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Advances in the Use of Digital Health Technologies in Self-Management of Maintenance Hemodialysis Patients

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Abstract: *This paper summarizes the progress of the application of digital health technology in the self-management behavior of maintenance hemodialysis patients, introduces the concepts of digital health technology and self-management behavior of maintenance hemodialysis patients, discusses the effectiveness of digital health technology in the self-management behavior of maintenance hemodialysis patients, and puts forward relevant remaining problems and suggestions, to provide a reference basis for further advancing the application of digital health technology in the self- management of maintenance hemodialysis patients.*

Keywords: *Digital Health; Hemodialysis; Self-Management Behaviors; Nursing Care; Review*

1. Introduction

According to statistics, chronic kidney disease (CKD) ranks as the 11th leading cause of human mortality and has been recognized as a critical global public health issue [1]. Studies indicate that the global prevalence of CKD is approximately 9.1%, with about 89% of patients undergoing hemodialysis [3]. In China, the incidence of CKD has also been increasing annually, with a prevalence rate of around 10.8% [4], and the number of patients receiving maintenance hemodialysis (MHD) reaching 850,800 [5]. Compared to other chronic diseases, MHD patients require stricter management of diet, fluid intake, medication, and physiological monitoring, which is crucial for disease control and treatment. Existing research has shown that MHD patients face significant challenges in self-management [6], while effective self-management behaviors can improve their quality of life and reduce hospitalization and mortality rates [7]. Therefore, optimizing disease management for MHD patients has long been a focus in the medical field.

With the rapid development of internet, mobile devices, and artificial intelligence technologies, digital health technologies have demonstrated broad application prospects in chronic disease management. Their advantages are particularly notable in the self-management of MHD patients [8, 9]. Compared to traditional self-management approaches, digital health technologies such as remote monitoring, mobile health applications, and artificial intelligence can provide patients with more intelligent, convenient, and personalized health management services. These technologies enable seamless connectivity between healthcare providers and patients, overcome geographical limitations, and improve the efficiency of medical resource utilization.

This review examines the application progress of digital health technologies in the self-management behaviors of MHD patients, based on the key elements of their self-management. The aim is to offer insights and references for optimizing disease management in clinical practice for MHD patients.

2. Concepts of both digital health technology and self-management behaviors of maintenance hemodialysis patients

2.1 Concepts of self-management behavior in maintenance hemodialysis patients

Self-management behaviors of maintenance hemodialysis patients refer to a series of behaviors adopted by patients to prevent complications and enhance their health status during dialysis treatment.

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These behaviors cover a wide range of aspects, including but not limited to dietary behaviors, medication behaviors, somatic activities, and psychosocial aspects [10].

The Theory of Planned Behavior (TPB) was proposed by Icek Ajzen [11] as one of the social psychological theories that can predict human behavior in different populations and contexts. It has been widely used in various health behavior change studies [12-14]. The theory suggests that behavioral intentions are the result of a combination of three factors, namely, attitudes toward the behavior, subjective norms (i.e., the pressure of social influences on people to perform or not to perform a particular behavior), and perceived behavioral control (i.e., individuals' perceptions of their ability to perform the behavior). When perceived behavioral control is stronger, an individual's intention to perform a behavior is stronger and the actual behavior is more likely to occur. According to the Theory of Planned Behavior, self-management behaviors of maintenance hemodialysis patients can be described as a set of behaviors that patients adopt that are designed to prevent complications and enhance their health status, driven by positive attitudes, influenced by the support of significant others or groups (subjective norms), and combined with confidence in their own ability to perform the behaviors and their perception of their ability to perform them (perceived behavioral control). These behaviors may include a variety of aspects such as dietary management, medication management, somatic activity, psychological adjustment, and treatment adherence.

2.2 Concepts of digital health technology

The World Health Organization defines digital health as “the field of knowledge and practice involving the development and application of digital technologies to improve health” [15], which covers a wide range of digital applications from personal health management to public health, and innovative health management solutions aimed at improving the health of individuals and groups. The U.S. National Institutes of Health (NIH) focuses more on the role of digital health technology in personal health management, which is considered to be “the use of digital technology to collect, analyze, and transmit personal health information in order to improve the quality and efficiency of health care” [16]. China's National Health Commission pointed out that during the “14th Five-Year Plan” period, digital health technology will be developed comprehensively, using digital, networked and intelligent means to promote the transformation and upgrading of the entire industry, and provide a solid support for the construction of a healthy China [17].

Digital health technologies include, but are not limited to, mobile health, telemedicine, electronic health records and personal health records, artificial intelligence, the Internet of Things, and other technologies, and these advanced technologies have been widely used in prevention, diagnosis and treatment, rehabilitation and other medical and health care fields, such as health management of chronic diseases, health education, disease prevention and control, and telemedicine [18]. Compared with the traditional face-to-face healthcare model, digital health technologies have significant advantages in terms of convenience, efficiency, safety, personalization, intelligence, and the promotion of medical resource sharing and innovation. These advantages not only enhance the quality and efficiency of healthcare services, but also profoundly change the patient experience and health management.

Studies have shown [19, 20] that digital health technologies have been applied in the disease management of MHD patients, and the effect is considerable.

3. Application of digital health technologies to self-management behaviours in MHD patients

3.1 Promoting Dietary Adherence in MHD Patients

Digital health technologies have significantly enhanced dietary and fluid management for patients with maintenance hemodialysis (MHD) through intelligent platforms. These platforms provide personalized dietary recommendations and generate precise fluid management strategies by recording and analyzing patients' weight fluctuations and fluid intake, thereby reducing interdialytic weight gain (IDWG) and preventing volume overload.

Teong et al. [21] developed a phosphate-focused mobile application and conducted a 12-week randomized controlled trial (RCT) to evaluate its effect on dietary adherence in MHD patients with hyperphosphatemia. The results demonstrated that the app successfully facilitated phosphate-targeted management in this population. Similarly, Crutzen et al. [22] designed a dietary mobile app for MHD patients and performed a pilot study to assess its potential efficacy. Their findings revealed a significant

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reduction in potassium- and sodium-rich food intake, while average protein intake increased from 0.9 g/kg/day to 1.3 g/kg/day, indicating improved dietary compliance. Shi Suhua et al. [23] conducted a 3-month RCT by integrating a health education module specifically for MHD patients into a hospital cloud platform, accessible only to the intervention group. The module allowed patient interaction and feedback. Post-intervention results showed marked improvements in serum albumin and potassium levels, along with enhanced self-management skills and quality of life (QoL).

These studies collectively demonstrate the positive impact of digital health technologies in improving dietary adherence among MHD patients. However, most existing research consists of short-term trials. Future studies should extend to long-term follow-ups to evaluate the sustained effects of digital interventions on patient adherence and QoL. Additionally, current research primarily focuses on single-platform applications. Future directions could explore integrating multiple platforms (e.g., mobile apps, wearable devices, and hospital information systems) to enable comprehensive and seamless patient management.

3.2 Facilitating Symptom Monitoring in MHD Patients

Remote monitoring systems refer to technological systems that enable local computers to monitor and supervise remote devices via communication systems (e.g., Internet/Intranet). In the field of hemodialysis, remote monitoring systems can assist patients in real-time tracking of physiological indicators and transmit the data to healthcare providers for analysis and feedback [24]. Robin et al. [25] developed a remote monitoring system for home hemodialysis patients, allowing them to record dialysis data through a dedicated app and receive feedback or notifications for abnormal parameters. After each dialysis session, patients could also select emoticons or add textual notes to express their experience, while healthcare providers adjusted treatment plans based on the system's feedback. Kolben Y et al. [26] utilized wearable devices to continuously monitor the hemodynamics and vital signs of maintenance hemodialysis (MHD) patients, measuring heart rate (HR), non-invasive systolic and diastolic blood pressure (SBP and DBP), stroke volume (SV), and other parameters 15 minutes before and after dialysis to track hemodynamic changes and identify intradialytic hypotension, achieving favorable outcomes. Xu Jun et al. [24] designed a remote medical platform for MHD patients, integrating remote monitoring, teleconsultation, bidirectional referral, and intelligent quality control, which effectively improved dialysis quality and reduced complications.

These studies demonstrate the significant advantages and potential of remote monitoring systems in symptom management for MHD patients. However, certain limitations remain. First, network connectivity instability may occasionally lead to data transmission interruptions or delays. Additionally, patient acceptance and operational proficiency could impact the effectiveness of remote monitoring. Future efforts should focus on optimizing the stability of network connections and data transmission efficiency to ensure real-time and accurate data acquisition by healthcare providers. Meanwhile, enhancing patient training and guidance on remote monitoring systems is essential to improve acceptance and operational competence, thereby maximizing the utility of remote monitoring data for health management.

3.3 Enhancing Exercise Adherence in MHD Patients

Research indicates that the physical activity levels of MHD patients are significantly reduced compared to their healthy state, with a sedentary lifestyle becoming their daily routine [27]. This severely impacts dialysis efficacy and quality of life [28, 29], while also increasing the risk of morbidity and mortality [30]. Appropriate exercise is of great significance for MHD patients, as it can effectively improve cardiovascular function, enhance quality of life, regulate mood, alleviate negative emotions such as anxiety and depression, and improve sleep quality [31].

The advancement of digital health technologies has provided support for personalized exercise interventions in MHD patients. Malhotra et al. [32] conducted a 12-week randomized controlled trial in which the control group used wearable activity trackers alone, while the intervention group combined wearable trackers with structured feedback guidance. The results demonstrated that integrating wearable activity trackers with structured feedback intervention was feasible and effectively increased patients' step counts and exercise adherence. Sheshadri [33] designed a pedometer and investigated its effectiveness in improving step counts, short-term physical performance (assessed via fitness tests), dialysis symptom indices, and heart rate variability in MHD patients. The findings revealed a significant increase in patients' daily steps. Similarly, Kooman et al. [34] showed that fitness trackers and wearable devices such

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as smartwatches could effectively enhance physical activity frequency and exercise adherence in MHD patients.

In summary, digital health technologies demonstrate notable advantages in promoting physical activity among MHD patients. However, the high costs of equipment and maintenance may impose additional financial burdens on patients. Moreover, domestic research on the application of digital health technologies in MHD patients' physical activity remains limited, and its efficacy requires further validation. Future studies could focus on cost-effectiveness analyses, widespread implementation, patient experience, and mental health research to advance the development and application of digital health technologies.

3.4 Providing medication guidance and education to MHD patients

For MHD patients, the long-term and complex nature of dialysis treatment often necessitates prolonged use of multiple medications to manage complications and support therapy, thereby increasing the difficulty of medication management [35]. Additionally, factors such as patients' education level, family support, financial status, and psychological state may influence their medication adherence [36, 37]. Currently, many countries have introduced online medication guidance platforms for MHD patients, including intelligent management systems, self-management platforms, and mobile health applications. These technologies aim to provide precise, personalized medication guidance, thereby improving medication adherence and treatment outcomes.

Shi Y et al. [38] demonstrated that smart mobile applications can not only provide MHD patients with follow-up appointment reminders, physiological and psychological assessments, and health education but also deliver personalized medication alerts, enhancing medication adherence. Another study [39] found that intelligent management systems can effectively improve self-management behaviors and strengthen medication adherence in MHD patients. Similarly, Singh et al. [40] reported that smart mobile applications can supply patients with medication lists and timely reminders, significantly boosting adherence.

These findings indicate that digital health technologies offer notable advantages in improving medication adherence among MHD patients, though certain limitations remain. Future research should further explore how to develop more precise, personalized medication reminder strategies based on individual patient differences and dialysis needs. Integrating big data analytics, artificial intelligence, and other advanced technologies could enable real-time monitoring and intelligent adjustment of medication regimens. Moreover, while smart reminder systems play a crucial role in enhancing adherence, their user experience still requires optimization. Future studies should focus on refining interface design, interaction methods, and reminder strategies to better align with patients' usage habits and needs.

3.5 Improving Psychosocial Well-being in Patients

Maintaining good mental health is crucial for improving the quality of life in MHD patients. Studies have shown that many MHD patients experience negative emotions such as anxiety and depression [41, 42], along with psychological challenges including stigma and social isolation [43], which significantly impair their self-management adherence [44]. Currently, digital health technologies have been widely applied to improve the mental health status of MHD patients.

Tomska et al. [45] conducted a randomized controlled trial in which MHD patients engaged in regular physical exercise using virtual reality (VR) devices. After the intervention period, significant improvements in anxiety and depression were observed. Similarly, in a randomized controlled study by Qi S et al. [46], MHD patients were encouraged to use VR technology to assess its effects on symptom burden, subjective well-being, and perceived stress. The results demonstrated that VR-based travel experiences significantly alleviated symptom burden, enhanced subjective well-being, and reduced perceived stress. Additionally, Hsieh et al. [47] explored the physiological and psychological effects of exposing MHD patients to forest landscapes via VR, finding notable reductions in negative emotions. Another study [25] indicated that remote monitoring systems could collect patients' emotional fluctuations and provide psychosocial support, thereby improving mental health outcomes.

In summary, digital health technologies demonstrate significant potential in enhancing the mental health of hemodialysis patients, though certain limitations persist. Overall, their application remains relatively limited, as many patients lack access to these technologies or face barriers such as technical complexity or financial constraints. Future research should further investigate cost-effectiveness. Moreover, existing digital health solutions often lack personalized psychological interventions tailored

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to the unique needs of hemodialysis patients. Given the variability in psychological needs, states, and coping mechanisms among individuals, current technologies frequently fail to provide sufficiently individualized support. Future studies should focus on developing more personalized mental health interventions based on the specific psychological characteristics and requirements of hemodialysis patients.

4. Deficiencies and recommendations

Digital health technologies play a crucial role in enhancing self-management behaviors among maintenance hemodialysis (MHD) patients. These technologies not only improve patient engagement and treatment adherence but also enable remote dynamic monitoring of physiological indicators, providing valuable data for clinical decision-making. Additionally, they address patients' psychological and social needs, enhance quality of life, and effectively prevent and manage common complications, thereby reducing hospitalization rates and healthcare costs.

However, several challenges remain. First despite the significant progress in applying digital health technologies in hemodialysis care, awareness of digital therapeutics remains insufficient in some hospitals, and adoption rates vary widely. This disparity prevents some patients from benefiting from digital solutions. To address this, governments and relevant institutions should strengthen promotional efforts to enhance awareness and acceptance among healthcare providers and patients, facilitating broader implementation. Second, patient acceptance and adherence vary significantly. Factors such as age, education level, and socioeconomic status may hinder effective use of digital health tools for self-management. Healthcare professionals should intensify educational campaigns, training, and awareness initiatives to improve patient understanding and engagement. Furthermore, personalized self-management plans tailored to individual patient needs should be developed to enhance treatment adherence and self-management capabilities. Third, data security and privacy protection remain critical concerns in digital health applications. Patients' personal and medical data are at risk of breaches. Ensuring data security and safeguarding patient privacy are urgent issues that must be addressed. Research [48] indicates that patients express significant concerns regarding data security and privacy in digital health technologies. Therefore, relevant institutions and developers must establish robust data protection mechanisms, employing advanced encryption and security measures to prevent unauthorized access or leakage of sensitive patient information.

In conclusion, while digital health technologies offer substantial benefits in improving self-management for MHD patients, overcoming barriers related to awareness, accessibility, and data security is essential for their sustainable and effective implementation. Future efforts should focus on policy support, patient education, and technological safeguards to maximize their potential in hemodialysis care.

5. Conclusion and outlook

This article reviews the progress in the application of digital health technologies in the self-management behaviors of maintenance hemodialysis patients. A review of recent related research and practical applications shows that digital health technologies have played a significant role in improving the self-management capabilities of hemodialysis patients, enhancing their quality of life, and optimizing the allocation of medical resources. Specifically, digital health technologies, through means such as patient self-management platforms, remote monitoring systems, and wearable devices, have effectively improved patients' dietary and medication adherence, reduced the risk of complications, alleviated negative emotions, and lessened the burden on the healthcare system. However, the development of digital health technologies in China is still in the preliminary exploration stage, with issues such as uneven technology adoption, incomplete functionality of patient self-management platforms, and concerns regarding data security and privacy protection. In future research, it is necessary to enhance technological innovation and integration, optimize and intelligently upgrade platforms, strengthen data security and privacy protection, and bolster policy support and regulation, as well as patient education and training, to promote the continuous development and innovation of digital health technologies and provide hemodialysis patients with higher-quality, more convenient health management services.

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