Journal of Macromolecular Science, Part A
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713597274

Past, Present, and Future of Artificial Kidney Treatment

Benjamin H. Barbour[a]
[a] University of Southern California School of Medicine, Los Angeles, California

To cite this Article Barbour, Benjamin H.(1970) 'Past, Present, and Future of Artificial Kidney Treatment', Journal of Macromolecular Science, Part A, 4: 3, 511 — 525
To link to this Article: DOI: 10.1080/00222337008074360
URL: http://dx.doi.org/10.1080/00222337008074360

J. MACROMOL. SCI.–CHEM., A4(3), pp. 511-525, May, 1970

Past, Present, and Future of Artificial Kidney Treatment

BENJAMIN H. BARBOUR

University of Southern California School of Medicine
Los Angeles, California 90033

SUMMARY

The past has seen the evolution of hemodialysis from a very complex operation to a systematized approach which allows the procedure to be instituted by minimally trained individuals. The first big advance in the application of hemodialysis to the problem of chronic renal insufficiency came in 1960 when a permanently implanted arteriovenous plastic fistulae was established. Improvements in dialyzer design and the logistics of hemodialysis since then have resulted in expansion of hemodialysis facilities. There is still a deficit between facilities available and suitable patients in need of therapy. Closure of this gap will depend upon a cheap, small, disposable dialyzer which most patients can operate themselves. In addition, an improvement in kidney transplantation results will remove many patients from the pool of those needing hemodialysis. It is likely that other medical applications of hemodialysis will be discovered in the future.

It is of some interest to consider a notorious attempt to save the life of a notorious Pope, Innocent VIII, as perhaps the beginning of the notion that blood from an ill person can be purified to restore health. Cross transfusion of blood from three healthy donor boys to Pope Innocent VIII in 1492 ended in death of the participants, and the physician who initiated this ill-fated therapy had to flee for his life [1]. Although this avant-garde therapeutic maneuver was poorly conceived, since nothing was known of the properties of blood incompatibilities at the time, it remains a milestone as the first recorded event marking an attempt to cleanse the blood of a sick individual by cross transfusion through a healthy individual. Furthermore, the concept remains one step removed from the idea of circulating the blood of a sick patient through an artificial kidney machine. It is of further interest that replacement transfusion was preferred to hemodialysis for the treatment of renal insufficiency by several authors up to the early 1950's [2-5].

The first experimental attempt to use an artificial kidney was undertaken by Abel, Roundtree, and Turner in 1912 [6]. Their construction led the blood of a living animal to circulate through self-made collodion tubes that acted as a semipermeable membrane. These workers also extracted hirudin from leech heads for use as an anticoagulant. A saline solution circulated around the outside of the blood-filled collodion tubes and it was demonstrated that such foreign substances as blood salicylates could be recovered. There were many technical difficulties involving the dialysate solution, and by fractionation of the dialysate solution various nonprotein blood constituents were identified. The preparation of the collodion membranes, the availability of a suitable anticoagulant, and inadequate sterilization all combined to discourage clinical application but work continued on the Abel, Roundtree, and Turner principal of "vivi diffusion" as they called it.

Numerous investigators sought animal membranes as substitutes for the collodion membrane of Abel, Roundtree, and Turner. Fish bladders, rat, rabbit, turkey, and chicken intestines as well as peritoneal membranes [7-9] were selected; the latter (Goldbeater's skin) was used successfully to isolate a humeral gastric secretory factor [10]. Although Thalhimer described the use of cellophane in 1938 [11], it was not widely used in artificial kidneys until the late 1940's.

After Able, Roundtree, and Turner's original description, the next 30 years saw a number of investigators try to improve on design but their various erratic attempts were not of much practical value. During the same period peritoneal dialysis was undergoing investigation. Early reports were made by Starling in 1894 [12] about the exchange of solutes across the peritoneum, but Ganter in 1923 was the first to report on peritoneal dialysis to treat renal insufficiency [13]. Subsequently several investigators demonstrated prolonged survival in uremic animals through peritoneal dialysis [14-16]. The optimal dialysis solution composition was defined [17] and the two major techniques, intermittent and continuous lavage, were described. By 1948 a total of 101 patients who had undergone peritoneal dialysis were listed in the medical literature [18]. Prior to the introduction of the Kolff kidney, peritoneal dialysis was the only effective method of eliminating waste production in oliguric renal failure and although its value seemed self-evident, it was not widely practiced for at least 30 years following its introduction in 1923. In fact, peritoneal dialysis probably underwent a decline in usage in the decade 1945-1955 when clinical activity in artificial kidneys increased. The developmental periods of artificial kidney and peritoneal dialysis were contemporary to each other and they both reached the period of application at about the same time.

The first clinically successful application of an artificial hemodialyzer was reported by Kolff [19] who described the treatment of a young woman who suffered rapidly progressive nephritis and malignant hypertension. This woman was treated in Kampen, Holland during World War II when Holland was occupied by the Germans. The kidney's membrane surface was approximately 20,000 sq cm of cellophane tubing wound around a rotating drum suspended in a tank of dialysis solution (Fig. 1). The patient was bled into a buret which then filled the kidney. The buret received the blood after passage through the kidney and returned it to the patient through the same vein. Later Kolff added a blood pump on the venous return line [20]. His first patient underwent 12 dialyses over a period of 50 days. Although Haas of Germany had conducted a series of studies in the 1920's on the human application of an apparatus constructed of collodion tubes, similar to the instrument of Abel, Roundtree, and Turner, he felt that such an instrument was ineffective to relieve uremia [21]. He was unable to significantly lower the nonprotein nitrogen in his patients and he concluded that the technique was inadequate. The report of Kolff from Holland was a striking success because it clearly showed the ability of his artificial kidney to clear urea. At the same time, workers in Sweden and in Canada [22, 23], each group pursuing an independent course and unaware of the other, constructed and applied an artificial hemodialyzer to humans (Fig. 1). This lack of awareness was no doubt in part due to the war but it illustrates how novel human endeavors can occur simultaneously, yet independently, across the world.

Alwall's [22] original artificial kidney consisted of a tube of cellophane, 1000 $\times$ 3.2 cm, wound tightly between two wire mesh cylinders, one contained within the other. These were immersed in an agitated dialyzer bath. Arterial blood was passed through the coils and returned to the patient via a peripheral vein. The Murray [23] kidney was described in

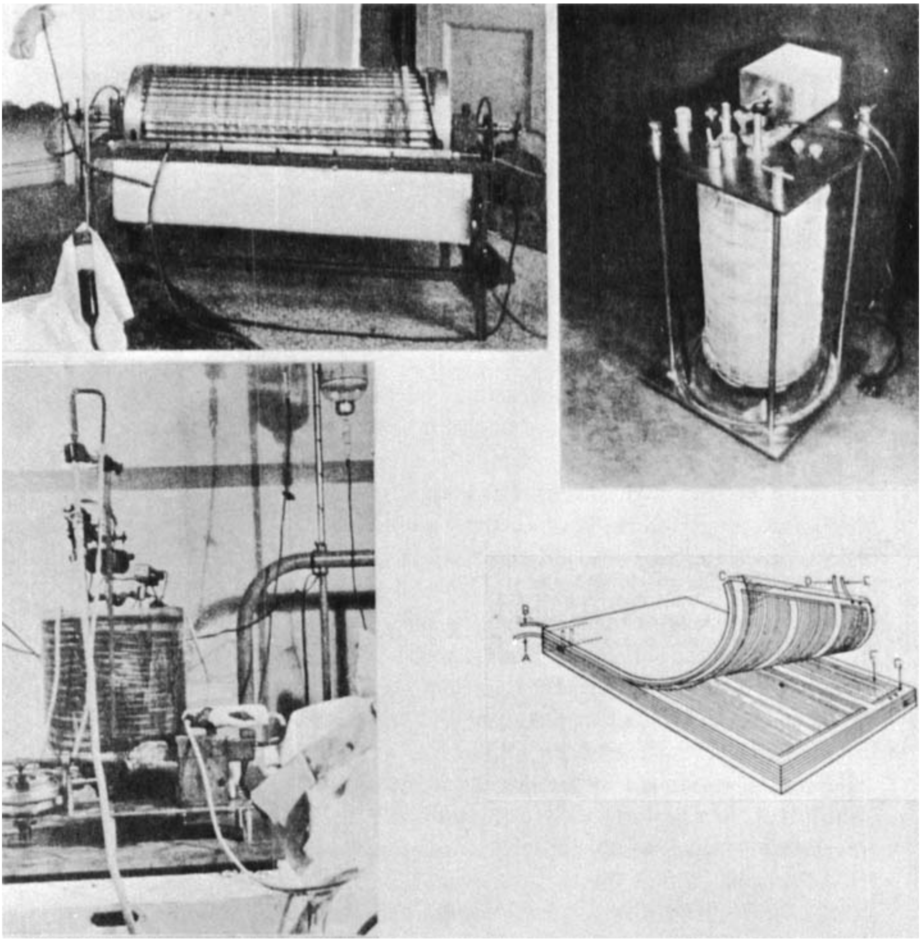

Fig. 1. Upper left shows Kolff's original dialyzer; upper right, Alwall's; lower left, Murray's; lower right, Skeggs-Leonard. Reprinted by permission from Refs. 19, 22, 23, and 24.

1947 as a cellophane tube of smaller diameter than that used by either Alwall or Kolff but wrapped around a wire mesh cylinder and held in place with wooden staves. Blood was pumped out of a large vein and returned to another vein after passage through the cellophane coil which was immersed in a dialysis bath. Their description of a clinical case of post abortal renal insufficiency suggests that the Canadian kidney, which was used several times, kept this woman alive until she recovered. Then in 1948, Skeggs and Leonards [24] reported on a plate-type dialyzer where a flat sheet of cellophane were compressed between two rubber pads with finely grooved surfaces. The grooves on one of the pads served as blood channels, the grooves on the other pad, on the opposite side of the cellophane sheet, as dialysate channels to allow passage of dialysate solution in the opposite direction. Practically all dialyzers subsequently applied clinically were derived from one of the original types described above (Fig. 1).

During World War II four Kolff kidneys were made in Holland to encourage clinical application. After the war they were donated to medical centers in London, Montreal, New York, and one disappeared behind the Iron Curtain. These historic instruments will undoubtedly become important museum pieces as monuments to bold ingenuity and the beginnings of artificial organ development.

Following these original reports, a proliferation of artificial kidneys occurred. Twelve new kidneys were reported in the medical literature between 1944 and 1951 [26-37] but each was simply a modification of either the plate-type dialyzer or the coil. It became apparent that although most of the types of artificial dialyzers were capable of correcting the deranged chemical imbalance measurable in uremia, the execution of artificial hemodialyzers required a considerable amount of time and energy on the part of a hospital's staff. Two excellent summaries of dialysis activities appeared in 1952 and in 1945 by Merrill [38] and Kolff [39], respectively. Merrill emphasized the necessity to institute hemodialysis early before the patient is terminal, and Kolff pointed to the importance of transfer of uremic patients to the care of a staff having access to hemodialysis equipment.

It seems as if the mid-fifties represented a period of stalemate for artificial kidney development and application, in spite of the fact that during this period Kolff [40] developed a disposable coil kidney and Baxter Laboratories manufactured this kidney and successfully marketed it to hospitals throughout the world (Fig. 2). In fact, most institutions found the disposable dialyzer convenient enough to discontinue the use of existing equipment. This "twin coil" disposable kidney consisted of two parallel lengths of cellophane tubing enveloped by a Fiberglas screen support and wrapped as a coil. Dialysis solution is pumped through the Fiberglas network supporting the coil while blood is pumped through the coiled cellophane tubes. It was unnecessary to build an artificial kidney for each treatment since the unit could be purchased already sterilized and assembled.

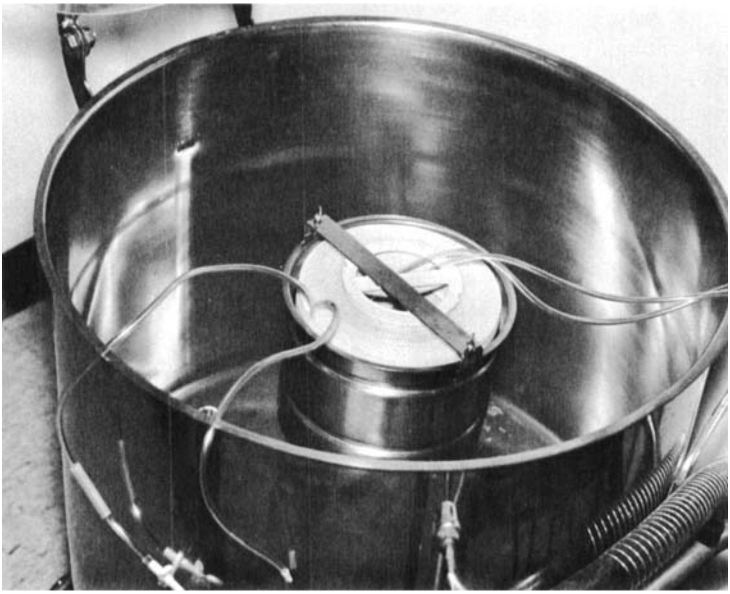

Fig. 2. Kolff's disposable twin coil dialyzer is placed in a cannister through which dialysis bath is circulated from the large tank. This type of artificial kidney was commonly available and widely used in the decade 1956-1965. Reprinted by permission from Ref. 19.

Another significant development in 1955 was the formation of the American Society for Artificial Internal Organs on June 5, 1955 [41]. Though this organization was not exclusively formed for artificial kidney specialists, they comprised a major proportion of the group and the meetings were an effective sounding board for the stimulation of new ideas. The reason for the aforementioned stalemate was the fact that most hospitals did not use the artificial kidney often enough to make its application an easily executed, smoothly operated, and successfully terminated procedure. And so the technique of peritoneal dialysis gained favor because little or no special equipment was required, it could be executed by a nurse with minimal physician assistance, it was simple to institute, and it was effective even though the clearance rate was less than for the artificial kidney. The intermittent peritoneal dialysis technique first described in detail by Grollman [42] and popularized by Doolan [43] and by Maxwell et al. [44] became the preferred method of dialysis therapy. By 1961 Boen was able to point out that the essential difference between artificial kidney dialysis and peritoneal dialysis was in the duration of dialysis [45]. The same chemical concentration of sodium, potassium, magnesium, calcium chloride, bicarbonate, phosphate, urea, and creatinine was achieved by the two methods except peritoneal lavage is about four times slower.

Between 1956 and 1960 while many artificial kidney specialists were in the process of evaluating and developing capability to use Kolff's disposable mass produced twin-coil dialyzer, the idea of prophylactic hemodialysis was advanced, largely by Teschan et al. [46] working at Brooks Army Medical Center in Texas. This group was the first to recommend chronic arterial and venous cannulation so that early, easy, and repeated access to the circulation could be met. They used both the plate-type dialyzer and the Kolff twin-coil disposable dialyzer. A team concept was developed whereby medical technicians who assembled the dialyzers played a major role in the execution of dialysis under the direction of nurses and physicians. The significance of Teschan's work must not be underemphasized for he introduced two important ideas: 1) Repeated early dialysis through chronically implanted vessel cannulae, and 2) a nurse-technician-physician team working in a center geared to execute hemodialysis. Up to this time most of the artificial kidney therapy had been highly individualized as a physician-patient oriented type of treatment. Now with Teschan, for the first time, the treatment of patients with renal failure became more nearly systematized with the physician making decisions but not playing much of a role in the execution of hemodialysis.

Teschan concentrated his therapy on patients with acute renal failure, but in the same year, 1960, Quinton, Dillard, and Scribner [47] reported on indwelling Teflon arterial and venous cannulae for prolonged hemodialysis of chronically ill patients (Fig. 3). The cannulae were shunted when not in use and the following year Hegstrom, Murray, Pendras, Burnell, and Scribner reported on four patients with terminal uremia who were kept alive 9-12 months by repetitive hemodialysis through their shunts [48]. In his early reports Scribner was of the opinion that prolonged hemodialysis (24 hr per treatment), which he called "continuous flow hemodialysis," was necessary to keep patients free of uremia [49]. At first he used a Skeggs-Leonard-type dialyzer but later switched to a

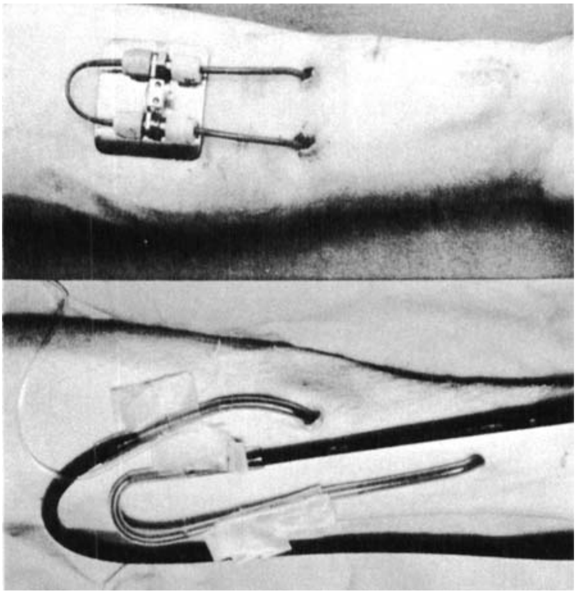

Fig. 3. In the top panel the original arterio-venous cannulae is seen. Stabilizers were used to limit motion in the silastic cannulae and a piece of Teflon shaped like a horseshoe connected the silastic pieces. In the bottom panel a popular adaptation of the original shunt is shown connected to polyvinyl chloride leading to and from a hemodialyzer. One link of the silastic is bent to align with the other by a small, straight Teflon tube between treatment periods. The top panel is reproduced by permission from Ref. 47.

Kiil-type dialyzer [50]. The Kiil is similar in design to the Skeggs-Leonard dialyzer but easier to build and somewhat more efficient. Others subsequently tried the A-V shunting technique of Quinton, Dillard, and Scribner using the Kolff twin-coil disposable dialyzer [51, 52], and it became apparent that some patients with chronic renal failure can be maintained in a useful form of existence for a significant period of time by a regularly scheduled program of hemodialysis.

The next major step in dialysis activities came through the opening of a community dialysis center in Seattle, Washington in 1962 so that a large number of patients could be treated simultaneously, by and large, by technicians and nurses [53, 54].

In 1964 the U.S. Public Health Service began a program to provide funds for selected institutions to set up demonstration centers for chronic hemodialysis. In addition, the National Institute of Arthritis and Metabolic Diseases established a bureau to stimulate the development of better equipment by contract research with cooperating industrial and medical institutions. At first, a series of demonstration centers were established for chronic hemodialysis but it was soon recognized that the cost of dialysis remains high even in centers and that perhaps a home dialysis self-treatment program would be a reasonable alternative for some patients. Merrill [55] reported the successful use of the coil-type artificial kidney in the home and the Seattle group [56] began to use the Kiil-type dialyzer in the home. According to the National Dialysis Registry, as of June 20, 1969, 826 patients out of 2,369 hemodialyzed patients were being treated in the home [57]. Although there is no doubt about the economic advantage of home dialysis, only a minority of patients are able to successfully execute dialysis at home. And even among those who dialyze themselves at home there are psychological and medical problems which arise that keep the patient dependent on a medical center.

Industrial and academic interest in artificial kidney therapy has increased dramatically within the past 5 years (Fig. 4). At least eight new type marketable artificial kidneys have been introduced [58-64] and even a "make it yourself" cellophane coil winding device adaptable to a commercially available washing machine has been used [65]. The National Institutes of Arthritis and Metabolic Diseases initiated an Annual Contractors Conference on artificial kidney development in January, 1968, to stimulate further interchange between industry and academic medicine concerning hemodialysis problems [66].

In spite of these advances there are still large numbers of patients who are unable to receive treatment. According to the Report of the Committee on Chronic Kidney Disease, 35,000 patients per year die of chronic renal failure and of this group 7,000 per year would be good candidates for treatment [67]. There is a real lack of medical resources to handle the problem. The major reason for this lack of resources rests in a deficiency of knowledgeable and interested medical personnel. The cost of dialysis is often raised as a crucial element which discourages the expansion of available facilities. When one considers a 7-year survival of 58% of the patients receiving treatment along with 7,000 new patients per year, the imagination staggers at the dimensions confronting society 10 years hence if all were treated.

One solution could come through a cheap, disposable, high efficiency,

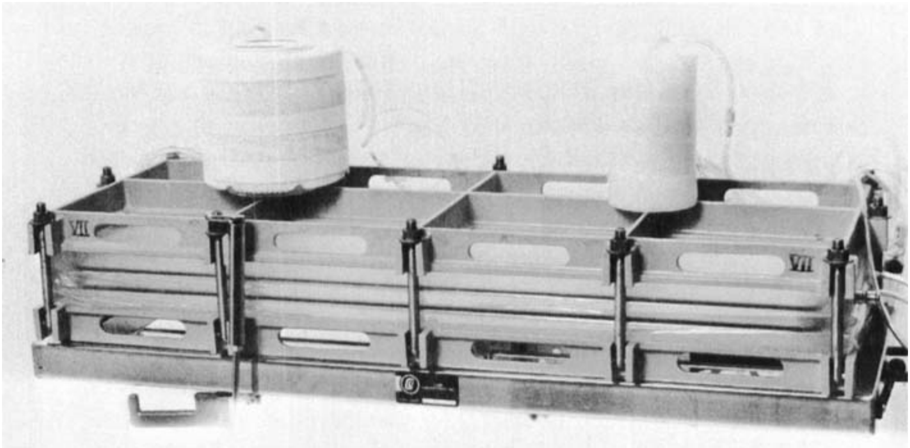

Fig. 4. Three of the most popular type of hemodialyzers in use today. The Travenol ultraflow coil and the Extracorporeal Medical Specialties EX01 coil rest to the right and left, respectively, on the Kiil-type hemodialyzer.

portable dialyzer. The patient could then dialyze himself with very little medical assistance, much like a patient who follows medical advice in taking medication. Another solution could come through successful kidney transplantation of cadaver organs. Neither of these goals is immediately obtainable, but there are indications that continued efforts along the lines currently being followed will yield both an ideal dialyzer and successful kidney transplantation. It is important to remember, however, that even if kidney transplantation is successfully developed, there are still some patients who cannot receive a transplant because of peculiar anatomical reasons and therefore hemodialysis would be the only alternative.

Finally, hemodialysis has been directed largely against the problem of renal failure. Yet, there may well be other applications. Just recently it was suggested that hemodialysis is an efficient method of treating delerium tremors and in time medical science will no doubt discover other applications. The final chapter in the history of dialysis is yet to be written.

REFERENCES

[1] P. F. Salisbury, "Artificial Internal Organs," *Sci. Amer.*, 191(2), 24 (1954).

[2] W. Thalhimer, D. Y. Solandt, and C. H. Best, "Experimental Exchange Transfusion using Purified Heparin," *Lancet,* **2**, 554 (1938).
[3] W. Nyiri, "Experimentelle Untersuchungen uber Gekreutze Bluttrausfusion bei Uramie," *Arch. Expr. Pathol. Pharmakol.,* **116**, 117 (1926).
[4] I. Snapper and L. Schaefer, "Treatment of Two Patients with Hepatorenal Syndrome and Acute Renal Failure by Exsanguinotransfusion," *Ann. Intern. Med.*, **34**, 692 (1951).
[5] M. Bessis, "Use of Replacement Transfusion in Disease other than Hemolytic Disease of Newborn," *Blood,* **4**, 324 (1949).
[6] J. J. Abel, L. G. Roundtree, and B. B. Turner, "On the Removal of Diffusible Substances from Circulating Blood by Means of Dialysis," *Trans. Ass. Amer. Physicians,* **23**, 51 (1913).
[7] H. C. Van der Heyde and W. Morse, "Modification of Technique of Vivi-diffusion Method of Abel," *J. Lab. Clin. Med.*, **6**, 520 (1921).
[8] G. R. Love, "Vivi-diffusion with Intestinal Membranes," *Med. Rec.,* **98**, 649 (1920).
[9] H. Necheles, "Uber Dialysieren des Stromenden Blutes am Lebenden," *Klin. Wochenschr.*, **2**, 1257 (1923).
[10] R. K. S. Lim and H. Necheles, "Demonstration of Gastric Secretory Excitant in Circulating Blood by Vivi-dialysis," *Proc. Soc. Exp. Biol. Med.*, **24**, 197 (1926).
[11] W. Thalhimer, "Experimental Exchange Transfusions for Reducing Azotemia. Use of Artificial Kidney for this Purpose," *Proc. Soc. Exp. Biol. Med.*, **37**, 641 (1938).
[12] E. H. Starling and A. H. Tubby, "On Absorption from and Secretion into the Serous Cavities," *J. Physiol.* (London), **16**, 140 (1894).
[13] G. Ganter, "Ueber die Beseitigung Giftiger Stoffe aus dem Blute durch Dialyse," *Muench. Med. Wochenschr.*, **70** II, 1478 (1923).
[14] S. Bliss, A. O. Kastler, and S. B. Nadler, "Peritoneal Lavage: Effective Elimination of Nitrogenous Waste in the Absence of Kidney Function," *Proc. Soc. Exp. Biol. Med.,* **29**, 1078 (1932).
[15] A. M. Seligman, H. A. Frank, and J. Fine, "Treatment of Experimental Uremia by Means of Peritoneal Irrigation," *J. Clin. Invest.,* **25**, 211 (1946).
[16] A. Grollman, L. B. Turner, M. Levitch, and D. Hill, "Hemodynamics of Bilaterally Nephrectomized Dog Subjected to Intermittent Peritoneal Lavage," *Amer. J. Physiol.,* **165**, 167 (1951).
[17] W. E. Abbott and P. Shea, "The Treatment of Temporary Renal Insufficiency by Peritoneal Lavage," *Amer. J. Med. Sci,* **211**, 312 (1946).

[18] H. M. Odel, D. O. Ferris, and H. Power, "Peritoneal Lavage as an Effective Means of External Excretion. A Clinical Appraisal," *Amer. J. Med.*, **9**, 63 (1950).
[19] W. J. Kolff, T. J. H. Berk, M. tev Welle, A. T. W. Van der Ley, E. C. van Dijk, and J. van Noordwijk, "The Artificial Kidney: A Dialyzer with Great Area," *Acta Med. Scand.*, **117**, 121 (1944).
[20] W. J. Kolff, *De Kunstmatige Niev Kampen*, Kok, 1946.
[21] G. Haas, "Uber Blutwaschung," *Klin. Wochenschr.*, **7**, 1356 (1928).
[22] N. Alwall, "On the Artificial Kidney: I. Apparatus for Dialyses of Blood in vivo," *Acta Med. Scand.*, **127**, 317 (1947).
[23] G. Murray, E. Delorme, and N. Thomas, "Development of an Artificial Kidney, Experimental and Clinical Experience," *Arch. Surg.*, **55**, 505 (1947).
[24] L. T. Skeggs and J. R. Leonards, "Studies on an Artificial Kidney: I. Preliminary Results with a New Type of Continuous Dialyzer," *Science*, **108**, 212 (1948).
[25] W. J. Kolff, "The Artificial Kidney - Past, Present and Future," *Circulation*, **15**, 285 (1957).
[26] J. A. Sterling, L. B. Weiss, A. Schneeberg, and W. Bernard, "New Type of Artificial Kidney: Preliminary Report," *Clin. Proc. Jewish Hosp.*, **1**, 128 (1948).
[27] J. Vanatta, E. E. Muirhead, and A. Grollman, "Improvement on Artificial Kidney: Experimental Study of Its Application to Dogs Bilaterally Nephrectomized or Otherwise Deprived of Renal Function," *Amer. J. Physiol.*, **156**, 443 (1949).
[28] J. P. Merrill, G. W. Thorn, C. W. Walter, E. J. Callahan III, and S. H. Smith, Jr., "Use of Artificial Kidney: Technique," *J. Clin. Invest.*, **29**, 412 (1950).
[29] O. S. Lowsley and T. J. Kirwin, "Artificial Kidney: Preliminary Report," *J. Urol.*, **65**, 163 (1951).
[30] S. S. Rosenak and S. Saltzman, "New Dialyzer for Use as Artificial Kidney," *Proc. Soc. Exp. Biol. Med.*, **76**, 471 (1951).
[31] Allis-Chalmers, *Time Magazine* (March, 1951).
[32] A. E. MacNeill, A. Mather, and W. L. McLaughlin, "A Dialyzer of Great Adaptability," Exhibit Association of Military Surgeons, Annual Convention, 1949.
[33] "Plastic Kidney is New Medical Tool," *Westinghouse News* (Pittsburg, Pa.), (May 6, 1952).
[34] M. R. Malinow and W. Korzon, "An Experimental Method for Obtaining an Ultrafiltrate of the Blood," *J. Lab. Clin. Med.*, **32**, 461 (1947).

[35] J. R. Guarino and L. J. Guarino, "An Artificial Kidney. A Simplified Apparatus," *Science,* **115**, 285 (1952).
[36] B. Van Garrelts, *23rd Meeting of the Northern Surgical Association, Stockholm, 1947,* Munksgaard, Copenhagen, 1948, p. 423.
[37] W. Y. Inouye and J. Engelberg, "A Simplified Artificial Dialyzer and Ultrafilter," *S. Forum,* **4**, 438 (1953).
[38] J. P. Merrill, "The Artificial Kidney," *New Engl. J. Med.,* **246**, 17 (1952).
[39] W. J. Kolff, "Dialysis in Treatment of Uremia. Artificial Kidney and Peritoneal Lavage," *Amer. Med. Ass. Arch. Int. Med.,* **94**, 142 (1954).
[40] W. J. Kolff and B. Watachinger, "Further Developments of a Coil Kidney. Disposable Artificial Kidney," *J. Lab. Clin. Med.,* **47**, 969 (1956).
[41] "American Society for Artificial Internal Organs; Constitution and By-laws," *Trans. Amer. Soc. Artif. Intern. Organs,* **1**, 103 (1955).
[42] A. Grollman, L. B. Turner, and J. A. McLean, "Intermittent Peritoneal Lavage in Nephrectomized Dogs and Its Application to the Human Being," *Amer. Med. Ass. Arch. Int. Med.,* **87**, 379 (1951).
[43] P. D. Doolan, "An Evaluation of Intermittent Peritoneal Lavage," *Amer. J. Med.,* **26**, 831 (1959).
[44] M. H. Maxwell, R. E. Rockney, C. R. Kleeman, and M. R. Twiss, "Peritoneal Dialyses," *J. Amer. Med. Ass.,* **170**, 917 (1959).
[45] S. T. Boen, "Kinetics of Peritoneal Dialysis," *Medicine,* **40**, 243, (1961).
[46] P. E. Teschan, C. R. Baxter, T. F. O'Brien, J. N. Frehot, and W. H. Hall, "Prophylactic Hemodialyses in the Treatment of Acute Renal Failure," *Ann. Intern. Med.,* **53**, 992-1016 (1960).
[47] W. Quinton, D. Dillard, and B. H. Scribner, "Cannulation of Blood Vessels for Prolonged Hemodialyses," *Trans. Amer. Soc. Artif. Intern. Organs,* **6**, 104 (1960).
[48] R. M. Hegstrom, J. S. Murray, J. P. Pendras, J. M. Burnell, and B. H. Scribner, "Hemodialyses in the Treatment of Chronic Uremia," *Trans. Amer. Soc. Artif. Intern. Organs,* **7**, 136-149 (1961).
[49] B. H. Scribner, J. E. Z. Cairer, R. Buri, and W. Quintos, "The Technique of Continuous Hemodialyses," *Trans. Amer. Soc. Artif. Intern. Organs,* **6**, 88 (1960).
[50] F. Kiil, "Development of a Parallel-flow Artificial Kidney in Plastics," *Acta Chir. Scand. Suppl.,* **253**, 142 (1960).
[51] W. R. Welzant, J. P. Merrill, C. Crane, and K. Rabelo, "Use of Teflon-Arteriovenous Bypass," *Trans. Amer. Soc. Artif. Intern. Organs,* **7**, 125-129 (1961).

[52] J. M. Brandon, S. Nakamoto, J. Rosenbaum, M. Franklin, and W. J. Kolff, "Experience with Periodic Long (±20 Hours) Dialyses," *Trans. Amer. Soc. Artif. Intern. Organs,* 7, 130-135 (1961).

[53] J. S. Murray, W. H. Tu, J. B. Albers, J. M. Burnell, and B. H. Scribner, "A Community Hemodialysis Center for Treatment of Chronic Uremia," *Trans. Amer. Soc. Artif. Intern. Organs,* **8**, 315-320 (1962).

[54] D. D. Lindholm, J. M. Burnell, and J. S. Murray, "Experience in the Treatment of Chronic Uremia in an Outpatient Community Hemodialysis Center," *Trans. Amer. Soc. Artif. Intern. Organs,* **9**, 3-9 (1963).

[55] J. P. Merrill, E. Schupak, E. Cameron, and C. L. Hampers, "Hemodialysis in the Home," *J. Amer. Med. Ass.,* **190**, 468-470 (1964).

[56] F. K. Curtis, J. J. Cole, B. J. Fellows, L. L. Tyler, and B. H. Scribner, "Hemodialysis in the Home," *Trans. Amer. Soc. Artif. Intern. Organs,* **11**, 7 (1965).

[57] *National Dialysis Registry,* University Hospital, University of Maryland, Baltimore, Maryland.

[58] J. H. Shinaberger, E. C. Pierce, II, E. P. Tuttle, Jr., M. A. Eidex, and F. S. Martinez, "Further Development and Clinical Evaluation of the Klung Dialyzer," *Trans. Amer. Soc. Artif. Intern. Organs,* **12**, 363 (1966).

[59] *Proceedings of the First Annual Contractors Conference of the Artificial Kidney Program of the National Institutes of Arthritis and Metabolic Disease,* Bethesda, Maryland, 1968.

[60] R. D. Stewart, R. J. Lipps, E. D. Baretta, W. R. Piering, D. A. Roth, and J. A. Sargent, "Short-term Hemodialysis with the Capillary Kidney," *Trans. Amer. Soc. Artif. Intern. Organs,* **14**, 121 (1968).

[61] J. R. Hunt, J. H. Sadler, J. H. Shinaberger, and P. M. Galletti, "Laboratory and Clinical Evaluation of a Small Countercurrent Dialyzer, the MiniKlung," *Trans. Amer. Soc. Artif. Intern. Organs,* **14**, 109 (1968).

[62] F. W. Miller, J. E. Clark, C. P. Jones, K. L. Smeltzer, and L. W. Bluemle, Jr., "A New Cuprophan No-prime Disposable Cartridge Dialyzer," *Trans. Amer. Soc. Artif. Intern. Organs,* **14**, 126 (1968).

[63] R. E. Easterling, O. G. Haig, and J. A. Greene, Jr., "The Plastic Mesh Support Twin-coil Hemodialyzer: Ultrafiltration, Volume, Erythrocyte Recovery and Safety," *Trans. Amer. Soc. Artif. Intern. Organs,* **14**, 114 (1968).

[64] V. M. Cestero and R. B. Freeman, "Comparative Performance Characteristics of 13 Hemodialyzers," *Trans. Amer. Soc. Artif. Intern. Organs,* **15**, 81 (1969).
[65] B. Khastagir, J. Erben, A. Shimizu, F. Rose, Y. Nose, D. Van Dura, and W. J. Kolff, "The Four-coil Artificial Kidney for Home Dialysis," *Trans. Amer. Soc. Artif. Intern. Organs,* **13**, 14 (1967).
[66] *Proceedings of the First Annual Contractors Conference of the Artificial Kidney Program of the National Institutes of Arthritis and Metabolic Disease,* Bethesda, Maryland, 1968.
[67] C. W. Gottschalk, "Report of Committee on Chronic Kidney Disease to the Bureau of the Budget," Washington, D. C., September 1967.

Received for publication January 20, 1970