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ORIGINAL RESEARCH

The Effect of a Novel Follow-up Mode Integrating Specialist Nurse-Led Care and an Intelligent Platform on Peritoneal Dialysis Patients

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Purpose: To evaluate the effect of a novel follow-up mode integrating specialist nurse-led care and an intelligent platform on fluid volume management in patients with end-stage renal disease (ESRD) undergoing peritoneal dialysis (PD).

Patients and Methods: A pre- and post-observational clinical cohort of 80 PD patients (Shanghai General Hospital South, Mar 2020–Mar 2021) evaluated the 12-month impact of the novel mode on fluid volume overload (FVL), cardiac function, laboratory indicators (including biochemical parameters and electrolytes), and clinically relevant complications (peritonitis, exit-site/tunnel infection and catheter displacement).

Results: After 12 months of follow-up using the novel mode, significant improvements were observed compared to the traditional follow-up approach. Specifically, levels of B-type natriuretic peptide (BNP) (144.12±14.21 vs 631.01±104.21 pg/mL, $P < 0.001$), systolic blood pressure (SBP) (136.99±12.04 vs 145.34±15.22 mmHg, $P < 0.001$), and diastolic blood pressure (DBP) (79.03±6.35 vs 84.87±8.17 mmHg, $P < 0.01$) were significantly lower in patients managed with the novel mode. Additionally, blood calcium (2.24 ±0.52 vs 2.18±0.02 pg/mL, $P < 0.05$), phosphorus (1.96±0.07 vs 1.80±0.06 mmol/L, $P < 0.01$), parathyroid hormone (PTH) (409.28 ±43.49 vs 250.84±23.26 pg/mL, $P < 0.001$), and albumin (38.89±0.60 vs 36.25±0.51 pg/mL, $P < 0.001$) levels were higher following implementation of the novel mode. FVL and cardiac function also showed significant improvement over the 12-months follow-up period. Notably, compared with the preceding 12-month control period, the platform-based follow-up reduced clinically relevant infectious complications from 10.3% to 3.8% (McNemar mid-p = 0.077).

Conclusion: The novel follow-up mode effectively reduced fluid volume overload and improved cardiac function, offering clinical benefits for PD patients.

Keywords: end-stage renal disease, peritoneal dialysis, novel follow-up mode, nurse-led care, intelligent platform, fluid volume overload

Introduction

Peritoneal dialysis (PD) is one of the crucial renal replacement therapies for patients with end-stage renal disease (ESRD), on which the residual renal function can be maximally protected due to its simple operation and low cost.[1,2] Outcomes of PD vary by patient characteristics, peritonitis occurrence and the management of fluid volume overload (FVL).[3] PD patients are mainly treated to manage FVL personally at home with guidance from doctor. However, most of them lack good self-management and understanding of the disease, which result in high incidence of complications, especially of the edema of lower limbs caused by excessive fluid volume overload which may lead to congestive heart

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failure (CHF). Imbalance of fluid volume overload in PD patients carries substantial morbidity, and contributes to added hospitalization events and treatment costs.[4,5]

At present, the mode of "Home Treatment+ In-hospital Management" is prevalent in PD patients. Most dialysis centers adopt the traditional "Manual Record + Telephone Follow-up" method to conduct follow-up management for PD patients. With the popularity of smartphones, some dialysis centers have established the "WeChat (a chatting app in cellphone) group follow-up" mode in recent years.[6] However, increasing evidence exhibited that patients' manual record at home treatment cannot guarantee the accuracy, integrity, and traceability of dialysis data. The abnormal data cannot be found and treated in time by the peritoneal dialysis center, making it hard to achieve good results.[7] And the WeChat follow-up raises privacy issues, which may negatively affect patient emotions, making the limitation more explicit. To better manage FVL and improve the prognosis of PD patients, a novel follow-up mode is proposed.

As an essential part of the treatment team,[8] PD specialist nurses serve as a bridge between doctors and patients. Therefore, the establishment of PD nurse-led follow-up mode, which combined intelligent platform, can not only improve patients' self-management ability but also collect daily dialysis data of patients' information. Since 2019, our PD center has used a nurse-led, smart-platform model that boosts patients' self-management while capturing daily dialysis metrics, enabling real-time detection of anomalies, on-demand education and instant consultation. This study explores its value for fluid-volume control.

Materials and Methods

Research Objects

Patients who were regularly followed up in the abdominal cavity center of the PD Center of Peritoneal Dialysis Center of Shanghai General Hospital (South) from March 2020 to March 2021 were selected as study subjects. The center maintains 150–200 prevalent PD patients; annual incident cases: 30–50, exits (death/loss to follow-up): 20–30, transfers to HD: 5–15.

Inclusion Criteria

(1) patients with regular PD ≥12 months and in stable clinical condition;
(2) patients aged 18–85 who could skillfully use smartphones and WeChat app;
(3) all respondents were given written informed consent and volunteered to participate in this study.

Exclusion Criteria

(1) patients with other substantial organ damages, such as chronic obstructive pulmonary disease (COPD), myocardial infarction, tumor, and infectious diseases;
(2) those who failed to make regular follow-up visits and upload relevant treatment records in accordance with the requirements of specialist nurses.

A total of 80 eligible patients were included. During the observation period, 2 patients withdrew, including 1 patient was transferred to hemodialysis and 1 patient received kidney transplantation. A total of 78 patients (aged 52.74±15.44), were followed up for 12 months, including 38 males (47.5%) and 40 females (50%). Among them, the primary disease was chronic nephritis in 40 cases, diabetic nephropathy in 10 cases, hypertensive nephropathy in 5 cases, lupus nephritis in 2 cases, polycystic kidney disease in 1 case, and the etiology was unknown in 22 cases. This study is in line with the requirements of the *Declaration of Helsinki* and conducted in accordance with the Consolidated Standards of Reporting Trials (CONSORT) 2010 guidelines.

Research Methods

Traditional Mode

The patients performed dialysis at home and recorded daily peritoneal ultrafiltration (PUF) volume, blood pressure, and body weight in the dialysis log, which should be carried along during outpatient follow-up. According to the follow-up requirements, PD nurses then checked and recorded PUF volume, blood pressure, diet, etc. of the PD patients. The

doctors eventually adjusted the medication according to the comprehensive evaluation and provided solutions to the problems. Traditional PD follow-up mode was adopted for all patients before enrollment. PD nurses conducted PD-related knowledge for patients during inpatient or outpatient follow-up. Physicians formulated outpatient follow-up plans according to patients' conditions, and PD specialist nurses conducted telephone follow-ups for patients once every 3 months.

Novel Mode

All the enrolled patients were completed the necessary baseline and follow-up assessments before adopting the novel mode. Baseline assessments included laboratory parameters, FVL, cardiac function, BP, etc. After enrollment, the novel follow-up mode, led by PD specialist nurses and integrated with the intelligent platform, was adopted for a period of 12 months. Clinically relevant infectious complications (peritonitis, exit-site/tunnel infection, and catheter displacement) were prospectively captured during the 12 months preceding enrolment (historical control) and throughout the subsequent 12 months of the novel follow-up program.

Platform and Patient Side

The Intelligent platform was divided into the medical side and the patient side. When daily weight, blood pressure, urine volume, and PUF data were input by each follow-up patient at the patient side, they could also be viewed on the medical side and automatically generated data graphs of PUF volume and other data (Figure 1). When abnormal data occurs, the platform could generate an intelligent warning. After detailed analysis, the doctors put forward a proposal, and the specialist nurse communicated precautions and appointment time to the patient through the platform. The patient side contains Daily Dialysis Records, Abdominal Dialysis Knowledge (including basic knowledge, operation videos, common complications of PD, diets for dialysis, etc.), Doctor-Patient Interaction, Examination Result Query, and other sections. Information such as outpatient follow-up notice, a reminder to make an appointment for replacement of abdominal catheters, an announcement of the PD center, and a follow-up questionnaire can be received on the patient side. Supposed abnormal conditions such as suspected peritonitis and infection at the exit of catheters ever occur to the patient at home, photos could be uploaded on the patient's side to get timely medical treatment.

Nurse and Medical Side

PD specialist nurses were the leading ones in the novel follow-up mode (Figure 2). Each patient had an ID number at the time of the initial follow-up, and the specialist nurses filled in the data (including the patient's name, gender, age, education level, medical card number, and other primary data, as well as the patient's principal diagnosis, date of

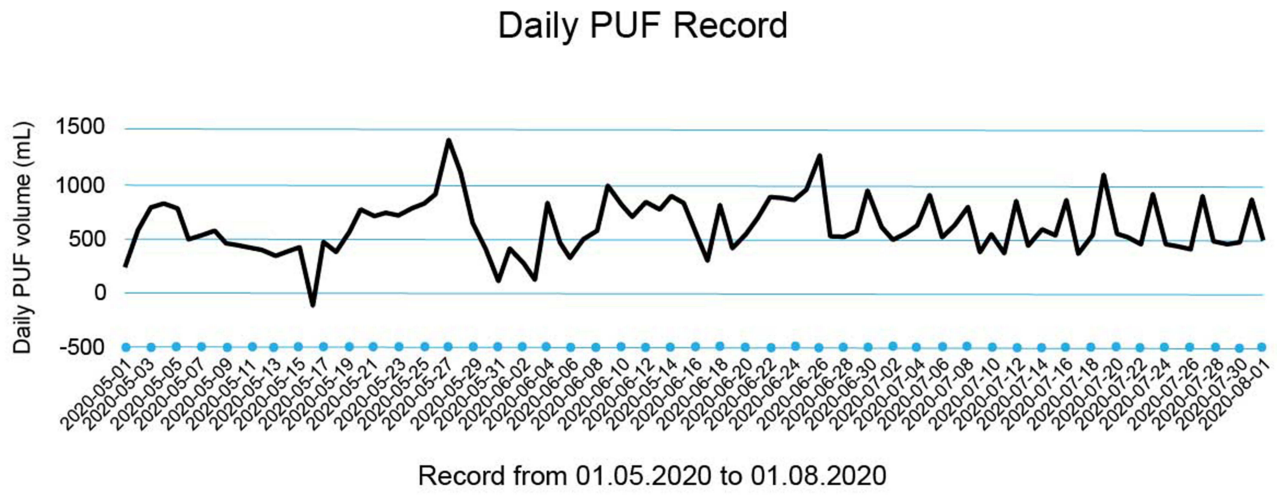

Figure 1 Patient index curve about daily PUF intelligent records. The Intelligent platform automatically generates data graphs of PUF volume when patients or medical sides input the data. It depicts the daily PUF trend of a representative participant from May 1st to August 1st 2020, illustrating pronounced fluctuations in PUF volume over the 3-month period.

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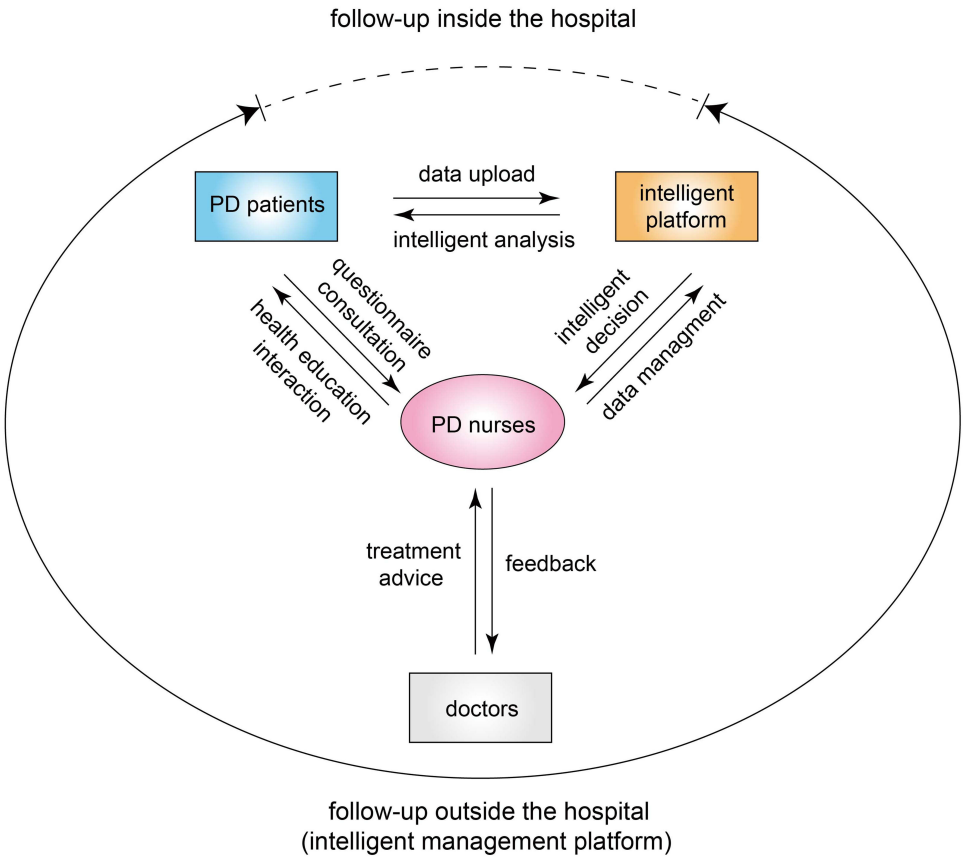

Figure 2 The novel follow-up mode of specialized nurse-led integrating intelligent platform management. Schematic workflow of the integrated intelligent management platform for PD patients. Patients transmit home-monitoring data (ultrafiltration, blood pressure, weight, etc.) to the cloud-based platform via a mobile terminal. The system performs real-time analytics, generates alerts and therapy suggestions, and simultaneously pushes the information to PD nurses and nephrologists. Nurses deliver immediate feedback and educational messages through the same platform, enabling continuous, round-the-clock follow-up and self-management support.

abdominal catheterization and other disease data), sorted and summarized them through the medical side. PD specialist nurses informed patients of follow-up arrangements, replied to patients' related problems promptly, communicated with doctors, gave feedback on problems that cannot be answered or solved, regularly reviewed patients' home treatment data, sent PD-related knowledge, took charge of the daily management of the intelligent platform and recorded the handling process of emergencies. They collected dialysis treatment data of patients on the intelligent management platform every week and reported emergencies and treatment of patients. They were also responsible for reporting the quality management of the PD center once a month, including the addition, loss of follow-up, outcome, time on therapy (TOT), dropout rate (DOR), and other information of PD center patients. This workflow shifts the conventional paradigm from "patient must present to the clinic to receive care" to dynamic follow-up of "data run first, nurse-led evaluation second, clinicians intervene third" establishing a 24/7 closed-loop management system.

Evaluation Method

Fluid Volume Overload

Fluid volume overload was evaluated by edema, which was divided into four grades according to the commonly used clinical grading standards:[9,10] (1) 0 degree: no edema (2) 1st degree: Edema occurs in eyelids, infraorbital soft tissue, and in front of the tibia. Slight depression appears after dactyl pressure. The recovery is quite fast. (3) 2nd degree: Visible edema occurs in the soft tissues of the whole body. Obvious or rather deep tissue depression can appear after dactyl pressure. The recovery is slow. (4) 3rd degree: Serious edema occurs in tissues of the whole body. The low-hanging part of the body skin becomes tense and shiny and may even see fluid exudate, sometimes accompanied by chest cavity, abdominal cavity, and sheath cavity effusion.

Cardiac Function

Cardiac status was classified with the New York Heart Association (NYHA) functional scale.[11,12] Class I: No symptoms (fatigue, palpitation, dyspnoea or angina) during ordinary physical activity. Class II: Mild symptoms with ordinary activity; relieved at rest. Class III: Symptoms with less-than-ordinary activity. Class IV: Symptoms at rest; any physical effort precipitates or worsens heart failure.

Blood Pressure

After ≥5 min of quiet sitting, BP was measured in the right brachial artery with an Omron HEM-7201 electronic device. Three readings were taken 1 min apart; if the range was ≤10 mmHg the mean was recorded, otherwise the procedure was repeated until three acceptable values were obtained.

Assessment of Clinically Relevant Complications

All episodes of peritonitis, exit-site/tunnel infection (ESI) and catheter displacement were prospectively ascertained for each patient during the 12 months before enrolment (historical control) and throughout the subsequent 12-month period of the novel follow-up program. Events were adjudicated by two independent nephrologists and verified against electronic medical records, nursing logs and microbiology reports. Each patient served as his/her own control; paired binary outcomes were analyzed with McNemar's exact mid-p test and 95% CIs for the difference in proportions were calculated using the Agresti-Min method.

Statistical Methods

SPSS 19.0 was used for statistical analysis, and the chi-square test was used to compare counting data. The measurement data were in accordance with the normal distribution and were expressed as mean ± standard deviation (X ± SD). Shapiro–Wilk test was used to confirm normality. Paired T-tests were used for pre- and post-intervention comparisons. Cardiac function grade and fluid volume overload were compared between the two follow-up modes using the Mann–Whitney *U*-test. Paired binary endpoints (peritonitis, exit-site infection, catheter displacement) were compared with McNemar exact mid-p test; 95% CIs for the difference in proportions were computed with the Agresti-Min method. $P < 0.05$ was considered statistically significant.

Result

Patient Disposition and Baseline Characteristics

Table 1 summarizes the baseline characteristics of the 78 enrolled peritoneal dialysis (PD) patients. The mean age was 52.7 ± 15 years, with the largest proportion (42.3%) aged 40–59 years; 51.3% were women. Cardiovascular risk was high: 91.0% had hypertension and 30.8% had diabetes. Regarding PD modality, 55.1% received intermittent PD (IPD), 43.6% continuous ambulatory PD (CAPD), and only one patient (1.2%) was treated with automated PD (APD) (Table 1). The cohort consisted predominantly of middle-aged peritoneal-dialysis patients with a heavy burden of cardiovascular comorbidities; conventional modalities (IPD and CAPD) accounted for the vast majority of treatments.

Comparison of Test Indexes Between the Two Follow-up Modes

Table 2 shows the comparison of main PD indicators in the cohort patients between the two follow-up modes. BNP was significantly lower in the novel follow-up mode than in the traditional follow-up mode (144.12±14.21 vs 631.01±104.21 pg/mL, $P < 0.001$). Serum calcium and phosphorus levels were significantly higher than those in the traditional mode (2.24±0.52 vs 2.18±0.02 mmol/L, 1.96±0.07 vs 1.80±0.06 mmol/L, $P<0.05$), and parathyroid hormone (PTH) and albumin levels were higher than those in the traditional mode (PTH 409.28±43.49 vs 250.84±23.26 pg/mL, $P<0.05$; ALB 38.89±0.60 vs 36.25±0.51 g/L, $P<0.05$), with statistically significant differences. In addition, SBP and DBP levels were also markedly lower in PD patients with novel follow-up mode, compared to the traditional old mode (SBP 136.99 ±12.04 vs 145.34±15.22 mmHg, $P < 0.01$; DBP 79.03±6.35 vs 84.87±8.17 mmHg, $P<0.01$). However, there were no significant differences in Kt/V (1.77±0.52 vs 1.82±0.52, $P=0.366$), hemoglobin (104.44±2.41 vs 102.34±2.10 g/L, $P=0.454$), and potassium (4.25±0.08 vs 4.28±0.08 mmol/L, $P=0.757$) (Table 2).

Table 1 Baseline Demographic and Disease Characteristics of Participants in Study

Characteristic	PD Patients (N=78)
Age, mean (SD), yr	52.7 (15)
Age category, yr, No. (%)	
<40	18 (23.1)
≥40 to <60	33 (42.3)
≥60	27 (34.6)
Female, No. (%)	40 (51.3)
Initial diagnosis, No. (%)	
Chronic nephritis	55 (70.5)
Hypertensive nephropathy	6 (7.7)
Diabetic kidney disease (DKD)	10 (12.8)
Lupus nephritis (LN)	3 (3.8)
IgA nephropathy (IgAN)	1 (1.3)
IgA vasculitis nephritis	1 (1.3)
ANCA-associated vasculitis	1 (1.3)
Polycystic kidney disease (PKD)	1 (1.3)
Diabetes, No. (%)	24 (30.8)
Hypertension, No. (%)	71 (91.0)
Dialysis mode, No. (%)	
IPD	43 (55.1)
APD	1 (1.2)
CAPD	34 (43.6)

Abbreviations: IPD, intermittent peritoneal dialysis; CAPD, continuous ambulatory peritoneal dialysis; APD, automated peritoneal dialysis.

Table 2 Comparison of Indicators of the Two Follow-up Modes

Group	Old mode	New mode	T value	P value
Kt/V	1.82±0.52	1.77±0.52	0.910	0.366
BNP (pg/mL)	631.01±104.21	144.12±14.21	4.63	0.000*
Hb (g/L)	102.34±2.10	104.44±2.41	−0.752	0.454
Serum Ca^{2+} (mmol/L)	2.18±0.02	2.24±0.52	−2.060	0.043*
Serum Pi (mmol/L)	1.80±0.06	1.96±0.07	−2.699	0.009*
PTH (pg/mL)	250.84±23.26	409.28±43.49	−4.613	0.000*
Serum K^+ (mmol/L)	4.28±0.08	4.25±0.08	0.311	0.757
Albumin (g/L)	36.25±0.51	38.89±0.60	−4.161	0.000*
SBP (mmHg)	145.34±15.22	136.99±12.04	8.883	0.000*
DBP (mmHg)	84.87±8.17	79.03±6.35	6.161	0.001*

Notes: *P<0.05 was considered statistically significant.
Abbreviations: Kt/V, urea distribution volume; BNP, B-Type Natriuretic Peptide; Hb, hemoglobin; PTH, parathyroid hormone; SBP, systolic blood pressure; DBP, diastolic blood pressure.

Comparison of the Cardiac Function and Fluid Volume Load Assessment Between Two Follow-up Modes

Compared with the traditional follow-up mode, the nurse-led, platform-integrated program significantly improved both cardiac functional class and fluid-volume control (Table 3). Cardiac function grades were markedly lower in the novel mode group: the proportion of patients in NYHA class I/II rose from 60.2% (47/78) to 85.9% (67/78), whereas class III/IV decreased correspondingly (Mann–Whitney U = 2,142, p = 0.001). Similarly, fluid-volume overload was less severe under the

Table 3 Comparison of Cardiac Function and FVL Assessment Between the Two Follow-up Modes

Variable	Old Mode (n=78)	New Mode (n=78)	*P*-value†
Cardiac function grade			
I	15 (19.2)	27 (34.6)	
II	32 (41.0)	40 (51.3)	
III	25 (32.1)	11 (14.1)	
IV	6 (7.7)	0 (0)	0.001*
Fluid volume load			
0 (no overload)	16 (20.5)	35 (44.9)	
1st degree	25 (32.1)	30 (38.5)	
2nd degree	28 (35.9)	11 (14.1)	
3rd degree	9 (11.5)	2 (2.6)	<0.001*

Notes: † Mann–Whitney *U*-test for ordered groups. Data are n (%). *$P<0.05$ was considered statistically significant.

novel mode; 44.9% (35/78) of participants achieved no evidence of overload (grade 0) versus 20.5% (16/78) under the old mode, and the prevalence of grade 2/3 overload fell from 47.4% (37/78) to 16.7% (13/78) ($U = 1,958$, $p < 0.001$).

Novel Mode Significantly Curbs Peritonitis Risk Over the 12-month Follow-up

Tables S1–S3 summarizes the paired comparison of three key device-related complications over the 12-month study horizon. McNemar exact tests showed a pronounced reduction in peritonitis episodes (10.3% vs 3.8%; mid-p = 0.077, relative-risk reduction 63%) (Table S1), whereas exit-site/tunnel infection rates remained essentially unchanged (19.2% vs 15.4%; mid-p = 0.664) (Table S2). Catheter displacement was infrequent; although the incidence fell from 5.1% to 1.3%, the 95% CI for the paired difference (−1.0% to 9.3%) crossed zero (mid-p = 0.388) (Table S3).

Discussion

Fluid volume overload is one of the most common complications in PD patients whereas it could usefully predict adverse clinical outcomes.[13–15] European body composition monitoring (EuroBCM) in Six European countries showed that 60% of CAPD patients had fluid overload, and 25.2% had a severe fluid overload.[15] Fluid overload accounted for 66.8% of the total number of CAPD patients in China.[14] Fluid overload significantly affects the prognosis of PD patients. Given that, optimizing the capacity status of PD patients is a crucial factor in improving the survival rate of PD patients, and proper volume control is one of the critical objectives of PD prescription. Therefore, self-management at home is crucial for patients.

The International Society for Peritoneal Dialysis (ISPD) 2020 guidelines recommend that patients' volume status should be regularly assessed clinically, with blood pressure monitoring and clinical testing as part of routine clinical care, and used blood pressure as one of the key objective indexes to evaluate the prescription quality of PD.[16,17] Our study identified that the BP control, volume management, and cardiac function were effectively improved under the novel follow-up mode. The synchronous optimization of the BP–volume–cardiac-function axis demonstrates that the novel mode constitutes an actionable implementation pathway for the 2020 ISPD recommendations. In addition, patients in the novel follow-up group exhibited significantly higher serum albumin levels compared to those in the traditional group. This improvement reflects the effectiveness of continuous dietary and dialysis-related education, timely nurse–patient communication, and responsive consultation, all of which enhanced dietary compliance and ultimately elevated the patients' nutritional status. The increase of blood calcium, phosphorus and parathyroid hormone in patients were also related to the improvement of the nutritional status of patients and the adjustment of drugs during follow-up.

With the advent of the era of big data and the continued popularity of telemedicine, APD has become the trend in the world, especially under the epidemic situation.[18,19] High equipment and consumable costs limit APD use in China to <2%.[20] Even only 1 APD case in our study, her serum albumin, BP control, and cardiac function was markedly improved (Supplementary Data1). Synergistic integration with automated peritoneal dialysis is poised to compress treatment

burden, enhance logistical efficiency, and redefine the patient experience from episodic encounters to seamless, home-centered care. Collectively, the nurse-led, platform-integrated follow-up strategy significantly improved the most clinically relevant infectious complication—peritonitis—while achieving directionally favorable but statistically non-significant trends for both local infection and mechanical displacement. These data support the safety of remote PD management, but larger or longer studies are warranted to confirm the impact on device-related morbidity.

This study confirms the mode's efficacy in three key areas: PD specialist nurses lead education, fine-tune prescriptions and reduce volume overload by strengthening patient self-management. A unified e-platform delivers real-time data review and instant feedback, lifting clinical efficiency. All CAPD and IPD patients report higher satisfaction and quality of life through personalized e-records and continuous nurse contact. This study has several inherent limitations. It was conducted at a single center and utilized a single-arm design with historical controls, as contemporaneous randomization was not feasible—virtually all eligible incident patients were enrolled. Temporal trends and case-mix changes may bias the comparison. The 12-month horizon captured early fluid and cardiac gains but cannot predict technique survival or late cardiovascular events. Extended 24- to 36-month follow-up and a planned multi-center trial will test durability.

Conclusion

The follow-up mode led by PD specialist nurses and combined with the intelligent management platform significantly reduces fluid volume overload and improves cardiac function of patients, with substantial clinical benefits. Therefore, it is an effective novel method to enhance follow-up management of PD, which warrants further exploration.

Data Statement

Patient data were safeguarded in full compliance with *China's Health Information Management Regulation* (National Health Commission) and the *GB/T 31722-2015 Information-Security Risk-Assessment Standard*. The intelligent platform uses end-to-end TLS 1.3 encryption, AES-256 cipher suites, and certificate pinning; all data are stored in a Level-3 certified hospital data center. Role-based access control (RBAC) limits internal viewing to the minimum necessary data set, while external ingress is blocked by a whitelist firewall and audited in real time. Each user interaction is logged with tamper-proof timestamps for traceability.

Ethics

This study was approved by the Ethics Committee of Shanghai General Hospital, Shanghai Jiao Tong University. This study complies with the requirements of the Declaration of Helsinki and conducted in accordance with the *Consolidated Standards of Reporting Trials (CONSORT) 2010* guidelines.

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Author Contributions

Ji Wang performed the study, collected and analyzed data, and drafted the manuscript. Jian Chang was responsible for ethical work. Jun Liu performed the statistical work. Jun Liu and Qing Yu were responsible for outpatient and research indicators detection. Zhihuang Zheng and Jinfang Bao designed this clinical study and supervised the work. All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Disclosure

The authors declare that they have no conflicts of interest in the work.

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