COMPACT COIL KIDNEY WITH BUILT-IN HEATING ELEMENT,
SMALL DIALYSATE SPACE AND HORIZONTAL COIL COMPARTMENT

K. F. KOPP, D. GROSSMANN and J. FREY

II. Medizinische Universitätsklinik, Frankfurt/Main, Federal Republic of Germany

The operation of the coil dialyzer in a recirculated single pass system offers many medical and technical advantages. This apparatus was designed on the basis of experience in the clinic and includes several important improvements (Fig. 1):

1. The heating and recirculation of the dialysate is combined in one process.

2. The overgrowth of bacteria in the dialysate is excluded by means of a small stationary dialysate volume.

3. The horizontal position of the coil ensures complete rinsing of the dialyzer.

*Fig. 1.* The ‘Kipp-Niere’, a tilting kidney machine operating by the ‘recirculated single-pass system’. It is an independent, space-saving unit which can be connected to any central system with cold dialysate or to an individual tank.
COMPACT COIL KIDNEY WITH BUILT-IN HEATING ELEMENT

Ad 1: Heating and temperature control of the dialysate

The dialysate is heated in a small vessel to a temperature which is set on the control panel. The precision is ±0.5°C. Automatic temperature control is effected by a two-fold safety device. A second thermostat assumes temperature regulation at 39°C if the first thermostat fail. This situation is indicated by a red light, dialysis may however continue. The recirculation and the heating cycle of the dialysate is driven by a single pump. The effluent pump eliminates actively the overflow of spent dialysate at the same rate as fresh dialysate fluid is added, the dialysate level is thus automatically controlled.

The design also allows automatic cleansing of all parts of the apparatus when it is filled with an appropriate solution and the tubes for inflow and outflow are connected. The apparatus may be independently connected to any central delivery system or to any individual tank with cold dialysate.

Ad 2: Bacteriology

The dialysate fluid usually contains a certain number of coliform organisms which is in the range of 10–1000/ml. Although these numbers are harmless a further increase is undesirable. The bacterial concentration in the dialysate shows however a well-defined relationship with the dialysate flow, the stationary dialysate volume, and the bacterial growth rate (which itself of course depends on the temperature and the growth medium).

Under the given condition of a continuous inflow and outflow of dialysate, the number of bacteria in the heated stationary volume will only increase to a limited concentration, because up to a critical bath volume the bacterial growth and the elimination of bacteria by the overflow tends to an equilibrium. The critical volume is the volume at which the bacterial growth becomes unlimited. It is expressed by:

$$V_{\text{crit}} = T \cdot \bar{\Omega}.$$  

$T =$ time in minutes after which the number of bacteria has multiplied by the factor $e$ ($= 2.71 \ldots$)

$\bar{\Omega} =$ flow rate of the dialysate ($= 500$ $\text{ml/min}$).

Assuming optimal conditions for the bacterial growth (neglecting the lag phase and self-inhibition) the time $T$ amounts to about 30 min. at $37^\circ\text{C}$, during logarithmic growth phase. In our case the critical volume would therefore be about 15 litres.

The functional relationship of the bacterial concentrations between the given stationary volume and the critical volume is given by the following expression:

$$C_{\text{lim}} = C_0 \cdot \left(1 - \frac{V_{\text{app}}}{V_{\text{crit}}}\right)^{-1}.$$  

$C_{\text{lim}} =$ (limited) bacterial concentration of the warm dialysate

$C_0 =$ bacterial concentration of the inflowing cold dialysate.

$V_{\text{app}} =$ dialysate volume of the apparatus ($= 4$ litres)

$V_{\text{crit}} =$ critical dialysate volume ($= 15$ litres).

In our case (dialysate flow $= 500$ $\text{ml/min}$, stationary volume $= 4$ litres) the bacterial concentration in the stationary volume would then increase maximally by the factor 1.4 (Fig. 2).

In practice serial measurements of the bacterial counts in the warm dialysate showed no significant increase as compared to the counts in the fresh dialysate.

Ad 3: Reduced loss of blood in the dialyzer due to horizontal position of the coil

The rinsing problem of the coil dialyzer, which usually retains significant amounts of blood that cannot be washed out, is very simply overcome. The geometry of the coil favours complete rinsing even with a small rinsing volume. This is demonstrated by experiments using a dye dilution technique:
Fig. 2. The curve gives the factor of multiplication for any bacterial concentration which is contained in the fresh dialysate as a function of the stationary volume when the dialysate flow is 500 ml/min. and the dialysate temperature is at 37°C.

Single injections of a dye solution were given into a coil which was perfused with water instead of blood. The concentration of the dye was measured with a photometric cell in the outflowing water as the extinction in function of time. It can be seen from the sharp rise and fall of the extinction curve, *i.e.* the concentration of the dye, that the passage of the coil has only a minimal mixing influence on the streaming volume (Fig. 3).

Fig. 3. Dye dilution curve from Chron-A-Coil outlet, after single injection of dye (crystal violet 1%, 0.2 ml), during perfusion with water (flow: 150 ml/min., venous pressure: 200 mm Hg). Paper speed: 2 cm/min.

The steep rise and fall of the curve shows the absence of significant mixing of the dye with the water.
COMPACT COIL KIDNEY WITH BUILT-IN HEATING ELEMENT

From this it follows that the coil is in principle very well suited for rinsing. The important residue of blood which is found in dialyzing coils which are unfolded after use is therefore exclusively due to the sedimentation of the corpuscular elements along the lower edge of the cellulose tubes (Fig. 4).

![Image]

Fig. 4. A section of a dialyzing coil which had been operated in the vertical position and which had been thoroughly rinsed after dialysis. There are still important amounts of blood contained in the cellophane tubes. Residues of the blood sediment are seen along the lower edge of the tubes.

The proof is given when the coil is operated in a horizontal position during dialysis. The blood stream is then circulating upwards and downwards and the blood cannot become stagnant. When rinsing is carried out after dialysis with air and subsequent flushing with 250-500 ml of Ringer's solution virtually no blood is retained in the cellulose tubings.

The following results were obtained when a series of 20 Travenol-145 coils which had been operated either in the vertical or in the horizontal position were examined after rinsing for residual blood:

Blood loss (haematocrit calculated to be 25%): vertical position: 96 ± 30 ml; horizontal position: 8 ± 4 ml.

From preliminary observations in several patients it can already be anticipated that significant reduction of the blood transfusion requirements will result from the use of the horizontal coil kidney.

Summary

The artificial kidney machine which is presented is an independent unit which includes heating and temperature control of the dialysate, eliminates the risk of bacterial overgrowth in the bath fluid, offers minimal cleansing and servicing requirements, and utilizes the horizontal coil during dialysis which minimizes the blood loss with the disposable coil dialyzer.