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Improvement of the Kolff quad-coil artificial kidney with a double-screen coil

Experimental Study

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In 1966 the Kolff quad-coil artificial kidney[1, 2] was introduced as a pumpless, inexpensive apparatus for performing dialysis at the patient's home. A polypropylene screen was used to separate individual coils of dialysis tubing, thereby distributing blood flow and limiting the thickness of the blood channel. This artificial kidney functions well under low pressures in the coil. Though urea clearances are high, the capacity for ultrafiltration is insufficient.[3] Several methods have been tried to increase the ultrafiltration of this dialyzer. Osmotic removal of water has been achieved by adding dextrose to the dialysate bath. Kolff[4] introduced the idea of using a high rate of dialysate flow through the coil to induce a negative pressure; this change increased the pressure gradient across the membrane, and ultrafiltration was improved using this technic. A simple vacuum attachment subsequently was used to create negative pressure outside the coil.[3]

During normal operation of the Kolff quad-coil artificial kidney, a decrease in urea clearance occurred as blood pressure increased. A similar decrease in urea clearance occurred when negative pressure was applied externally to the coil. This decrease is caused by distension of the cellophane membrane under an increasing pressure gradient. The membrane distends through the pores of the screen until it contacts the next layer of cellophane. The portions of the membranes which are in contact are blocked, and the effective dialyzing surface of the membranes is decreased. Studies showed that when the pressure across the membrane is more than 150 mm Hg, about 30 percent of the surface area is excluded from performing hemodialysis, and when the pressure across the membrane is about 250 mm Hg, about 60

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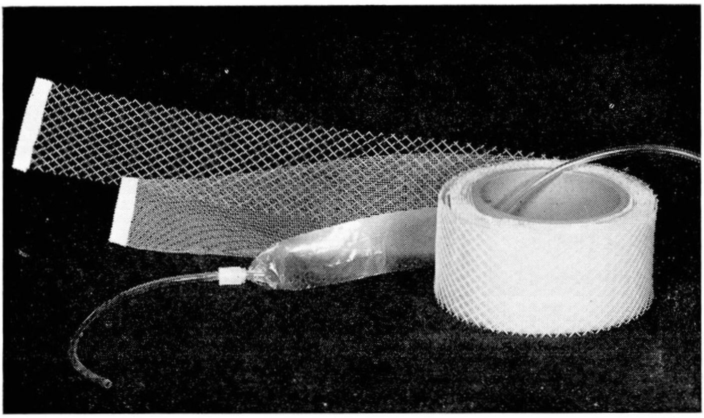

Fig. 1. Photograph of a double-screen coil for the Kolff quad-coil artificial kidney. The coarse screen (outside) and the fine screen (inside) were wound together on a central core.

percent of the surface area is obstructed.[3] Kolff[4] attempted to reduce the distension of the membrane by using a stronger, more rigid screen than originally used. However, that screen at the pressure necessary for good ultrafiltration was also unsatisfactory. In an effort to eliminate these undesirable complications associated with attaining good ultrafiltration, we incorporated a fine screen into the coils along with the coarse screen, to prevent the cellophane membrane from distending excessively. This report presents our experience with the double-screen coil (*Fig. 1*).

Experimental Method

All experimental work was done with a standard quad-coil washing machine artificial kidney previously described by Kolff[1] and by Khastagir and associates.[2] In addition, a fine fiber glass screen* (pore size, 1 mm by 1.5 mm) was used with the coarse polypropylene screen† (pore size, 4 mm by 5 mm) (*Fig. 1*). The technic of winding the coil was the same as that previously described.[1, 2] When assembled, each of the four component coils consisted of concentric layers of coarse screen, fine screen, and dialysis tubing (cellulose tubing 3.5 m long, 4.5-cm flat width).‡ The simple vacuum attachment[3] was used to obtain the necessary pressure gradients. The total membrane surface area comprised 1.26 m^2 or 0.315 m^2 per coil. In vitro and in vivo tests were performed.

In vitro studies. Initially, experimental studies were made of the following three functions of the four coils: flow distribution, pressure-flow relationship,

* *Fiber glass screening—18–24 mesh, Lumite Division, Chicopee Mills Inc., 47 Worth Street, New York, New York.*

† *Norddeutsche Seekablewerke Aktiengesellshaft, Nordenham, West Germany.*

‡ *Cellulose tubing, 45-mm flat width, 1 mil thick, Union Carbide Corporation, Chicago, Illinois.*

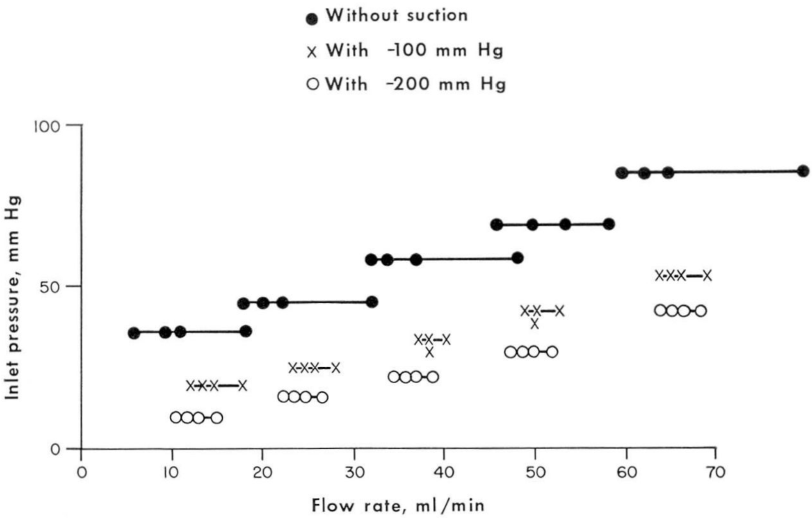

Fig. 2. Graph showing flow distribution to the four double-screen coils that comprise the quad-coil artificial kidney.

and urea clearance. Staining studies were conducted on the coils to determine how well the double-screen coils eliminated excessive membrane distension. Comparisons were made with standard coils containing only the original single screen.

In vivo studies. Eight dogs in the weight range of 11 to 15 kg were used for the in vivo studies. Preoperatively each dog was maintained on a low-protein diet for 48 hr before undergoing total nephrectomy, to avoid a sudden postoperative increase in blood urea content. Postoperatively, the blood urea level was allowed to accumulate to more than 150 mg per 100 ml before the dog was dialyzed. Six hemodialyses were performed on four dogs, with a coil* of the artificial kidney containing only the original screen. No vacuum was applied. On the other four dogs, nine hemodialyses were performed with the double-screen coils. The duration of hemodialysis usually was from 3 to 4 hr. Dialyses were performed at two-day intervals, to allow the blood urea level to increase to 150 mg or more per 100 ml.

Results

Initial measurements made in the Kolff quad-coil artificial kidney indicated a rather poor flow distribution under normal experimental operation. *Figure 2* shows the effects of applying a vacuum to the dialysate bath. Because the reduction of external pressure tended to expand the volume of the

* *Body weights of experimental animals are approximately one fourth of the weights of man. Only one coil of the quad-coil artificial kidney was used for the experiment.*

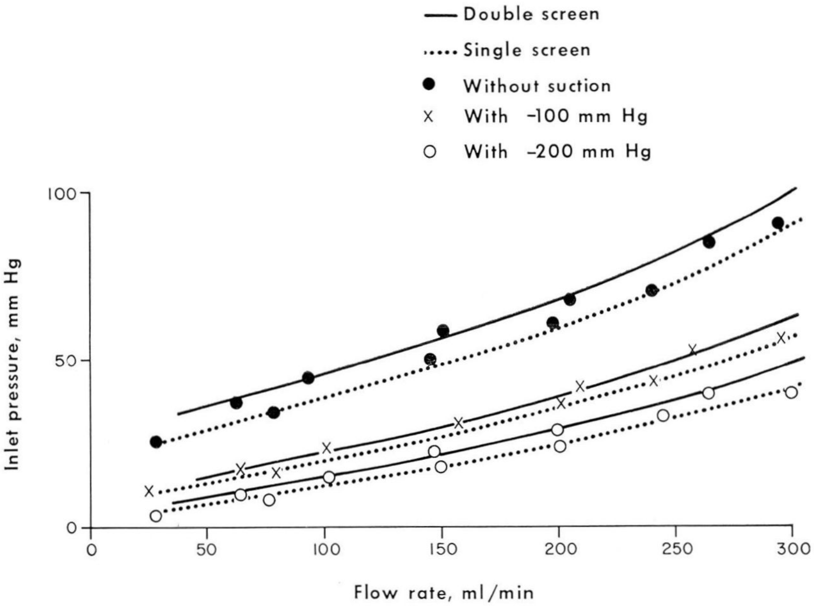

Fig. 3. Comparison of pressure-flow relationship in the double-screen coil and in the standard screen coil.

dialysis tubing and to reduce the resistance of the coils to nearly equal values, there was an improvement in flow distribution. Under normal conditions, the average flow difference between coils was 14.6 ml per minute. Under a pressure of −100 mm Hg, the average difference was decreased to 4.4 ml per minute, and at −200 mm Hg the average difference was only 2.1 ml per minute.

Flow resistance in the coils increased when the double-screen was used. The increase was not excessive (from 15 to 17 percent) (*Fig. 3*), and quite sufficient blood flow rates in the normal arterial pressure range were attained without suction.

Differences in urea clearance between the standard and the double-screen coils are not significant under normal operating conditions and normal blood flow rates. However, at higher blood flow rates (from 250 to 300 ml per minute) the double-screen coil showed the expected advantage under high pressures by being 14 percent more efficient than the standard coil (*Fig. 4*). When negative pressure was applied to the system for ultrafiltration, the difference in performance of the two types of coils became obvious. Under a vacuum condition, urea clearance decreased in both types of coils, but the decrease was much less in the double-screen coil than in the standard screen coil. Under a pressure of −100 mm Hg, at a blood flow rate of 200 ml per minute,

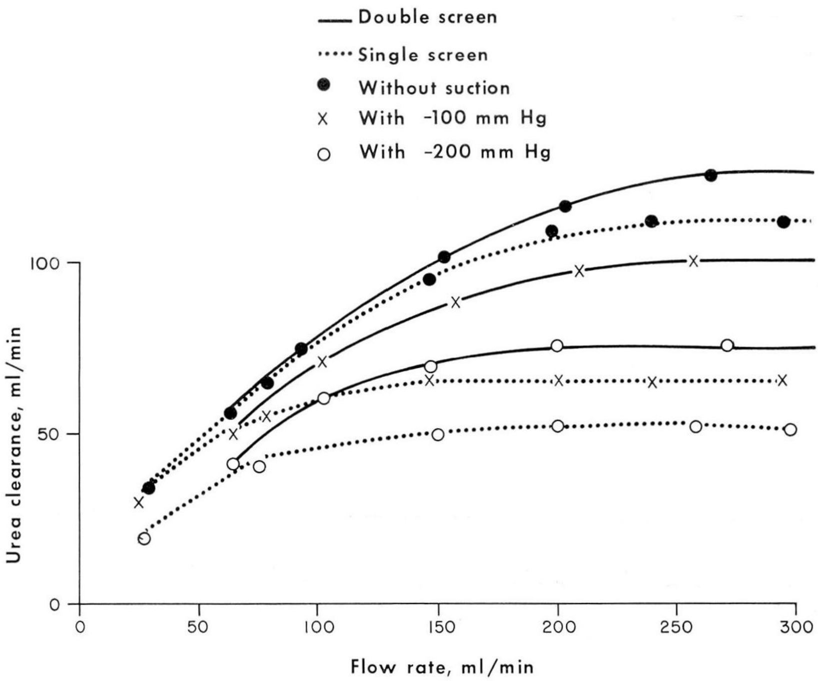

Fig. 4. Comparison of urea clearance in the standard screen coil and in the double-screen coil.

the urea clearance was reduced 41 percent for the standard screen coil, but only 17 percent for the double-screen coil.

Staining tests on coils under vacuum conditions illustrated the effects of negative pressure on membrane distension both with and without an additional fine screen. A smaller percentage of the membrane area was blocked in the double-screen coils (*Fig. 5*) than in the single-screen coils.[3]

In vivo studies with nephrectomized dogs showed significant improvement in blood urea removal with the use of the double-screen coil. *Figure 6* presents data for the dialyses of eight dogs, in which the standard coils and the double-screen coils were used. The urea removal rate was 22.2 ± 8.2 mg per 100 ml of urea per hour with the double-screen coil, as compared to 16.2 ± 4.5 mg per 100 ml of urea per hour for the standard coils, without the vacuum attachment.

COMMENT

One advantage a coil type of artificial kidney offers, in comparison to a plate type of model, is its compactness—it is much less cumbersome to handle. However, with the current technic for winding the coils, it is difficult

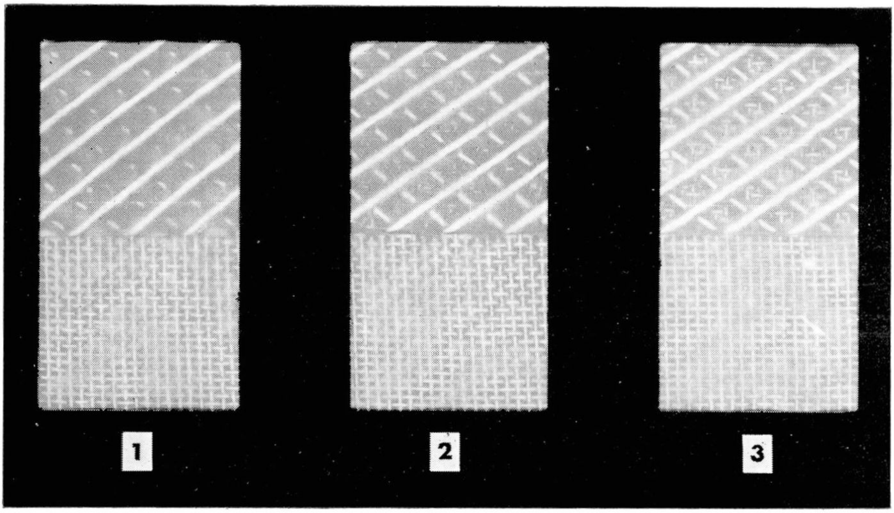

Fig. 5. Photographs of Evans blue stained cellulose tubing used in the double-screen coil. Inlet pressure was always 100 mm Hg; pressures outside of the coil were: (1) 0 mm Hg, (2) −100 mm Hg, and (3) −200 mm Hg.

to control the priming volume and the resistance in each coil. For any one hemodialysis the resistance usually is different in each of the four coils. The variations in coil resistance then cause uneven flow distribution and decrease the overall efficiency of the system. These disadvantages can be overcome: when a pressure of −100 mm Hg was applied, the differences in flow resistance in the individual coils were reduced so that the blood flow was substantially evenly distributed. The introduction of a vacuum in the system serves to open a flow channel in each coil which is essentially similar in each of the four coils.

The application of a vacuum to the dialysate bath, and the double-screen coils, have several significant advantages. During ultrafiltration, as much as 3 lb. of water was removed per hemodialysis with a pressure of −100 mm Hg, and 4 lb. with −200 mm Hg.[3] Although dialysis efficiency is decreased by the use of a vacuum for ultrafiltration, the resulting performance is still adequate. Using a pressure of −100 mm Hg, the urea clearance of the quad-coil artificial kidney was reduced 15 percent, but still was adequate, at 95 ml per minute, for a blood flow of about 200 ml per minute.

The concept of the double-screen support is quite similar to that of the nickel-foam membrane support introduced by Babb and Grimsrud.[5] Both

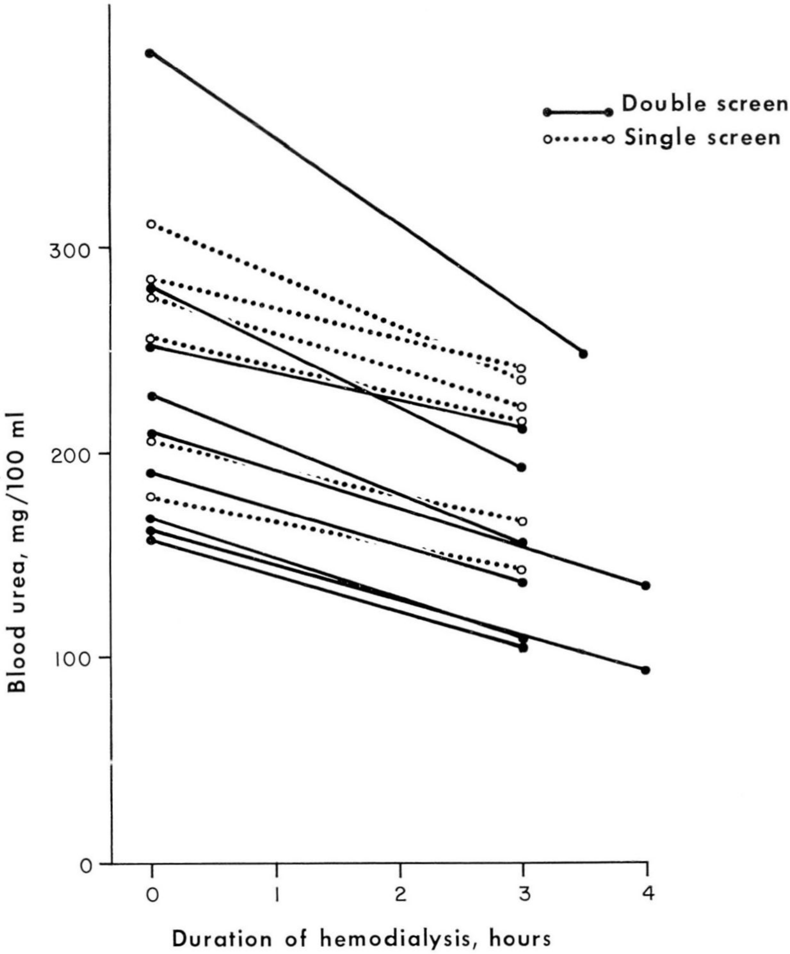

Fig. 6. Graph showing comparison of blood urea changes in nephrectomized dogs undergoing hemodialysis with the standard screen coil (dashed line) and the double-screen coil (solid line). These studies were performed with one coil of the Kolff quad-coil artificial kidney.

a greater percentage of the membrane surface area while at the same time giving increased support.

SUMMARY AND CONCLUSION

In order to improve the ultrafiltration capabilities of the Kolff quad-coil artificial kidney, a vacuum was introduced into the experimental system, which however, decreased the efficiency. To restore the efficiency, a coil with a double screen was used, and the test results were as follows. The efficiency of the coil improved 45 percent under a pressure of −100 mm Hg, and 15 percent without a vacuum. The cellophane membranes were kept from making contact through the screen (and obstructing the dialyzing surface), by the introduction of an additional fine screen between the cellophane membrane and the coarse screen. Results of in vivo studies of dialysis showed a 37 percent improvement in blood urea removal rate with the double-screen coil.

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