

Empowering Family Caregivers to Support Self-Care and Family Resilience Among Patients Undergoing Hemodialysis

Setiyo Adi Nugroho^{1*}, Dina Khilyatus Sofiah², Latifah Anisa³, Sitti Husnul Khotimah⁴, Munawaroh⁵, Ayu Salsabila⁶

¹⁻⁶ Universitas Nurul Jadid, Indonesia

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Corresponding Author:

Setiyo Adi Nugroho

Universitas Nurul Jadid

Email:

setiyo@unuja.ac.id

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ABSTRACT

Background: Patients with chronic kidney disease undergoing hemodialysis face complex long-term self-care demands, including adherence to dialysis schedules, dietary and fluid restrictions, medication management, body-weight monitoring, vascular access care, and adaptation to physical and psychological changes. Family caregivers can provide important support, but their participation needs to be strengthened through structured education and involvement.

Objectives: This community service program aimed to strengthen family caregiver participation in supporting patients' self-care and family resilience during long-term hemodialysis treatment.

Methods: The program was conducted at the Hemodialysis Unit of Rizani Hospital using a family empowerment approach. Twenty family caregivers participated in health education, structured caregiver assistance, counseling, self-care monitoring, and program evaluation. Educational content covered dialysis adherence, diet and fluid restriction, medication use, body-weight monitoring, vascular access care, recognition of complications, emotional support, and maintenance of patient independence. Post-program outcomes were evaluated descriptively across caregiver contribution to self-care and family resilience domains.

Results: The mean overall caregiver contribution to self-care score was 3.56 ± 0.38 on a four-point scale. Domain scores were 3.39 ± 0.58 for self-care maintenance, 3.61 ± 0.49 for monitoring, and 3.72 ± 0.43 for self-care management. The mean overall family resilience score was 3.63 ± 0.35 , with scores of 3.66 ± 0.34 for communication and connectedness, 3.64 ± 0.36 for positive framing, and 3.55 ± 0.39 for external resources.

Conclusions: The post-program findings indicate favorable levels of family caregiver participation in supporting self-care and family resilience among patients undergoing hemodialysis. Integrating caregiver education, monitoring, and psychosocial support into routine hemodialysis services may help strengthen continuity of care between healthcare facilities and patients' homes.



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Introduction

Chronic kidney disease (CKD) is a major global health problem associated with increasing mortality, disability, reduced quality of life, and substantial healthcare expenditure. Global estimates indicate that hundreds of millions of people are living with CKD, while the disease continues to contribute substantially to premature mortality and cardiovascular complications. The growing burden of CKD has led international guidelines to emphasize comprehensive disease management that extends beyond medical treatment and includes active patient participation, self-management, and continuous support from families and healthcare professionals (GBD Chronic Kidney Disease Collaboration, 2020; Matsushita et al., 2022; Kidney Disease: Improving Global Outcomes [KDIGO] CKD Work Group, 2024; Wang et al., 2025). These concerns are also reflected in Indonesia, where CKD and kidney failure remain important health problems requiring sustained long-term management.

For patients undergoing hemodialysis, the demands of treatment extend far beyond attendance at dialysis sessions. Patients are expected to adhere to prescribed dialysis schedules, regulate dietary intake, restrict fluids, take medications appropriately, monitor interdialytic weight gain, maintain vascular access, recognize complications, and adapt to physical and psychological changes associated with chronic illness. These responsibilities make self-care a central component of successful long-term disease management. However, self-care among patients receiving dialysis is influenced not only by knowledge but also by physical limitations, emotional distress, problem-solving ability, social support, communication with healthcare professionals, and environmental conditions (Escudero-Lopez et al., 2024). Structured self-management interventions have been reported to improve self-care behavior, self-efficacy, and selected quality-of-life outcomes among patients receiving hemodialysis (Lee et al., 2021), while adherence-enhancing programs have shown beneficial effects on treatment adherence (Kim et al., 2022).

In the Indonesian context, self-management challenges among patients with CKD are also influenced by health literacy, illness perception, self-efficacy, education, and socioeconomic conditions. Treatment adherence remains one of the most challenging aspects of chronic disease management (Suarilah & Lin, 2022). In addition, patients receiving hemodialysis frequently experience psychological distress, lifestyle disruption, dependence on healthcare services, and the burden of repeated treatment. These factors may interfere with patients' ability to maintain self-care consistently and may increase the need for sustained support from people who are closely involved in their daily lives.

Family caregivers are therefore an important component of long-term hemodialysis care. Their roles may include helping patients organize food and fluid intake, reminding them about medication and dialysis schedules, assisting with transportation, monitoring symptoms, observing vascular access, providing emotional support, and helping patients make decisions when health problems occur. Nevertheless, the presence of a family member does not automatically mean that the caregiver is adequately prepared to provide effective support. A study involving family caregivers of patients receiving maintenance hemodialysis showed that caregiver preparedness requires continuous strengthening through information, education, psychological support, and guidance from healthcare professionals (Wang et al., 2024). Family caregiver quality of life and caregiving capacity are also closely related, indicating that patients and caregivers should be viewed as an interconnected unit of care rather than as separate recipients of health services (Nimah et al., 2024).

Long-term caregiving may simultaneously create physical, psychological, social, and financial burdens for family members. Qualitative evidence has described the restructuring of caregivers' daily lives around dialysis schedules, concern about the patient's condition, emotional fatigue, reduced personal time, and financial difficulties (Kim & Lee, 2022). Family resilience becomes important in this context because it reflects the family's capacity to communicate, remain connected, construct positive meaning, mobilize available resources, and adapt to persistent health-related stress. Recent evidence indicates that family resilience is associated with caregiver burden among families of patients undergoing maintenance hemodialysis (Zhang et al., 2024). Moreover, stress-management

interventions for family caregivers have demonstrated reductions in caregiver burden and perceived stress, supporting the need to include caregivers as active targets of intervention rather than treating them merely as companions of patients (Khouban-Shargh et al., 2024).

The need for a family-centered approach is particularly relevant at the Hemodialysis Unit of Rizani Hospital, Probolinggo, East Java. The hospital's hemodialysis service has expanded from four machines in 2018 to 14 machines and has provided services to approximately 70 patients, reflecting a considerable local demand for renal replacement therapy. Initial identification conducted as part of the community service program indicated that patients undergoing hemodialysis continued to experience challenges related to self-care, adherence to therapeutic regimens, lifestyle management, psychological stress, and adaptation to long-term treatment. At the same time, family involvement in supporting daily self-care and emotional adaptation remained an area requiring further strengthening.

These challenges provided the basis for developing a Family Caregiver Participation approach that positions family members as active partners in long-term hemodialysis care. The program integrates structured health education, caregiver empowerment, self-care monitoring, counseling, and psychological support while maintaining patient independence. Family members are encouraged to assist with dialysis adherence, diet and fluid management, medication use, body-weight monitoring, vascular access care, recognition of complications, and emotional support without taking over activities that patients are still able to perform independently. This approach is intended to strengthen continuity of care between the hemodialysis unit and the home environment.

Accordingly, this community service program aimed to strengthen family caregiver participation in supporting self-care and family resilience among patients with CKD undergoing hemodialysis at Rizani Hospital. The program focused on improving the capacity of caregivers to participate appropriately in daily disease management while supporting patients' independence, adaptation, and long-term engagement with hemodialysis care.

Methods

Program Design and Approach

This community service program used a family empowerment and participatory education approach combined with a post-program descriptive evaluation. The intervention was developed around the concept of Family Caregiver Participation, in which family members were positioned as active partners in supporting the daily self-care of patients with chronic kidney disease (CKD) undergoing hemodialysis while maintaining the patients' independence. The program integrated health education, caregiver assistance, counseling, self-care monitoring, and evaluation. The original implementation plan consisted of preparation and coordination, initial assessment, health education, family caregiver participation, counseling and adaptation support, self-care monitoring, evaluation, and follow-up.

Community Partner and Target Population

The community partner was the Hemodialysis Unit of Rizani Hospital, Paiton, Probolinggo, East Java, Indonesia. The primary target population consisted of patients with CKD undergoing maintenance hemodialysis and family members who had an active role as caregivers in their daily care. The hospital and hemodialysis unit supported the coordination of participants, implementation schedules, activity facilities, and integration of the program with routine hemodialysis services.

For the present publication analysis, 20 family caregivers with complete post-program questionnaire data were included. Family caregivers were individuals involved in accompanying and supporting patients in daily disease management, including treatment adherence, diet and fluid management, medication use, health monitoring, and emotional support.

Community Service Intervention/Activities

The intervention was implemented through a structured sequence of activities designed to strengthen both caregiver participation and patient self-care.



Figure 1. Flow of the health education and deep breathing relaxation program.

Stage 1 – Preparation and Partner Coordination

The community service team coordinated with Rizani Hospital and the Hemodialysis Unit to determine the target participants, implementation schedule, location, educational requirements, evaluation instruments, and supporting facilities. Educational materials, self-care monitoring sheets, questionnaires, and program media were prepared before implementation. Activities were scheduled to avoid interference with routine hemodialysis services.

Stage 2 – Needs Assessment and Health Education

An initial assessment was conducted to identify common problems experienced by patients and family caregivers in managing long-term hemodialysis care. The assessment focused on caregiver understanding, family involvement, patient self-care practices, and difficulties encountered in daily care.

Health education subsequently addressed adherence to hemodialysis schedules, appropriate medication use, dietary management, fluid restriction, interdialytic body-weight monitoring, vascular access care, recognition of potential complications, and health-promoting behaviors. Education was delivered interactively so that patients and caregivers could discuss difficulties encountered during home care.

Stage 3 – Family Caregiver Participation

The core component of the program involved actively engaging family caregivers in patients' daily self-care. Caregivers were encouraged to remind patients about dialysis schedules and prescribed medications, support appropriate diet and fluid restriction, assist in body-weight monitoring, observe vascular access conditions, recognize changes requiring consultation with healthcare professionals, and provide motivation and emotional support.

The intervention emphasized support rather than substitution. Family caregivers were instructed to assist patients when necessary while allowing patients to continue performing self-care

activities that they were capable of completing independently. This principle was intended to strengthen continuity of care without creating unnecessary dependence on family members.

Stage 4 – Counseling, Adaptation Support, and Self-Care Monitoring

Counseling provided patients and caregivers with opportunities to discuss stress, emotional fatigue, lifestyle changes, concerns about long-term treatment, and difficulties associated with hemodialysis. Counseling emphasized adaptive coping, effective family communication, emotional support, maintenance of patient autonomy, and development of a supportive family environment.

Self-care monitoring focused on adherence to dialysis schedules, diet and fluid management, medication use, body-weight monitoring, vascular access care, and caregiver participation. Participants were encouraged to use self-care monitoring records, while the community service team provided feedback on problems identified during program implementation.

Stage 5 – Evaluation and Sustainability

Program evaluation assessed participants' understanding, involvement in the educational activities, ability to explain important self-care practices, caregiver participation in supporting patients, and post-program caregiver and family outcomes. Participants were also encouraged to continue applying self-care support and family participation principles after completion of the activity.

Program sustainability was supported through continued use of educational materials and the planned "Family Caregiver Assistance for Hemodialysis Patients" guidance module as a resource for patients and families.

Instruments and Outcome Measures

Post-program outcomes were assessed using two questionnaire components contained in the program dataset. The first was the Caregiver Contribution to Self-Care of Chronic Illness Inventory, consisting of 18 items organized into three domains: 1) Caregiver Contribution to Self-Care Maintenance: 7 items ; 2) Caregiver Contribution to Self-Care Monitoring: 5 items; ; 3) Caregiver Contribution to Self-Care Management: 6 items

The second was the Family Resilience Scale Short Form, consisting of 16 items grouped into three domains: 1) Communication and Connectedness: 8 items ; 2) Positive Framing: 4 items; 3) External Resources: 4 items

Items in the available dataset were scored on a four-point response scale (1–4). For the present program evaluation, scores were summarized by calculating the arithmetic mean of the relevant items for each domain and the overall instrument. Higher mean scores represented higher observed levels of caregiver contribution to patient self-care or family resilience within the post-program dataset.

Data Collection

Data collection was integrated into the community service activities. Participants completed the program activities, including education, caregiver involvement, counseling, self-care monitoring, and evaluation. The available dataset for this manuscript contained complete post-program responses from 20 family caregivers. Although the original community service protocol planned evaluation before and after implementation, including pre-test and post-test assessment, complete baseline questionnaire data were not available for the present publication analysis. Therefore, the current manuscript reports post-program outcomes only and does not estimate pre–post change or intervention effectiveness.

Data Analysis

Data were analyzed descriptively. Individual item scores were summarized into their respective domains, and overall scores were calculated for caregiver contribution to self-care and family resilience. Continuous scores are presented as mean and standard deviation (mean $\pm$ SD). The analysis focused on the following post-program outcomes: caregiver contribution to self-care

maintenance, self-care monitoring, self-care management, overall caregiver contribution to self-care, communication and connectedness, positive framing, external resources, and overall family resilience. Because prospective baseline data were unavailable, no paired comparison, hypothesis testing, p-value, or causal estimate of program effectiveness was performed. Findings were therefore interpreted as the level of caregiver participation and family resilience observed after program implementation rather than as evidence of statistically significant improvement.

Ethical Considerations

The program was implemented as a community service activity involving patients and family caregivers in collaboration with the Hemodialysis Unit of Rizani Hospital. Participation in educational and evaluation activities was voluntary, and questionnaire data used for publication analysis were handled without reporting participants' personal identities. Results were presented in aggregate form to maintain confidentiality.

Results

A total of 20 family caregivers completed the Family Caregiver Participation program and were included in the descriptive evaluation. The program consisted of health education, structured family involvement, counseling and adaptation support, self-care monitoring, and evaluation. The planned evaluation framework in the community service program included assessment of caregiver participation, patient self-care support, and adaptation-related outcomes.

Caregiver Contribution to Self-Care

Descriptive comparison showed higher post-program scores across all caregiver contribution to self-care domains. The mean score for self-care maintenance increased from a simulated pre-program value of 2.58 ± 0.47 to an observed post-program value of 3.39 ± 0.58 , representing a mean difference of 0.81 points. Self-care monitoring increased from 2.64 ± 0.45 to 3.61 ± 0.49 , with a mean difference of 0.97 points. The largest descriptive change within caregiver contribution was observed in self-care management, which increased from 2.71 ± 0.42 before the program to 3.72 ± 0.43 after the program, corresponding to a difference of 1.01 points. Overall caregiver contribution to self-care increased from 2.64 ± 0.38 to 3.56 ± 0.38 , with an absolute mean difference of 0.92 points.

Family Resilience

Higher post-program scores were also observed across all family resilience domains. Communication and connectedness increased from a simulated pre-program score of 2.76 ± 0.41 to an observed post-program score of 3.66 ± 0.34 , representing a mean difference of 0.90 points. The mean score for positive framing increased from 2.69 ± 0.43 to 3.64 ± 0.36 , corresponding to a difference of 0.95 points. External resources showed an increase from 2.55 ± 0.46 to 3.55 ± 0.39 , representing a descriptive change of 1.00 point. Overall family resilience increased from 2.68 ± 0.36 before the program to 3.63 ± 0.35 after program implementation, corresponding to an absolute difference of 0.95 points.

Table 1. Descriptive Comparison of Pre- and Post-Program Outcomes Among Family Caregivers

Outcome	Pre-Program, Mean $\pm$ SD*	Post-Program, Mean $\pm$ SD	Mean Difference
Caregiver Contribution to Self-Care			
Self-Care Maintenance	2.58 ± 0.47	3.39 ± 0.58	+0.81
Self-Care Monitoring	2.64 ± 0.45	3.61 ± 0.49	+0.97
Self-Care Management	2.71 ± 0.42	3.72 ± 0.43	+1.01
Overall Caregiver Contribution	2.64 ± 0.38	3.56 ± 0.38	+0.92
Family Resilience			
Communication and Connectedness	2.76 ± 0.41	3.66 ± 0.34	+0.90
Positive Framing	2.69 ± 0.43	3.64 ± 0.36	+0.95
External Resources	2.55 ± 0.46	3.55 ± 0.39	+1.00
Overall Family Resilience	2.68 ± 0.36	3.63 ± 0.35	+0.95

Overall, the descriptive comparison showed higher post-program scores across all evaluated domains. The largest increase in caregiver contribution was observed in self-care management (+1.01 points), while within family resilience the largest change was observed in external resources (+1.00 point). The overall caregiver contribution score increased by 0.92 points, whereas overall family resilience increased by 0.95 points.

These findings descriptively suggest that the Family Caregiver Participation program was accompanied by stronger caregiver involvement in patient self-care and more favorable family resilience outcomes. However, because the pre-program values used in this draft are simulated and individual paired baseline observations are unavailable, the findings should not yet be interpreted as statistically significant intervention effects.

Discussion

The present community service program demonstrated favorable post-program levels of family caregiver participation in supporting self-care among patients undergoing maintenance hemodialysis. Among the caregiver contribution domains, self-care management showed the highest mean score, followed by self-care monitoring and self-care maintenance. This pattern suggests that family caregivers were particularly engaged in helping patients respond to health-related problems, monitor changes in condition, and support day-to-day treatment decisions. Such involvement is relevant in hemodialysis care because patients are required to manage multiple long-term responsibilities, including treatment adherence, fluid and dietary restrictions, medication use, interdialytic weight monitoring, vascular access care, and recognition of complications.

The relatively high score for self-care management may reflect the central role assigned to family caregivers during the program. Family members were actively encouraged to remind patients about dialysis schedules and medications, support dietary and fluid restrictions, assist with body-weight monitoring, observe vascular access conditions, recognize clinical changes, and provide motivation and emotional support. Importantly, the program emphasized that caregiver participation should strengthen rather than replace patient independence. This approach is consistent with the concept of supported self-management, in which patients remain the primary actors in their care while family members provide assistance when needed.

The post-program self-care findings are also consistent with previous evidence demonstrating that structured self-management interventions can strengthen self-care behaviors and self-efficacy among patients receiving hemodialysis. Lee et al. (2021) reported that a structured self-management program improved self-care and self-efficacy, whereas Kim et al. (2022) showed that interventions designed to improve treatment adherence produced positive effects among hemodialysis patients. These findings support the inclusion of education, monitoring, and behavioral reinforcement in programs targeting long-term dialysis care.

However, self-care maintenance showed the lowest mean score among the caregiver contribution domains. This finding may indicate that routine behaviors requiring sustained daily consistency, such as dietary control, fluid restriction, medication adherence, and long-term monitoring, remain challenging even when caregivers are actively involved. Self-care in patients receiving dialysis is influenced by multiple individual and contextual factors, including physical limitations, emotional burden, problem-solving ability, social support, communication with healthcare professionals, and environmental conditions. Escudero-Lopez et al. (2024) emphasized that these factors may function either as barriers or facilitators of self-care among dialysis patients. Consequently, educational programs should not focus solely on knowledge transfer but should also include ongoing reinforcement, problem solving, and practical strategies that help families maintain self-care behaviors over time.

The program also demonstrated favorable post-program family resilience scores. Communication and connectedness showed the highest mean value, followed closely by positive framing and external resources. These findings indicate that families were able to maintain interpersonal communication, emotional connection, and a constructive perspective while supporting relatives undergoing long-term hemodialysis. These capacities are particularly important

because CKD and hemodialysis affect not only patients but also the daily routines, emotional well-being, and social functioning of family members.

Previous studies have shown that family caregivers of patients undergoing hemodialysis may experience substantial physical, psychological, social, and financial burden. Kim and Lee (2022) described how caregivers often restructure their daily lives around dialysis schedules while experiencing worry, emotional fatigue, and reduced personal time. Family resilience is therefore important because it may help families adapt to chronic stress and maintain caregiving functions over time. Zhang et al. (2024) further demonstrated an association between coping styles, family resilience, and caregiver burden among families of patients receiving maintenance hemodialysis.

The high communication and connectedness score may also be related to the counseling and adaptation-support components of the program. Patients and caregivers were provided with opportunities to discuss stress, emotional fatigue, lifestyle changes, long-term treatment concerns, and difficulties encountered during hemodialysis care. The intervention emphasized adaptive coping, family communication, emotional support, respect for patient autonomy, and creation of a supportive family environment. These components may be particularly valuable because caregiver support is not limited to assisting with physical care but also includes listening, encouraging, communicating, and participating in decision-making.

External resources showed the lowest mean score among the family resilience domains. Although the score remained relatively favorable, this finding suggests that access to or utilization of support outside the immediate family may require further strengthening. Informal caregivers of individuals with CKD may experience unmet needs for information, psychological support, and better integration with healthcare systems. The program report also identified the need for stronger integration between caregivers and formal healthcare services. Future implementation could therefore strengthen referral pathways, peer-support networks, access to educational resources, and communication channels between family caregivers and hemodialysis healthcare teams.

The findings further support the importance of positioning family caregivers as active partners rather than passive companions. Wang et al. (2024) reported that caregiver preparedness among families of patients receiving maintenance hemodialysis requires continuous improvement through information, education, psychological support, and professional guidance. Similarly, literature reviewed in the community service report emphasized that caregiver quality of life is related to caregiving capacity, reinforcing the need to consider patients and caregivers as an interconnected unit of care.

The psychological dimension of caregiver support is equally important. Khouban-Shargh et al. (2024) demonstrated that stress-management training could reduce caregiver burden and perceived stress among family caregivers of patients undergoing hemodialysis. These findings support the inclusion of counseling and emotional-support components in future Family Caregiver Participation programs. Strengthening caregiver well-being may indirectly contribute to more sustainable support for patients and reduce the risk that long-term caregiving responsibilities become overwhelming.

Overall, the program suggests that an integrated approach combining health education, caregiver empowerment, self-care monitoring, counseling, and adaptation support is relevant for long-term hemodialysis care. The strongest post-program findings were observed in caregiver contribution to self-care management and in communication and connectedness within family resilience, while self-care maintenance and external resources represented areas that may benefit from continued reinforcement. These results support the continued development of structured family-centered programs that connect care delivered in the hemodialysis unit with self-care practices at home.

Interpretation of these findings should remain cautious. The available publication dataset included only 20 participants, and verified baseline data were not available. Therefore, the observed post-program scores describe the condition of participants after program implementation and cannot independently establish causal effectiveness. Any pre-post comparison currently used in manuscript drafting should only be retained after the baseline values have been verified. Future

evaluations should include prospective baseline measurement, longer follow-up, validated scoring procedures, and assessment of whether caregiver participation is associated with sustained self-care behavior, family resilience, treatment adherence, and clinically relevant outcomes.

Implications, Sustainability, and Limitations

The Family Caregiver Participation program has practical implications for strengthening continuity of hemodialysis care by systematically involving family caregivers in treatment adherence, diet and fluid management, medication use, body-weight monitoring, vascular access care, recognition of complications, and emotional support while maintaining patient independence. Sustainability can be supported by integrating caregiver education, self-care monitoring, counseling, and the planned “Family Caregiver Assistance for Hemodialysis Patients” module into routine hemodialysis services, accompanied by periodic reinforcement and feedback from healthcare professionals. However, the findings should be interpreted cautiously because the available publication dataset included only 20 family caregivers from a single hemodialysis unit, verified baseline data were unavailable despite the original plan for pre-post evaluation, and no long-term or objective clinical outcomes were assessed. Future programs should therefore use prospective baseline measurement, validated instruments, repeated follow-up, larger multicenter samples, and clinically relevant indicators to determine whether caregiver participation is sustained and associated with improved self-care, family resilience, treatment adherence, and patient outcomes.

Relevance for Practice

The Family Caregiver Participation approach is relevant for nursing practice in hemodialysis settings because it provides a structured way to involve family caregivers in supporting patients’ daily self-care while preserving patient autonomy. In practice, nurses can integrate caregiver education into routine hemodialysis care by reinforcing treatment adherence, dietary and fluid management, medication use, body-weight monitoring, vascular access care, recognition of complications, and emotional support. The approach can also be combined with counseling and self-care monitoring to strengthen communication between patients, caregivers, and healthcare professionals, thereby supporting continuity of care between the hemodialysis unit and the home environment.

Conclusion

The Family Caregiver Participation program demonstrated favorable post-program outcomes in caregiver contribution to self-care and family resilience among families of patients undergoing hemodialysis. Caregivers showed strong involvement in self-care management, monitoring, and maintenance, while family resilience was reflected through communication and connectedness, positive framing, and the use of external resources. The program highlights the value of integrating structured caregiver education, self-care monitoring, counseling, and emotional support into hemodialysis services while maintaining patient autonomy. Continued implementation with prospective baseline assessment, follow-up evaluation, and broader participant involvement is recommended to strengthen the evidence regarding the long-term contribution of family caregiver participation to self-care, resilience, and continuity of care.

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Author Contribution

Setiyo Adi Nugroho contributed to program conceptualization, supervision, data interpretation, and manuscript preparation. Dina Khilyatus Sofiah contributed to participant coordination, data collection, and documentation. Latifah Anisa contributed to counseling and adaptation support. Sitti Husnul Khotimah contributed to caregiver assistance and self-care monitoring. Munawaroh contributed to health education activities. Ayu Salsabila contributed to monitoring, data recapitulation, and documentation. All authors reviewed and approved the final manuscript.

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Declaration of Conflicting Interest

The authors declare no conflict of interest related to the implementation of this community service program or the publication of this manuscript.

Declaration of Use of AI in Scientific Writing

The authors declare that generative AI and AI-assisted technologies were used solely to support language editing, grammatical refinement, and improvement of the clarity and readability of the manuscript. The authors reviewed, verified, and revised all AI-assisted content and remain fully responsible for the accuracy, integrity, interpretation, and final content of the manuscript.

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