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DESIGN INSIGHT

The role of design in dialysis innovation, sustainability, and patient quality of life

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SUMMARY

This article explores the redesign of the Wearable Artificial Kidney (WAK). The article aims to show how crucial a designer's intervention can be even for medical purposes. It suggests how a renewed setting of the WAK's components and the review of its usability can spark the transformation of a therapeutic method that has remained unchanged over many years, but is no longer sustainable, both in terms of resources and patients' quality of life.

Key Words: Medical design; product design; design-driven innovation; wearable artificial kidney; portable hemodialysis

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INTRODUCTION

Chronic Kidney Disease affects 13.4 percent of the global population, with 4,902 to 7,083 million requiring renal replacement therapy (RRT), including kidney transplants or dialysis.[1] Hemodialysis (HD) is the most common form of RRT, used by 89 per cent of dialysis patients worldwide, with constant increases.[2] HD is costly because it involves direct medical costs (eg, staff, machine rentals), non-medical costs (eg, 300–600 litres of water per person weekly plus electricity), and indirect costs (eg, caregiver time).[3] Patients face significant challenges, including intense treatment schedules, fluid retention, toxin buildup, and associated symptoms like headaches and nausea. These factors lead to reduced mobility, loss of independence, and mental health issues.[2]

Home hemodialysis offers a potential solution, allowing patients to receive treatment at home and on a more flexible schedule. It remains underutilized, however, due to the complexity of setup and bulky, user-unfriendly devices. Despite its advantages, such as reduced toxin accumulation and fluid retention, home dialysis still requires substantial water usage and limits patient mobility.

Given the rising incidence of kidney disease and its associated costs, there is a clear need for cost-effective, accessible methods that improve patient outcomes. Current HD treatments, both at home and in hospitals, are increasingly unsustainable.[2]

SUMMARY

The Wearable Artificial Kidney (WAK)[4]—developed by nephrologists Claudio Ronco, Victor Gura, and Andrew Davenport—is an advanced prototype of a wearable hemodialysis device that tries to overcome the hemodialysis limits (Figure 1).[4,5] WAK uses the REDY Sorbent System to regenerate dialysate, enabling continuous daily treatment with minimal water usage.[4,5] This system reduces the accumulation of toxins and dialysis intolerance, offering greater mobility and comfort compared to traditional hemodialysis methods. WAK uses three miniaturised Redy cartridges to ensure 24-hour treatment with only 350 cc of dialysate.[5]

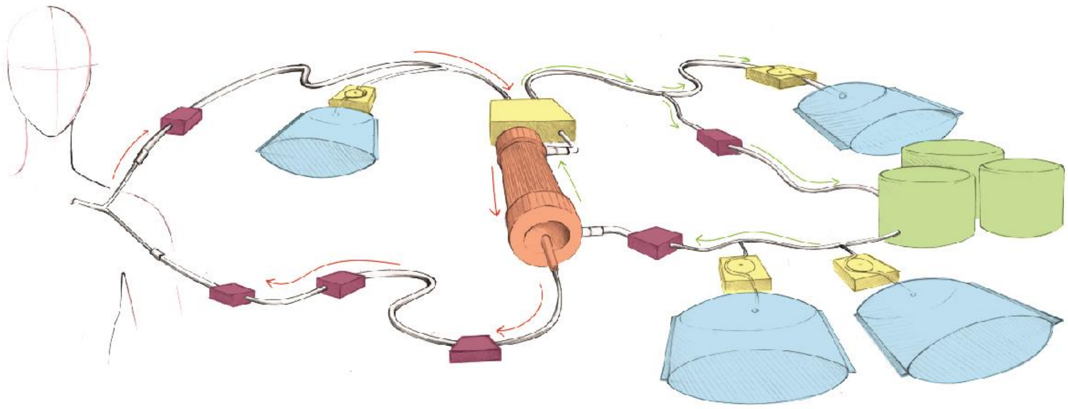
The WAK's current design is bulky, complex, and lacks ergonomic considerations. Wearing such a harness, with its visible tubes, fluids, and medications, requires confidence and can serve as a stark reminder of one's condition, potentially leading to psychological distress. Moreover, the WAK cannot be assembled or disassembled without help, further adding to patients' frustration with their ongoing reliance on caregivers. To improve the WAK, a product designer's intervention is required to simplify and streamline its components for better usability and patient experience. This initially became the subject of a master's degree thesis in product design under the supervision of Prof Claudio Ronco and his team of bioengineers, mechatronics experts, and research fellows at the International Renal Research Institute of Vicenza (IRRIV).

Figure 1: The Wearable Artificial Kidney (WAK)

Images provided courtesy of Dr Victor Gura

The designer's task is to outline a practical, comfortable, and aesthetically pleasing shape for the WAK, incorporating all its components effectively. To achieve this, a thorough understanding of the precise positioning, order, and quantities of both technological and medical components is necessary. The process begins by redrawing the WAK's dialysis circuit, revealing the minimum components required for accurate functioning (Figure 2).

Figure 2: The WAK's schematic drawing



Legend:
Sensors and clamp (purple); peristaltic pumps (yellow); solutes bags and ultrafiltration (blue); dialyser filter (red); Redy Sorbent System (green); pipes (white). Red arrows: blood circuit; green arrows: dialysate circuit.

The WAK comprises fixed components: 1) five sensors, including pressure, bubble-detection, blood-leak, and electrolyte sensors; 2) four peristaltic pumps, three for solution infusion and one for ultrafiltration drainage; and 3) one double-channel shuttle pump. Disposable components include one hemofilter, four bags (heparin, bicarbonate, electrolyte, and ultrafiltration), three Redy cartridges, and two lines of pipes for the blood and dialysate circuits. The main flaw of the current prototype is its complex daily setup, requiring patients to unpack and reassemble the entire system, including fixed components, making it difficult for self-management.

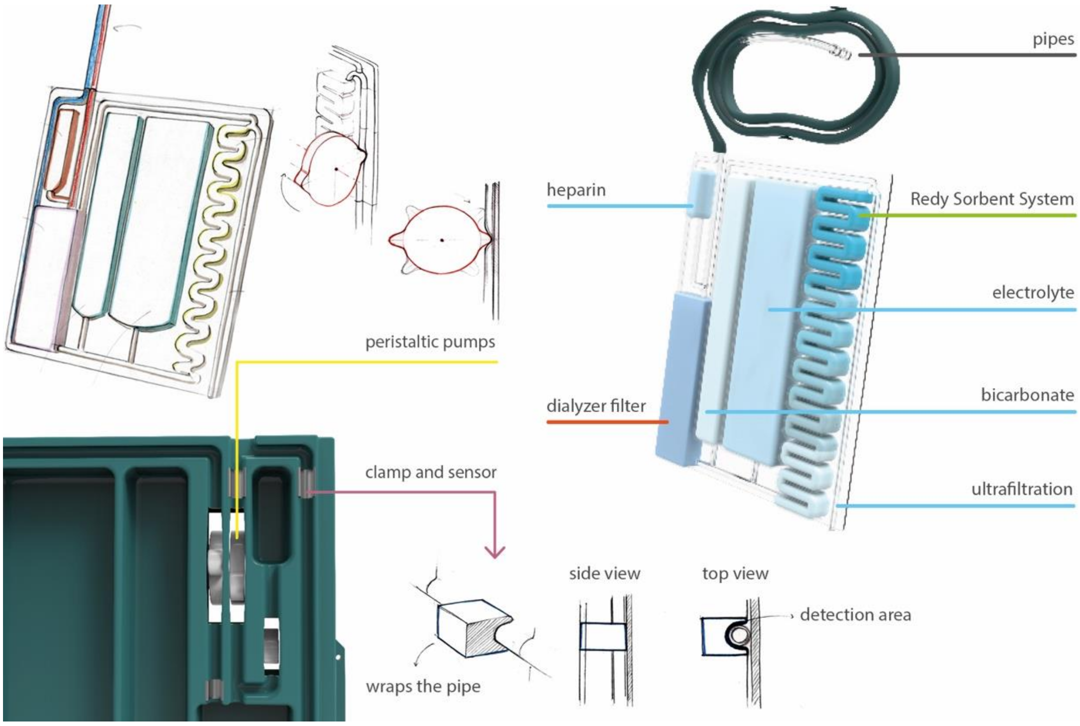
The designer aimed to redesign the WAK to be portable, user-friendly, and efficient. The new design should simplify the number and size of components, be effective for 6–8 hour treatments, usable day or night, portable and wearable, easy to set up and operate, easy to clean, rechargeable, telemedical, reliable, convenient, and visually appealing. Achieving these goals requires considering human factors and usability.

To overcome the challenges in WAK research, the designer suggested prioritising portability over strict adherence to the device being "wearable." The first step entails envisioning the WAK as a compact element that fits into a backpack (maximum dimensions 46 x 32 x 18 cm) rather than a belt. This approach addresses the device's lack of affordance by simplifying daily setup, which is currently a major obstacle—a solution also appreciated by the dialysis centre patients who were involved in the user research and concept definition phases.

After three design iterations, the designer proposed Re-Feel, an all-in-one, rigid, pre-assembled cartridge incorporating all disposable components (hemofilter, heparin, bicarbonate, electrolytes, Redy Sorbent System, inner and outer pipes) (Figure 3). This cartridge can be easily connected to the fixed electrical/mechanical components (sensors and pumps) within the device shell. The cartridge must maintain the same sequence of blood and dialysate circuits, use minimum volumes of solutions for effective dialysis, redesign the hemofilter for efficiency, and house a new REDY sorbent system.

DESIGN INSIGHT
JHD 2024;9(2):656–662

Figure 3: Re-Feel, the new all-in-one and plug-and-play cartridge



This all-in-one cartridge design simplifies the WAK's use, making it easy for patients. After validation by Prof Ronco and the IRRIV team, the maximum cartridge size is set at 25 x 30 x 2 cm. The cartridge will consist of biocompatible bags and pipes attached to a polycarbonate layer, covered by soft silicone. Solutions (20 cc heparin, 400 cc electrolyte, 200 cc bicarbonate) are packaged in shrinkable bags, and ultrafiltration drainage falls into a removable tank.

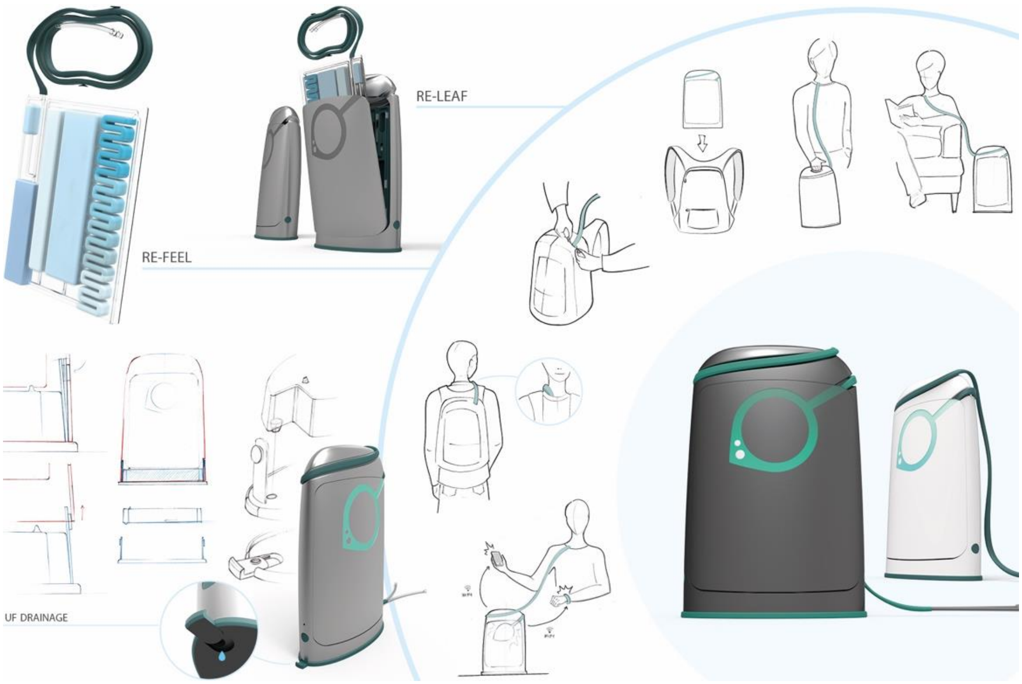
A weekly home supply of these cartridges may reduce hospital waste and allows bearable, repeatable dialysis treatments. Local health units can collect used cartridges and deliver new ones weekly. This approach minimises material consumption and allows some materials to be reused.

The final design, named Re-Leaf, is a portable and user-friendly hemodialysis device. It includes a rear handle for easy carrying at home, work, or school, and fits into a backpack for use on the go. The inner cover protects the electronic board, pump motors, lithium battery, and other components. The bottom houses a one-litre tank for ultrafiltration, with a sensor to check liquid level and a drainage hole for emptying during sessions. A silicone wristband and smartphone app connect Re-Leaf to the hospital for real-time monitoring.

Re-Leaf can be supplied to patients on a free loan basis, with recyclable polymeric components. The cartridge, Re-Feel, is special medical waste, except for the reusable polycarbonate layer. The device's overall weight is minimised for ease of carrying or wearing. The design reflects values like comfort, simplicity, relief, empathy, help, regeneration, and replacement, making it user-friendly and easy to clean. This comprehensive redesign transforms the WAK into a viable, efficient, and patient-friendly device for home-based dialysis.

JHD 2024;9(2):656–662

Figure 4: Re-Leaf's operations and functions



LESSONS LEARNED

The advanced concept of Re-Leaf, along with its cartridge Re-Feel (both developed over seven months), not only aims to make the hemodialysis portable—or wearable when needed, by fitting it into a backpack—but also more comfortable and discreet, avoiding the stigma of the disease, and thereby reducing the user's psychological and physical stress. Most importantly, it makes using the device much easier. The all-in-one cartridge is designed to be plug-and-play in a fail-safe way. With a single gesture, the treatment is set up without the help of medical or skilled staff. The new patients would be only trained to connect pipes themselves using either a central venous access catheter (located between the chest and neck) or a standard vascular access (such as fistula needles in the arm)—a practice that the current home dialysis patients are already trained to manage independently.

In addition to improving patients' quality of life—by making them independent from hospital routines and reassured by the fact of support through telemedicine—Re-Leaf saves on water, electricity, and disposable components. It stands to be more sustainable than any current hemodialysis method and quite consistent with the ongoing dehospitalisation trend.

The concept can also be adapted and upgrade to present-day hospital equipment. The Re-Feel design can be developed in different sizes and the inner parts rearranged. The concept of a sole cartridge hosting all the disposable components could be embraced by the leading dialysis companies (Asahi Kasei, Baxter, B. Braun, Fresenius, Becton Dickinson, etc.) and begin to refashion (and green) the hospital dialysis routine.

In conclusion, this Design Insight shows how essential the designer's intervention is in the medical field. Through thoughtful, careful and innovative redesign, one of the most widely used medical devices was reimagined and developed. Although the WAK is still a research concept (prototyped but not yet selected for production) its redesign also demonstrates how the discipline of design—ie, the reorganization of spaces and components, the review of usability and gestures, the attention to human factor, ergonomics, empathy, and sustainability—can drive the evolution of a method of treatment that has remained unchanged over decades and convert it into a more sustainable option, both in terms of resources and patients' quality of life.

DESIGN INSIGHT

This article discusses a high-level story of design playing a role in improving health outcomes for people with renal disease. Incorporating a human-centered design approach in product development, the industrial designer explored new design opportunities towards making the science of this hemodialysis device fit better into the actual user experience.

While the original prototype was functional, it was cumbersome to set up and put on and did little to reduce the stigma a patient can feel wearing such a physically predominant medical device on their body. Incorporating the nephrologists' design intent and science, Re-Leaf was a reimagination of the original wearable device concept that also provides the user with the mobility during their treatment that the doctors intended and the users desired. The development of the Re-Feel component seems a very smart solution with its combination of disposable and reusable parts. The distribution of new and collection of spent parts offers a sustainable way to reduce the amount of medical waste.

This design collaboration between a graduate industrial design student and a group of doctor/inventors showcases how combining good design and good science offers potential to improve patient outcomes.

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