Smart Peritoneal Dialysis Control System to Enhance Mobility and to Reduce the Mortality Rate

Dr. A. Murugan, M.E., Ph.D.,[1], Arulkumar S[2], Pradheesh S[3], Raghubalan R[4]
[1]*Professor, Department of Biomedical Engineering, Paavai College of Engineering, Namakkal.*
[2,3,4] *Studen[4], Department of Biomedical Engineering, Paavai College of Engineering, Namakkal.*

***Abstract*—Peritoneal Dialysis (PD) is a widely adopted home-based therapy for patients with end-stage renal disease (ESRD). However, traditional PD lacks real-time monitoring, leading to potential complications such as peritonitis, cardiovascular issues, and glucose imbalances. This paper presents the design and implementation of a Smart Peritoneal Dialysis (SPD) system that integrates vital parameter monitoring, glucose sensing, pH detection, and waste management using Super Absorbent Polymer (SAP). The SPD system aims to enhance the effectiveness of PD, reduce adverse events, and promote telemedicine. The integration of these components facilitates early detection of anomalies, timely interventions, and improved patient safety.**

***Index Terms*—Adverse event, Dextrose, Dialysate, Glucose monitoring, pH detector, Peritoneal dialysis, Super Absorbent Polymer.**

1 INTRODUCTION

Peritoneal dialysis (PD) has emerged as a popular and patient-centred option for managing end-stage renal disease (ESRD), primarily because it allows individuals to receive treatment at home without the need for frequent clinical visits. Unlike hemodialysis, PD is less invasive, promotes autonomy, and supports a more flexible lifestyle. However, despite these advantages, PD continues to present several operational and clinical challenges that can negatively impact patient outcomes. Among the most common issues are fluid overload, the risk of peritonitis, inefficient dialysis cycles, and limited patient mobility due to bulky equipment and waste handling procedures.

To address these issues, this paper proposes a novel approach that combines two technological advancements within the PD workflow: a multiparameter monitoring system that enables real-time, automated assessment of key dialysis parameters, and the application of superabsorbent polymers (SAPs) in the waste dialysate collection process to solidify effluent and improve hygiene, safety, and portability.

2 KEY NOTES

From the literature survey, we analysed the difficulties with the PD and we formulated a new smart system in order to solve the issue with the following key notes.

1. To design and implement an intelligent peritoneal dialysis system that monitors key parameters like blood pressure, temperature, flow rate, glucose levels, and pH in real-time to improve the safety and efficiency of dialysis treatment.

2. To integrate non-invasive glucose and pH sensing technologies for early detection of glucose fluctuations and acid-base imbalances, minimizing the risk of type 2 diabetes and peritoneal infections during dialysis.
3. To incorporate Superabsorbent Polymer (SAP) for safe and hygienic storage of drain fluid, aiding in infection prevention and environmentally friendly disposal.
4. To enable remote monitoring and telemedicine by facilitating real-time communication between patients and healthcare providers, thereby reducing emergency interventions and enhancing patient adherence.
5. To evaluate the SPD system's impact on clinical outcomes, patient safety, and its potential for integration with AI, IoT, and predictive healthcare models for future dialysis advancements.

3 EXISTING WORK

The multiparameter monitoring system consists of a suite of compact sensors embedded in the dialysis circuit, capable of continuously measuring critical indicators such as inflow and outflow volume, intra-abdominal pressure, dialysate temperature, pH, glucose concentration, and conductivity. These parameters provide essential insights into the physiological status of the patient and the effectiveness of each dialysis cycle. For example, monitoring pressure and flow rates helps prevent underfilling or overfilling, which are associated with discomfort and increased infection risk.

Real-time glucose readings reflect ultrafiltration efficiency, while abnormal pH or conductivity levels can signal early signs of infection or chemical imbalance. This integrated sensor data is transmitted to a central processor or mobile application, which generates alerts and allows healthcare providers and patients to respond swiftly to any deviations [1][2][3][4].

The SAP-based dialysate management system introduces a second layer of innovation aimed at improving hygiene and patient mobility. After each dialysis cycle, waste dialysate is drained from the peritoneal cavity and typically collected in large, liquid-filled drainage bags. These bags are difficult to manage, susceptible to leaks, and pose infection and odor risks, especially for patients traveling or living in small spaces. SAPs are cross-linked polymer materials capable of absorbing many times their weight in water. When incorporated into the drainage bag, SAP rapidly solidifies the effluent, turning it into a semi-solid gel. This reduces the likelihood of spills, simplifies disposal, and enables the development of compact, lightweight containers that patients can use more discreetly and safely [6].

One of the most significant implications of this study is its potential to shift PD toward a more intelligent, patient-driven model of care. The feedback from the multiparameter system empowers both patients and clinicians to make informed decisions, thereby reducing complications and hospitalizations [1][2][4][5].

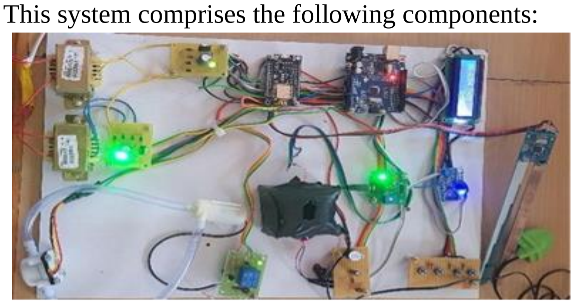
Meanwhile, SAP technology addresses long-standing practical challenges associated with waste handling, enabling patients to carry out dialysis with less disruption to their daily activities [6].

4 PROPOSED WORK

The proposed work aims to enhance peritoneal dialysis (PD) by integrating two innovative technologies: a multiparameter monitoring system and a Superabsorbent polymer (SAP)-based waste dialysate management system. The multiparameter monitoring system will involve embedding compact sensors in the dialysis circuit to continuously measure key parameters such as inflow and outflow volume, intra-abdominal pressure, dialysate temperature, pH, glucose concentration, and conductivity. This real-time data will be transmitted to a central processor or mobile application, providing alerts and insights for both patients and healthcare providers to adjust treatment promptly. This system will improve fluid balance accuracy, reduce the risk of infections, and allow for more informed decision-making. The SAP-based waste management system will address the challenges associated with collecting waste dialysate. By incorporating SAP into the drainage bags, the dialysate will solidify into a semisolid gel, reducing the risks of leaks, spills, and odor, and improving hygiene and mobility for the patient. Patients will be able to carry and dispose of the solidified waste more easily, promoting greater independence and safety. Together, these technologies are expected to enhance patient outcomes by providing better control over dialysis parameters and simplifying waste management, ultimately offering a more patient-centered, efficient, and portable solution for PD.

5 SYSTEM ARCHITECTURE

This system comprises the following components:



Vital Parameter Monitoring: Sensors to measure Blood Pressure (BP), body temperature, flow rate, and pre/post dialysis weight. Glucose Monitoring System: Continuous glucose monitoring to detect hyperglycemia during dialysis sessions. pH Detection System: Sensors to monitor the pH levels of dialysate and drained fluid, indicating potential infections or metabolic imbalances. Super Absorbent Polymer (SAP): SAP is used to solidify and safely contain drained dialysate, reducing contamination risk. Telemedicine Integration: Connectivity modules transmit real-time data to healthcare providers for remote monitoring and timely intervention.

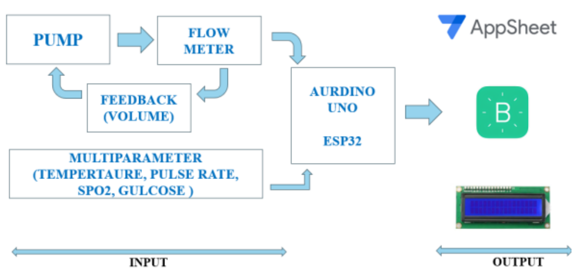
Methodology

Vital Parameter Monitoring

The system employs non-invasive sensors to continuously monitor BP, temperature, flow rate, and weight. Data is analyzed in real-time to detect abnormal values, triggering alerts for immediate intervention, which improves clinical safety and response time.

Glucose Monitoring

Since PD solutions commonly contain dextrose, there’s a risk of glucose absorption leading to hyperglycemia. The SPD system uses glucose sensors for realtime blood glucose monitoring. Technologies such as near-infrared spectroscopy are employed to ensure noninvasive yet accurate detection



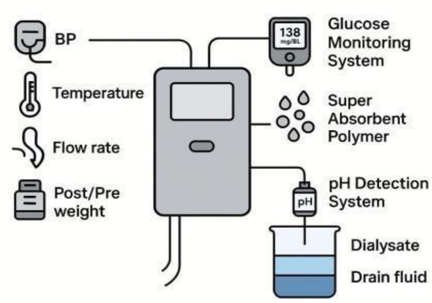
pH Detection

pH sensors measure the acidity of both the incoming dialysate and the drained effluent. Abnormal pH levels may signal the onset of peritonitis or metabolic issues. Monitoring these parameters provides early warning for infections.

Waste Management with Superabsorbent Polymers (SAPs)

Effective management of dialysate effluent is crucial in peritoneal dialysis to prevent infection and ensure patient safety. The SPD system employs Superabsorbent Polymers (SAPs) to solidify and contain the drained dialysate, thereby minimizing the risk of contamination and facilitating safe disposal. SAPs are cross-linked polymer networks capable of absorbing and retaining large volumes of aqueous fluids relative to their mass. Their high swelling capacity and water retention abilities make them suitable for various medical applications, including wound dressings and fluid management systems. In the context of peritoneal dialysis, SAPs can rapidly absorb the drained dialysate, transforming it into a gel-like substance that is easier to handle and dispose of safely. Moreover, advancements in SAP technology have led to the development of disinfectant-impregnated SAPs (DSAPs), which combine fluid absorption with antimicrobial properties. For instance, SAPs impregnated with sodium dichloroisocyanurate (NaDCC) have demonstrated 100% bactericidal activity against pathogens such as Klebsiella pneumoniae and methicillin-resistant Staphylococcus aureus (MRSA) at a 5 wt% concentration. This dual functionality not only solidifies the waste fluid but also actively reduces microbial load, thereby enhancing infection control measures within the SPD system. Incorporating SAP-based waste management into the SPD system enhances overall patient safety and aligns with best practices in infection control.

Smart Peritoneal Dialysis (SPD) System

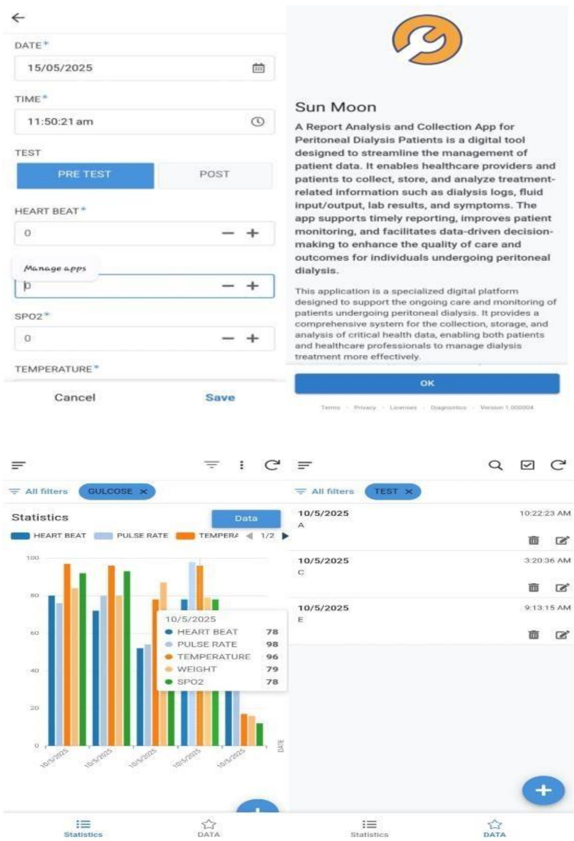


Telemedicine Integration

The system is connected to a cloud platform for real-time data transmission to healthcare providers. This enables remote monitoring and reduces hospital readmissions. Previous studies confirm the benefits of telemonitoring in improving blood pressure control and reducing complications.

6 RESULTS AND DISCUSSION

The SPD system demonstrated notable improvements in real-time monitoring, safety, and patient engagement. Glucose and pH sensors contributed to early detection of metabolic imbalances and potential infections. SAP-based waste containment provided hygienic disposal, while remote monitoring features improved patient compliance and reduced emergency interventions [1][4][5]. This dual innovation also opens pathways for future development, such as the integration of AI-based trend analysis for predictive healthcare, automated dosage adjustments based on real-time data, and fully wearable PD systems.



Additionally, the SAP component could be adapted for use in emergency settings, disaster relief, or low-resource environments where sanitation and disposal options are limited. In conclusion, the combination of multiparameter monitoring and SAP based dialysate containment represents a significant advancement in peritoneal dialysis. By improving safety, reducing adverse events, and enhancing mobility, this system aligns with the growing movement toward personalized, homebased renal care. Larger-scale clinical trials and long-term evaluations are recommended to further validate these findings and explore cost-effectiveness. However, the initial results are encouraging and suggest that this approach can redefine the standard of care in peritoneal dialysis.

7 CONCLUSION AND FUTURE SCOPE

The Smart Peritoneal Dialysis system addresses several limitations of conventional PD therapy. By integrating smart sensors and telehealth features, it ensures better monitoring, reduced complications, and enhanced patient safety. Future work will aim to validate the system in large-scale clinical studies and expand its feature set for personalized dialysis care. Future scope, The Smart Peritoneal Dialysis (SPD) system presents promising opportunities for future enhancement and broader implementation. Clinical validation through large-scale trials will be essential to confirm the system's efficacy in reducing complications such as infections, hospitalizations, and adverse cardiovascular events. Integrating artificial intelligence and predictive analytics could enable the system to forecast health risks like peritonitis, fluid overload, and glucose fluctuations, allowing for proactive interventions. Additionally, the development of a patient-friendly mobile application could enhance user engagement by providing real-time vitals monitoring, health alerts, and direct communication with healthcare professionals. Enhanced biosensing capabilities, including sensors for creatinine, urea, and lactate levels in the dialysate, can provide a more comprehensive view of the patient's health status. Incorporating wearable technologies may further expand continuous monitoring outside the dialysis session. Future system versions may also be integrated with cloud-based electronic health records (EHRs) to support seamless telehealth consultations and data sharing among care teams.

Moreover, the SPD system could evolve into a fully IoT-enabled device, interacting with smart home systems to improve safety and automation. For instance, emergency alerts could be automatically sent to caregivers or medical teams if critical health thresholds are breached. Regarding sustainability, research into biodegradable or reusable superabsorbent polymers (SAPs) could reduce environmental impact and improve waste management. Finally, efforts to reduce production costs and simplify the user interface can make the SPD system more accessible, particularly in rural and low-resource settings, thereby expanding its global health impact.

REFERENCES

[1] Nayak, K.S., Ronco,C., Karopadi, A. N., & Rosner, M. H. (2016). Telemedicine and Remote Monitoring: Supporting the Patient on Peritoneal Dialysis. Peritoneal Dialysis International, 36(4), 362–366.

[2] Yeter, H. H., Akcay, O. F., Ronco, C., et al. (2020). Automated remote monitoring for peritoneal dialysis and its impact on blood pressure. Cardiorenal Medicine, 10, 198–208.

[3] Jain, P., Joshi, A. M., Agrawal, N., & Mohanty, S. (2020). iGLU 2.0: A new non-invasive, accurate serum glucometer for smart healthcare. arXiv preprint, arXiv:2001.09182.

[4] Viglino, G., Crepaldi, C., Giuliani, A., et al. (2020). Remote monitoring in peritoneal dialysis: benefits on clinical outcomes and on quality of life. Journal of Nephrology, 33(6), 1181– 1188.

[5] Sanabria, M., Buitrago, G., Lindholm, B., et al. (2019). Remote patient monitoring program in automated peritoneal dialysis: impact on hospitalizations. Peritoneal Dialysis International, 39(5), 472–478. [6] Lu, X., Zhang, M., et al. (2023).

[6] Development of Disinfectant- Impregnated Superabsorbent Polymers for Infection-Control Fluid Management. ACS Omega, 8(20), 17512–17522.

[7] Ronco, C., et al. (2019). Remote patient monitoring in peritoneal dialysis: benefits and challenges. Peritoneal Dialysis International, 39(1), 2-5.

[8] Sharma, S., et al. (2020). Sensors for continuous glucose monitoring: Current progress and future perspectives. Sensors, 20(19), 5525.

[9] Lu, H., et al. (2023). Superabsorbent Polymers in Biomedical Applications: A Review of Recent Advances. ACS Omega, 8(17), 15403– 15416.

[10] Finkelstein, F.O., et al. (2020). Telemedicine for CKD: Advances and Limitations. Clinical Journal of the American Society of Nephrology, 15(3), 348–354.

[11] Chan, C., et al. (2022). Barriers and facilitators to home dialysis adoption. Kidney International Reports, 7(4), 819– 829.