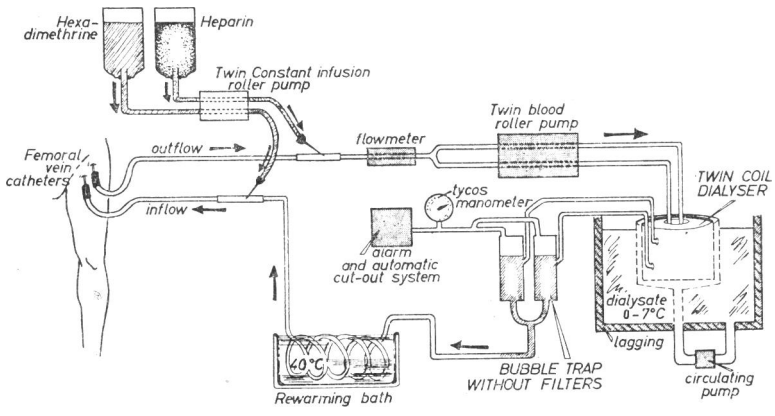

FIG. 1.—Schematic diagram of refrigerated haemodialysis system with regional heparinization. Refrigeration was obtained by the addition of ice to the dialysate, with lagging of the stainless-steel tank.

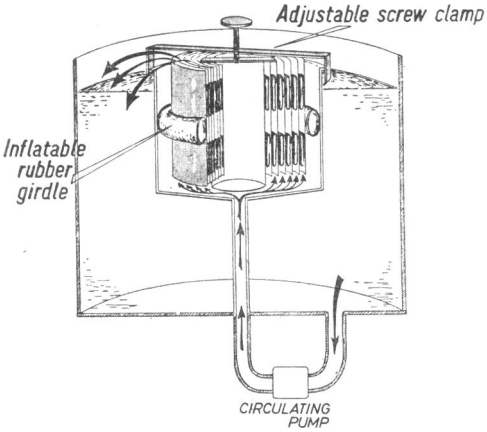

FIG. 2.—Diagram of modified straight-walled can to facilitate entry and withdrawal of coil; inflatable rubber girdle to prevent leakage of rinsing-fluid around the coil and adjustable screw clamp to fix the coil in the can.

Two 40-cm. Teflon catheters[8] were inserted into the same femoral vein by a percutaneous technique (Seldinger, 1953). The puncture sites were situated 4 cm. below the inguinal ligament to reduce frictional trauma with bending of the leg (Fig. 4). The catheters were made from commercial Teflon electrical sleeving[9] (PTFE.TWT 13) (1.8 mm. lumen ; 0.3 mm. wall thickness). The proximal end of the catheter was narrowed (0.91 mm. lumen ; 0.09 mm. wall thickness) by stretching in the flame of a spirit-lamp to facilitate percutaneous introduction (Shaldon *et al.*, 1961). After boring side-ports, the distal end of the catheter was flanged with a heated mandrel and a siliconized rubber tube (2.5 mm. lumen ; 1 mm. wall thickness) was attached to the flanged end by a crimp ring. At the other end of the siliconized rubber extension a plastic female Luer fitting[10] was attached by a crimp ring. Patency of the catheter between dialyses was maintained by a heparin-perfusion unit[11] delivering hourly 0.5 ml. of heparin solution containing 500 units per ml. (Giovannetti *et al.*, 1963). The unit was sterilized by autoclaving. The silicone-rubber extension prevented kinking of the Teflon during movement of the leg. It also avoided the need for a tap, as the rubber tube could be clamped during removal of the perfuser and connexion of the catheter to the dialyser. The catheter site was cleaned twice daily with a chlorhexidine solution and sprayed with a powder containing neomycin and bacitracin. With great care, skin sepsis did not develop and the puncture sites granulated cleanly. The catheters and perfusors were stabilized by an adhesive-strapping attachment to the thigh. Initially zinc oxide plaster adhesive was used, but this caused skin irritation and blistering. Subsequently a porous non-irritant plastic adhesive (Aerostrip) has been used without any skin irritation or blistering. No evidence of thrombosis or clot formation in relation to these catheters was seen in these patients.

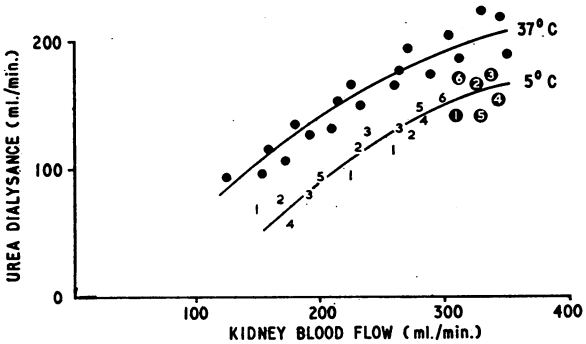

FIG. 3.—Efficiency of individual disposable twin-coil units used at 37° C. compared with refrigerated haemodialysis and re-utilization of the twin-coil dialyser. Black dots represent urea dialysance recorded from individual twin coils during haemodialysis performed with rinsing-fluid heated to 37° C. Numbers represent urea dialysance recorded from coils during refrigerated haemodialysis at 5° C. Individual sets of numbers (1-5 ; 1-3 ; 1-6 ; 1-6) represent urea dialysance measured from twin coil reused as indicated between three and six times. Refrigeration reduces urea dialysance by approximately 30% (1% per degree Centigrade below 37° C.), but repeated use of the same coil with refrigeration does not result in any further loss of efficiency.

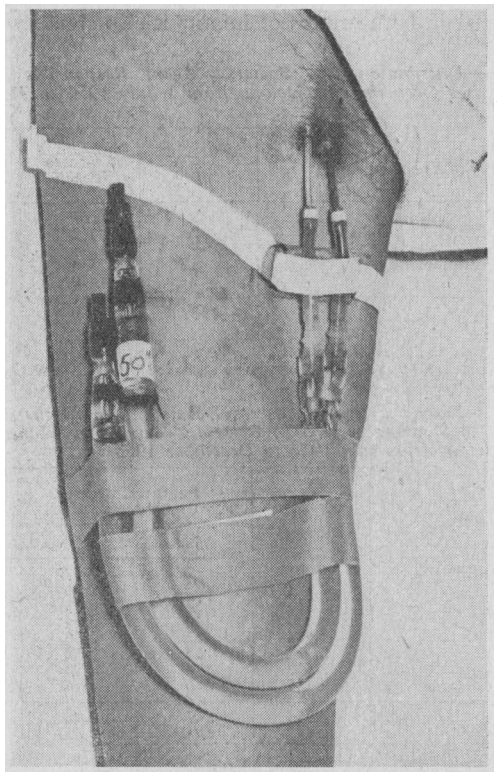

FIG. 4.—Twin femoral venous catheters *in situ* with siliconized rubber extensions and heparin-perfusion units attached (see text).

To remove the catheters, firm pressure was applied to the puncture site for 15 minutes after withdrawal of the catheters from the femoral vein. Subsequent oozing was not common, but it always subsided with gentle pressure and the puncture site invariably healed cleanly.

These techniques have been applied in the treatment of acute renal failure and have permitted daily haemodialysis to be performed on a safe and economic basis. The results of treatment are reported separately (Silva *et al.*, 1964).

Summary

A technique of daily haemodialysis is described involving repeated use of the same disposable twin-coil dialyser by refrigerated haemodialysis with indwelling femoral venous catheters. The technique can be applied to a modified twin-coil Kolff artificial kidney.

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[8] The catheters are now commercially available from the Watson-Marlow Air Pump Co., Marlow, Bucks.

[9] The Teflon sleeving is obtainable from Polypenco Ltd., Gate House, Welwyn Garden City, Herts.

[10] The plastic Luer fittings are obtainable from Capon Heaton and Co. Ltd., Hazelwell Mills, Stirchley, Birmingham 30.

[11] The heparin-perfusion unit consists of a rubber reservoir made from siliconized rubber tubing of a uniform wall thickness (4.5 mm. lumen ; 1.6 mm. wall thickness) supplied by Pirelli Ltd., Milan, and an asbestos glass capillary and non-return valve supplied by Linskey Bros. Ltd., 72 Holloway Road, London N.7. The perfusion unit is assembled from the three components and a sleeve of Tygon tubing joins the asbestos glass capillary to a plastic male Luer fitting which fits into the female Luer mount of the catheter.

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