METHODIST DEBAKEY CARDIOVASC J | 16 (4) 2020

The Wearable Artificial Kidney

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INTRODUCTION

The goal of renal replacement therapy is to replace the functions of the kidneys for patients with end-stage renal disease. Renal transplant is the optimum intervention, but the number of available kidneys for transplant is less than 10% of the patients who need them. Thus dialysis techniques have been developed over the past 100 years to serve as renal replacement therapy.

The kidneys perform multiple biochemical tasks that maintain human health. These bean-shaped organs receive 20% to 25% of cardiac output, or 1 to 1.2 liters of blood each minute. Human kidneys generate a cell-free filtrate of approximately 144 liters each day—about 6 liters per hour or 100 mL per minute (the glomerular filtration rate). The tubules subsequently absorb and secrete water, electrolyes, and valuable nutrients, eventually producing a few liters of urine that contains concentrated wastes, excess water, and electrolytes.[1]

In addition to maintenance of the internal milieu, the kidneys also serve a plethora of vital metabolic functions, including but not limited to blood pressure regulation, vitamin D metabolism and bone health, erythropoietin synthesis and regulation of red blood cell production, and detoxification of organic compounds. These processes are not duplicated during conventional hemo- or peritoneal dialysis; thus, medical care for patients with severe renal failure is quite complicated and time consuming. Wearable or portable dialysis modalities to help alleviate this time burden for patients are under development.

CURRENT DIALYSIS

Renal dialysis therapies all use a semipermeable membrane to separate the patient's blood from a synthetic dialysate containing electrolytes. Waste products and excess water in blood cross the dialysis membrane into the dialysate and are then removed from the body. During hemodialysis, blood from the patient circulates outside of the vascular system and passes through an artificial kidney containing a synthetic semipermeable membrane. Waste products and excess water diffuse across the membrane into the dialysate and are removed, while cleaned blood is returned to the patient. Peritoneal dialysis, in contrast, does not involve removing the patient's blood. Rather, dialysate is instilled into the abdominal space, with the peritoneal membrane serving as the semipermeable blood-dialysate barrier. The dialysate is then exchanged with fresh fluid, thereby removing waste products and excess volume.

APPROACHES TO PROVIDING PORTABLE DIALYSIS

Wearable and portable dialysis systems perform the same functions as described above but are contained in smaller, less intrusive packages.[2,3] The techniques described below are in development but not yet commercially available.

Peritoneal dialysis is already a home-based treatment modality that can be performed with minimum equipment. A modified automated wearable artificial kidney (AWAK) automates peritoneal dialysis by providing small tidal infusions of dialysate.[4] The patient initiates therapy by instilling a usual amount of dialysate into peritoneal space. A purse-sized controller with batteries is carried by the patient and contains a disposable cartridge that rejuvenates used dialysate, a small pump, and reservoir containing approximately 500 mL of dialysate. The AWAK automatically removes dialysate in 500 mL quantities, regenerates it, and infuses it back into the patient. This process repeats 8 times per hour. The dialysate cartridge lasts about 7 hours, after which it is changed. Periodically, the patient infuses fresh dialysate.

Hemodialysis-based wearable artificial kidneys (WAK) are also under development. As in traditional hemodialysis, a pump circulates blood and dialysate through a disposable artificial kidney. Used dialysate is regenerated in a disposable cartridge and recirculated. Batteries, pump, reservoirs, and controls are housed in a wearable pack that weighs about 10 lbs.[5] These systems are external to the body, so patients still require vascular access and blood lines that carry blood to and from the WAK.

An implantable artificial kidney (IAK) is under development but not yet tested in humans. In this approach, a small manmade kidney would be surgically inserted into the patient. As in native kidneys, the cardiovascular system perfuses the kidney without the need for pumps or batteries. The implantable kidney cartridge is made of silicon with highly porous micro slits, thus generating an ultrafiltrate that drains into the patient's bladder.[6] Volume and electrolyte balance is maintained by oral supplementation of an electrolyte solution to replenish lost volume and minerals. Research to culture living human kidney cells on the silicone frame is ongoing, thus this version of the artificial kidney might replace renal metabolic functions in addition to simply making cell-free ultrafiltrate. If and when fully developed, an IAK would provide renal replacement therapy 24 hours per day with minimal impact on the patient's lifestyle.

TRANSPLANTABLE BIOLOGICAL KIDNEYS

Human kidneys for transplant are in short supply, and several approaches are being considered for expanding the supply. One approach is to convert nonhuman mammalian kidneys into organs that may be transplanted into humans. For example, porcine kidneys would be denuded of pig tubular and interstitial cells and repopulated with human cells.[7] Alternatively, advances in antirejection therapy may allow zoonotic transplants. Neither of these treatments are viable options for treating patients with renal disease at this time.

CONCLUSIONS

Portable or wearable renal replacement therapy is being developed but not yet available for routine clinical practice.

Presently, renal transplant comes closest to “curing” end-stage renal disease. If a kidney transplant is not available, home-based therapies using peritoneal or hemodialysis come closest to providing a normal lifestyle. In-center hemodialysis causes the most disruption in patients' family and work life but provides lifesaving therapy for those unable to undergo home-based dialysis.

REFERENCES

1. Carlstrom M, Wilcox CS, Arendshorst WJ. Renal Autoregulation in Health and Disease. Physiol Rev. 2015 Apr;95(2):405-511.
2. Van Gelder MK, Mihaila SM, Jansen J, et al. From portable dialysis to a bioengineered kidney. Expert Rev Med Devices. 2018 May;15(5):323-336.
3. Salani M, Roy S, Fissell WH 4th. Innovations in Wearable and Implantable Artificial Kidneys. Am J Kidney Dis. 2018 Nov;72(5):745-51.
4. Gura V, Macy AS, Beizai M, Ezon, C, Golper TA. Technical breakthroughs in the wearable artificial kidney (WAC). Clin J Am Soc Nephrol. 2009 Sep;4(9):1441-8.
5. Gura V, Beizai M, Ezon C, Polaschegg HD. Continuous renal replacement therapy for end-stage renal disease. The wearable artificial kidney (WAK). Cont Nephrol. 2005;149:325-33.
6. Fissell WH, Dubnisheva A, Eldridge A, Fleischman AJ, Zydney AL, Roy S. High-Performance Silicone Nanopore Hemofiltration Membranes. J Memb Sci. 2009 Jan 5;326(1):58-63.
7. Oxburgh L Carroll TJ. The bioengineered kidney: science or science fiction? Curr Opin Nephrol Hypertens. 2016 Jul;25(4):343-7.