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ORIGINAL RESEARCH RENAL PATHOLOGY

Development of a multimedia-based real-time electronic fluid intake restriction model as a PACER tool to optimize self-monitoring of CKD patients undergoing hemodialysis

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ABSTRACT

Background & objective: Chronic kidney disease (CKD) is a major global and national health concern, with an increasing prevalence among the productive-age population. In Riau Province, Indonesia, the growing number of hemodialysis patients underscores the urgent need for effective self-monitoring strategies to control fluid intake. Non-adherence to fluid restriction frequently leads to interdialytic weight gain (IDWG), which can result in serious complications. While pharmacological therapy is often necessary, it may cause adverse effects and does not address behavioral factors contributing to poor fluid control. Conventional educational approaches have shown limited long-term effectiveness, highlighting the need for innovative, technology-based solutions. This study aimed to develop and evaluate a multimedia-based real-time electronic fluid intake restriction model to optimize self-monitoring and adherence among CKD patients undergoing hemodialysis.

Methodology: A Research and Development (R&D) design was implemented at Arifin Achmad Regional Hospital, Riau, Indonesia. The development process included a preliminary needs assessment through interviews and focus group discussions (FGDs), application design, expert validation, limited trials, and large-scale testing using a quasi-experimental one-group pretest–post-test design without a control group. During the intervention phase, patients used the PACER (Productivity And Capacity Evaluation in Research) application for two consecutive weeks, with daily fluid intake logging and automatic IDWG calculation after each dialysis session. Quantitative data were analyzed using paired t-tests, and qualitative data were interpreted through the Colaizzi's method of descriptive data analysis.

Results: Expert validation produced a mean feasibility score of 4.6 (very feasible). Limited trials involving 15 patients indicated high acceptability (mean = 4.3) and usability (mean = 4.2). In a large-scale test (n = 76), the mean fluid balance significantly decreased from 738.08 mL to 665.71 mL (P = 0.001, 95% CI: 3.46–112.28), demonstrating improved compliance and self-monitoring.

Conclusion: The PACER model is a feasible, user-friendly, and effective digital health application that enhances fluid self-monitoring and adherence among CKD patients. It represents an innovative step in Indonesia's digital health transformation, supporting patient self-efficacy, clinical outcomes, and the integration of smart health technologies into preventive nephrology care in Indonesia.

Abbreviations: CKD: Chronic kidney disease, FDG: focus group discussions, IDWG: interdialytic weight gain,

Keywords: Chronic kidney disease; Hemodialysis; Fluid intake; Patient compliance; Mobile application

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1. INTRODUCTION

Chronic kidney disease (CKD) has a high prevalence worldwide.[1–3] It is a global health problem with a steadily increasing prevalence in both developed and developing countries. According to data from the International Society of Nephrology (ISN). CKD now affects more than 850 million people worldwide and is projected to become the fifth leading cause of death globally by 2040.[4] In Indonesia, the prevalence of CKD reaches 0.38%. This translates to a population of approximately 267 million, meaning more than 1 million people suffer from CKD. This condition not only impacts the elderly population but also shows a significant increase in the productive age group.[5]

Riau Province has one of the highest CKD incidence rates nationally, reflected in the high number of patient visits to hemodialysis units at referral hospitals. There are approximately 42,383 CKD patients in Riau, and approximately 25% of them are in the end-stage stage, requiring regular hemodialysis therapy. Thus, it is estimated that there will be around 10,600 active hemodialysis patients in Riau by 2024.[6]

Hemodialysis is the primary renal replacement therapy for patients with end-stage CKD with significantly decreased kidney function. This procedure aims to remove metabolic waste and excess fluid through external filtration using a dialyzer.[7] The success of hemodialysis depends heavily on patient compliance, particularly in limiting fluid intake. Non-compliance can lead to fluid buildup between dialysis sessions (Interdialytic Weight Gain/IDWG), which carries the risk of edema, hypertension, and even serious cardiovascular complications such as congestive heart failure—particularly when IDWG exceeds 4.5% of the patient's dry body weight. Beyond being a clinical risk, IDWG > 4.5% also reflects non-adherence to fluid restriction, a preventable behavior that can be effectively addressed through digital self-monitoring interventions.[8]

In hot climates like Riau, hemodialysis patients often experience difficulty limiting their daily fluid intake. This is due to a lack of understanding of the risks of fluid overload and the limited availability of practical monitoring tools. Counseling is generally verbal and ineffective in promoting sustainable behavior change.[9] This situation underscores the importance of interactive and personalized technology-based education. A preliminary survey at Arifin Achmad Regional Hospital in Pekanbaru showed that 68% of patients had an IDWG of more than 4.5%. Most did not record their daily fluid intake, and reported difficulty monitoring and remembering fluid intake limits due to a lack of adequate equipment. These findings further emphasize the need for innovative interventions to assist patients in self-managing fluid intake.[10]

Internet of Things (IoT) technology enables real-time fluid monitoring and has been implemented in several countries as part of hemodialysis patient care systems.[11,12] However, in Indonesia, its implementation remains very limited and has not yet become a standard service. Most domestic studies still rely on conventional methods, such as educational leaflets or manual reminders via SMS.[13]

Existing educational interventions also primarily rely on verbal counseling, leaflets, or SMS messages, which are one-way and not yet digitally integrated. Studies show that this approach is less effective in driving long-term behavior change.[14] The PACER (Real-Time Electronic Fluid Intake Restriction) application offers an innovative solution an Android based system connected to supporting devices and equipped with fluid monitoring features, automatic IDWG calculations, notifications, and online consultations. Beyond its monitoring function, PACER also serves as an interactive educational platform designed to enhance patient self-efficacy, engagement, and behavioral change through real-time feedback and health education content.[15] This application serves as a liaison between patients, families, and healthcare teams, while also aligning with the

Indonesian Ministry of Health's digital healthcare transformation roadmap toward smart healthcare development.[16]

Therefore, the development of a digital-based fluid monitoring system through the PACER application is urgently needed to improve hemodialysis patient adherence, prevent complications, enhance clinical outcomes, and strengthen technology-based health literacy in Indonesia. This study aims to develop the PACER (Multimedia-Based Real-Time Electronic Fluid Intake Restriction) model as an interactive digital strategy to optimize self-monitoring and enhance adherence among CKD patients undergoing hemodialysis

2. METHODOLOGY

This study employed a Research and Development (R&D) approach to design and evaluate the PACER (Real-Time Electronic Fluid Intake Restriction) application as a digital innovation for daily fluid monitoring among patients with chronic kidney disease (CKD) undergoing hemodialysis. The research was conducted at Arifin Achmad Regional Hospital in Riau Province, Indonesia, and received ethical approval from the Health Research Ethics Committee of Hang Tuah University, Pekanbaru (No. 597/KEPK/UHTP/IX/2025).

The preparatory phase began with a needs assessment involving in-depth interviews and focus group discussions (FGDs) with patients, families, nurses, and nephrologists. The results indicated that most patients experienced difficulties in controlling fluid intake and expressed the need for a practical and user-friendly monitoring tool. Based on these findings, the PACER application was developed using Android Studio with Java as the programming language and integrated with Firebase for real-time data storage and cloud-based notifications. The application was designed with several key features, including fluid intake recording, automatic interdialytic weight gain (IDWG) calculation, adaptive reminder notifications, interactive educational media, and a monitoring dashboard that connects patients, families, and healthcare providers.

The implementation phase consisted of expert validation, limited trials, and large-scale testing. Expert validation involved nephrologists, hemodialysis nurses, and IT specialists who evaluated the application using a 5-point Likert scale to assess content accuracy, functionality, aesthetics, and security. The average validation score was 4.6, indicating that the PACER application was highly feasible for clinical use. A limited trial involving 15 patients was subsequently conducted to evaluate feasibility, acceptability, and usability, yielding high mean scores for acceptability (4.3) and usability (4.2). The large-scale trial adopted a quasi-experimental one-group pretest–posttest design to assess the effectiveness of PACER in reducing IDWG, improving adherence, and enhancing patient self-efficacy. During the intervention, participants used the PACER application for two consecutive weeks, recording their daily fluid intake and automatically calculating IDWG after each hemodialysis session.

The final phase involved data analysis and evaluation. Qualitative data obtained from interviews were analyzed using the Collaizi phenomenological framework, which included seven stages: reading all participant transcripts, extracting significant statements, formulating meanings, clustering themes, developing an exhaustive description, identifying the fundamental structure, and validating findings with participants to ensure accuracy. Quantitative data were analyzed using the paired t-test for normally distributed variables and the Wilcoxon signed-rank test for non-parametric data, ensuring appropriate interpretation based on data characteristics. User experience and satisfaction with the PACER application were also evaluated using the System Usability Scale (SUS) instrument.

3. RESULTS

A preliminary study was carried out using in-depth interviews and focus group discussions with a total of 18 respondents, comprising eight end-stage CKD patients, four family members, five hemodialysis nurses, and one nephrologist. The study revealed several important insights into the challenges faced by patients in managing their condition. A significant finding was that 75% of patients reported difficulty in controlling their fluid intake, particularly during hot weather. Family involvement also posed challenges, with around half of the family members indicating difficulties in reminding patients not to exceed their fluid limits. From a clinical perspective, nurses noted that 60% of patients experienced inter-dialysis weight gain exceeding 3 kg. In terms of behavioral adherence, only 40% of patients consistently followed fluid restriction guidelines, while 45% adhered partially and 15% were non-compliant. Furthermore, 83% of patients expressed a need for a daily fluid monitoring tool. Physicians highlighted the importance of having a real-time, data-driven monitoring system, whereas nurses emphasized the need for the application to be simple and easy to use. These insights informed the design of the PACER application, which includes features such as daily fluid input, automatic inter-dialysis weight gain calculations, adaptive notifications, multimedia education, and a monitoring dashboard.

Expert validation of the PACER application was

Table 1: Expert validation results for the PACER application

Assessment aspects	Nephrologist	Hemodialysis nurse	IT expert	Mean	Category
Content	4.7	4.5	4.6	4.6	Very Worthy
Functionality	4.6	4.4	4.5	4.5	Very Worthy
Appearance	4.3	4.5	4.4	4.4	Worthy
System security	4.8	4.6	4.7	4.7	Very Worthy
Total mean	4.6	4.5	4.6	4.6	Very Worthy

Table 2: Results of limited trials in CKD patients (n = 15)

Assessment aspects	Minimum score	Maximum score	Mean	Category
Acceptability	4.0	4.6	4.3	High
Ease of use	3.8	4.5	4.2	High

Table 3: Patient response to the PACER application

User response	n (%)
Easy to use without assistance	12 (80)
Requires initial assistance	3 (20)
Feels helpful with the fluid recording feature	13 (86.7)
Suggests simplifying the app's interface	4 (26.7)

conducted with three professionals, including a kidney specialist, a hemodialysis nurse, and an IT expert. The validation results indicated a very high level of feasibility, with the application receiving an mean score of 4.6, supporting its practicality and potential effectiveness for patient use (Table 1).

A pilot test was conducted on 15 CKD patients. Results showed high app acceptability (mean = 4.3) and ease of use (mean = 4.2) (Table 2).

The majority of patients (80%) stated that the app was easy to use without assistance. 86.7% found the fluid recording feature helpful, but 26.7% suggested simplifying the app's interface (Table 3).

The development of the PACER application involved respondents whose characteristics were carefully documented. The majority of participants were male, accounting for 55.3% of the sample, with an mean age of 41.84 years, ranging from 15 to 65 years. Most respondents had a high school level education, representing 47.4% of the participants, and a significant portion were self-employed, comprising 32.9% of the sample.

The effectiveness of the PACER application was evident in the observed outcomes after two weeks of continuous use, showing a significant decrease in Interdialytic Weight Gain (IDWG), referred to in this study as fluid balance, following the intervention. This suggests that the application successfully supported patients in managing their fluid intake, aligning with the initial goals of providing a practical and user-friendly tool to improve adherence to fluid restrictions (Table 4).

Table 4 shows the distribution of the mean frequency of pre-test is high (738.08) post-test fluid balance in patients shows low (665.71) with a minimum pre-test fluid balance of 420, maximum 1450 and post-test 500, maximum 900. And with a pre-test standard deviation of 175.867 and a post-test standard deviation of 65.870, so it can be concluded that fluid balance in chronic kidney disease (CKD) patients who undergo hemodialysis therapy after using the PACER application, on mean patients can reduce their drinking fluid intake.

Table 5 shows the results of the paired sample t-test, indicating a p-value of 0.001 ($p \leq 0.05$), indicating a significant difference between the pre-test and post-test values. Thus, the PACER application is effective in reducing IDWG, improving fluid compliance, and supporting self-monitoring in CKD patients. The 95% confidence interval (CI = 3.46 to 112.28) further supports the statistical significance of the findings, indicating a consistent reduction trend in IDWG after the intervention. This confidence interval suggests that the true mean difference in fluid balance lies between 3.46 and 112.28 mL, reinforcing the reliability of the observed improvement.

Overall, these findings demonstrate that the PACER application effectively enhances patient adherence to fluid restriction and reduces interdialytic

Table 4: Frequency distribution of before and after using PACER (multimedia-based real-time electronic fluid intake restriction)

Fluid balance	Range	Median (min-max)	Mean ± SD
Before intervention PACER	1030	700.00 (420-1450)	738.08 ± 175.867
After intervention PACER	400	650.00 (500-900)	665.71 ± 65.870

Table 5: Results of the paired sample t-test for the fluid balance for chronic kidney disease PACER

No	Fluid balance	Mean ± SD	95% Confidence interval	P-value
1.	Before intervention using PACER	738.08 ± 175.867	3.461- 112.276	0.001
2.	After Intervention using PACER	665.71 ± 65.870		

weight gain, highlighting its potential as a practical digital health innovation in hemodialysis management

4. DISCUSSION

The PACER intervention has been shown to be effective in improving fluid monitoring and control among patients with chronic kidney disease (CKD) undergoing hemodialysis. After two weeks of consistent use, patients demonstrated a significant reduction in interdialytic weight gain (IDWG), indicating better adherence to fluid restriction and enhanced self-regulation. This result supports the statistical finding of a significant difference between pre- and post-intervention fluid balance (P = 0.001, 95% CI: 3.461–112.276). The improvement suggests that PACER facilitated daily behavioral control and awareness of fluid intake, which are critical for long-term CKD management. These findings are consistent with Ahmad et al (2021), who emphasized that adherence to fluid restriction is essential to prevent fluid overload and protect kidney function in patients with kidney dysfunction. [18, 19]

The success of the PACER application reflects the growing role of digital health technology in improving patient self-management. Studies by Chang et al (2021) and Zhang et al (2023) have demonstrated that Android-based mobile applications can enhance patients' ability to independently monitor their condition, fostering autonomy and long-term behavioral change. [6,22] The PACER platform, which integrates real-time monitoring, adaptive notifications, and multimedia education, empowers patients to actively participate in managing their health and reinforces positive habits.[23] This aligns with Pratama et al. (2023), who define self-management as an individual's capacity to implement strategies that improve motivation, goal setting, and adherence to health behaviors.[24,25] In this study, patients reported increased confidence and consistency in monitoring their fluid intake, demonstrating that digital tools can effectively complement traditional health education in chronic care.[26,27]

Non-adherence to fluid restriction remains a major clinical challenge among hemodialysis patients. Previous studies by Lestari et al. (2022) and Sinurat et al. (2022) reported that many CKD patients have low levels of self-management, particularly in regulating fluid and dietary intake. [28,25] In this study, baseline findings also showed that 60% of patients experienced IDWG exceeding 3 kg, reflecting poor adherence to fluid restriction.[29,30] IDWG serves not only as a clinical indicator of fluid overload but also as a measurable marker of behavioral non-compliance.[31,32,33] Through real-time feedback and daily input features, the PACER application successfully addressed this issue by transforming IDWG monitoring into a continuous and educational process.[34,35].This approach encourages patients to recognize the link between fluid intake and weight gain, thereby improving their ability to self-regulate between hemodialysis sessions.

5. Strengths / weaknesses

Strengths: This study has several strengths. The PACER app represents an innovative, pioneering approach by integrating digital technology with self-management education for fluid monitoring. Its design allows patients to easily access guidance and track their fluid intake independently, making it highly practical and applicable in daily life. By focusing on self-management, the intervention empowers patients to take responsibility for their own care, promoting consistency and better adherence to fluid and dietary recommendations. Additionally, the intervention is efficient, as significant improvements were observed within a short two-week period. Finally, by enabling patients to monitor their condition independently, the app can reduce the workload on healthcare providers, allowing them to focus on other aspects of patient care. Weaknesses: This study has several **limitations**, including a relatively limited sample size, a short intervention duration, and only one hospital, which limits the generalizability of the results. Furthermore, external factors such as lifestyle differences, long-term adherence, and variations in patients' digital literacy levels were not fully accounted for. Therefore, further research with a longitudinal design, a larger sample size, and a multicenter approach is needed to strengthen the validity and generalizability of the findings.

6. CONCLUSION

This study successfully developed the PACER application, a health technology–based instrument designed to monitor fluid intake restrictions among patients undergoing hemodialysis. The development

process, which involved interviews, focus group discussions (FGDs), expert validation, and limited trials, demonstrated that the application is feasible, user-friendly, and clinically relevant. Quantitative findings revealed a significant reduction in interdialytic weight gain (IDWG) following the use of PACER, indicating improved patient adherence to fluid restriction. Beyond its function as a real-time monitoring tool, PACER also contributes to enhancing self-efficacy, promoting behavioral change, and improving long-term clinical outcomes by strengthening patients' health literacy and self-regulation. These findings support the integration of PACER into technology-based nephrology services in Indonesia as part of the national digital health transformation. Overall, this research makes an important contribution to the development of digital innovation in chronic disease management, particularly in chronic kidney disease, and opens opportunities for further studies examining the long-term effectiveness and large-scale implementation of the PACER application in clinical practice.

7. Data availability

Data presented in this study will be available on a fair request to the corresponding author of first author.

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10. Conflict of interest

All authors declare no conflict of interest.

11. Author's contribution

BS: conceptualization, study design, data collection, data analysis, manuscript drafting, and correspondence.
SS: contributed to the literature search, data collection, and manuscript editing.
M: statistical analysis, data interpretation, and provided critical review of the manuscript.
ARM: literature search, provided technical support in application development, and assisted in manuscript editing.
DHP: supervision, guidance, and critical review of the manuscript.
HSWN: supervision, project administration, and gave final approval of the manuscript.

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