Original Article

Comparison of the Dialysis Adequacy Across Four Types of Dialysis Machines in Hemodialysis Patients

Abstract

Background: Chronic renal failure causes a gradual loss of kidney function. This study compares four types of dialysis machines for blood purification in hemodialysis patients. **Materials and Methods:** This descriptive-analytical cross-sectional study was conducted in 2024 at the Dialysis Department of Sepehr Dialysis Center and Pasteur Hospital in Kerman Province, Iran. It included 64 dialysis patients selected through convenience sampling. Four different dialysis machines, Fresenius 4008 S, Fresenius 4008 B, ATF1022, and B. Braun, and 102 blood samples were analyzed, with patients undergoing either one or two sessions of hemodialysis. Data were gathered using a questionnaire about demographic and clinical information before and after dialysis. Vital signs and biochemical tests were taken, and dialysis adequacy was measured using KT/V and urea reduction ratio (URR), where K = urea clearance, T = dialysis time, and V = urea distribution volume. Data were analyzed using chi-square, *t*-tests, and Pearson correlation tests. **Results:** The mean (SD) dialysis adequacy (KT/V) among patients was 1.21 (0.41), and the mean (SD) URR was 58.97 (7.65). Only 17.06% of patients achieved a URR greater than 65%, and 21.60% achieved a KT/V greater than 1.20, which are established indicators of hemodialysis adequacy. Although the performance of the four machines varied, with higher values observed for the Fresenius 4008 B (KT/V = 1.16 ± 0.299 and URR = 61.47 ± 8.48), there was no statistically significant difference between dialysis machine types and dialysis adequacy ($p > 0.05$). **Conclusions:** Healthcare officials and stakeholders should examine factors affecting dialysis adequacy and implement newer machines and better quality assurance programs.

Keywords: *Adequacy, dialysis, dialysis machines, hemodialysis, renal patients*

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Introduction

Chronic renal failure (CRF) is characterized by a gradual decline in kidney function. As CRF worsens, it can lead to the accumulation of dangerous levels of fluids, electrolytes, and waste products in the body, resulting in serious complications such as uremia and metabolic acidosis.[1] In 1990, CRF was recognized as the 27th leading cause of death worldwide, with an age-standardized death rate of 9.6 per 100,000 people, which increased to 11.1 per 100,000 by 2010.[2] The adult population is particularly affected, with over 0.1% experiencing complete kidney failure, and this number continues to rise.[3] Common complications of CRF include hyperphosphatemia, hypocalcemia, anemia, and uremic pruritus.[4] Although options such as transplantation, peritoneal dialysis, and home hemodialysis are on the rise, in-center hemodialysis remains the most frequently used kidney replacement therapy globally.[5]

Hemodialysis fundamentally transformed the treatment of chronic kidney failure, leading to substantial improvements in patient survival rates. Presently,[6] more than 2 million individuals worldwide rely on kidney transplants or dialysis for survival,[7] with approximately 3.4 million people currently receiving dialysis.[8] Advances in hemodialysis technology over the past five decades have notably enhanced the quality of life.[9] Nevertheless, long-term hemodialysis can lead to complications such as fatigue, infertility, sexual dysfunction, and cardiovascular problems.[10] Improving the adequacy of hemodialysis is critical not only for reducing these complications but also for lowering mortality rates and alleviating the physical, psychological, and

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Access this article online

Website: https://journals.lww.com/jnmr

DOI: 10.4103/ijnmr.ijnmr_117_25

Quick Response Code:

How to cite this article: Choopani Y, Rezaei M, Mohammadinia N. Comparison of the dialysis adequacy across four types of dialysis machines in hemodialysis patients. Iran J Nurs Midwifery Res 2026;31:618-22.

Submitted: 07-Apr-2025. **Revised:** 14-Oct-2025. **Accepted:** 17-Oct-2025. **Published:** 16-Jul-2026.

social challenges that patients face.[11] It also helps decrease hospitalization duration and associated healthcare costs.[12]

Dialysis adequacy is evaluated using two key metrics: The urea reduction ratio (URR) and KT/V, where K = urea clearance, T = dialysis time, and V = urea distribution volume.[12,13] This process essentially compares the concentration of urea, a substance representative of uremic toxins, in the blood before and after dialysis.[14] Specifically, adequate hemodialysis is indicated by a URR of more than 65% and a KT/V of greater than 1.2.[15] Poor dialysis can result in higher rates of disability and mortality.[16,17] Several factors influence the effectiveness of dialysis, such as the type of filter used, the dialysis pump rate, treatment duration and speed, the use of high-flux dialyzers, blood flow rate, patient education, dietary factors, and the presence of underlying diseases.[15,18,19] Despite extensive research on hemodialysis technologies and their impact on waste removal, no conclusive evidence suggests that different types of hemodialysis machines significantly influence dialysis adequacy.[15,18]

The market for hemodialysis products and services is currently dominated by several major companies, including Fresenius Medical Care, DaVita Healthcare Partners, Toray Industries, Asahi Kasei Medical, Baxter International, WEGO Healthcare, B. Braun Mesulgen, Membrane GmbH, Nipro Corporation, and Gambro. All these companies compete to produce high-quality dialyzers, which are critical components of hemodialysis treatment.[18] The hemodialysis procedure effectively reduces the levels of potassium, sodium, phosphorus, urea, creatinine, blood urea nitrogen (BUN), average blood pressure, and overall patient weight.[20,21]

However, despite the importance of the hemodialysis process in these patients and the role of the dialysis machine, no study has been found in Iran that compares the performance of dialysis adequacy among the four studied machines, which are among the most commonly used machines in the country. Therefore, the researcher decided to conduct this study in the mentioned centers to present results, to determine and introduce more effective machines for reducing body waste materials and balancing serum electrolytes. This could help reduce long-term complications in chronic conditions and even mortality in acute situations. Additionally, it may increase dialysis efficiency and improve the quality of life of these patients who have unfavorable mental and physical conditions and must endure several hours of treatment every week (between 3 and 4 h).[22] This study aims to compare four types of dialysis machines for blood purification in hemodialysis patients.

Materials and Methods

This study was a descriptive-analytical and cross-sectional study, carried out in the Dialysis Department of Sepehr Dialysis Center and the dialysis ward of Pasteur Hospital in Kerman province, southeastern Iran, from January to September 2024. The sample size was calculated using power analysis with $\alpha = 0.05$ ($Z_{1-\alpha/2} = 1.96$), $\beta = 0.20$ (power = 80%, $Z_{1-\beta} = 0.84$), and accounting for a 10% probability of attrition, resulting in a minimum of 25 participants from each center.[15,23]

The total number of patients in the two centers was 92, of which 64 eligible dialysis patients were selected by a convenience sampling method. Four dialysis machines (Fresenius 4008 S, Fresenius 4008 B, ATF.1022, B. Braun) and 102 blood samples (26 patients underwent hemodialysis once, and 38 patients underwent hemodialysis twice with different machines under previous conditions) were collected and analyzed. The inclusion criteria were as follows: Signed informed consent, age over 18 years, no medication use or disease during dialysis that could affect the results, end-stage renal disease in both kidneys, and a history of hemodialysis for more than 2 years. The exclusion criteria were as follows: More than one vascular access and intolerance to the dialysis procedure.

Data were collected using a two-part researcher-administered questionnaire. The first part, which included demographic and clinical characteristics, was completed pre-dialysis (age, sex, marital status, occupation, education level, income, weight, drug history, complications during hemodialysis, and cause of renal failure). The second part focused on the hemodialysis process post-dialysis (dialysis history, sessions of dialysis per week, blood flow rate (BFR), vascular access, filter type, Eprex dose and injection method, UF, and hemodialysis machine type). Vital signs and blood indices (urea, creatinine, BUN, sodium, potassium, phosphorus, hematocrit, and hemoglobin) were monitored in both pre- and post-dialysis stages. Up to 5 mL of blood was collected from the arterial line at a flow rate of 40–80 mL/min. Blood test levels (from both centers) were measured at the central laboratory of Pasteur Hospital.

Dialysis adequacy for all samples was calculated using the following KT/V[19,20] and URR[21] formulas, and recorded in questionnaires. KT/V = $\ln\{(R - 0.008t) + (4 - 3.5R) + \frac{UF}{W}\}$ URR= $(1 - U_{post}/U_{pre}) \times 100$. In the KT/V formula, ln is the natural logarithm, R is the ratio of BUN post-dialysis to pre-dialysis, t is the duration of each dialysis session in hours, UF is the volume of ultrafiltration or the volume of fluid displaced during dialysis in liters, and W is the post-dialysis weight in kilograms. According to available sources, URR > 65% and KT/V > 1.2 indicate optimal adequacy of dialysis.[18] In this study, the acceptable adequacy of dialysis was considered according to these values. Data were analyzed using descriptive statistics (mean and standard deviation) and inferential statistics (t-test, analysis of variance (ANOVA), χ^2 test, and Pearson's correlation coefficient) at a 95% confidence level using SPSS version 27 software, which was developed by IBM Corporation (used under official license and with authorized access).

Ethical considerations

Permission was obtained from the Ethics Committee of Bam University of Medical Sciences (MUBAM), with the approval code (IR.MUBAM.REC.1402.094). All participants were fully informed about the nature of the study and were told that they could withdraw at any time. All participants provided written informed consent.

Results

A total of 102 samples from patients undergoing hemodialysis were analyzed. Most of the participants were male (58.80%), married (90.20%), and illiterate or had primary education (56.90%). The mean (SD) age of the participants was 58.80 (14.38) years, and they had undergone hemodialysis for a mean (SD) of 3.58 (0.37) years. All samples were dialyzed three times per week in different shifts, and sampling was performed only in the morning shift. The most common cause of kidney failure in the majority of patients (72.50%) was hypertension. The mean and standard deviation of laboratory variables and some of the characteristics are presented in Table 1.

The mean (SD) BFR was 298.82 (5.10) mL/min. In most participants, the type of vascular access (52.90%) was a fistula, and the most commonly used hemodialysis machine (33.30%) was ATF.1022. The mean dialysis adequacy (KT/V) in the participants was 1.21 (0.41), and the URR was 58.97 (7.65). Only 17.06% of patients had an acceptable URR >65%, and 21.60% of patients had good dialysis adequacy or KT/V > 1.20. The highest dialysis adequacy KT/V, 1.16 (0.29), and URR 61.47 (8.48) were obtained using the Fresenius 4008 B machine; however, the type of hemodialysis machine was not significantly associated with URR and KT/V ($p > 0.05$) [Table 2]. It should be noted that other investigated variables (duration of dialysis, number of dialysis sessions per week, occupation, education, marital status, and type of vascular access) did not have a significant relationship with URR and KT/V ($p > 0.05$).

Among the examined variables, weight ($p = 0.001$), urea ($p = 0.001$), hematocrit ($p \leq 0.001$), and post-dialysis BUN ($p \leq 0.001$) had an inverse and significant correlation with the KT/V, and weight ($p \leq 0.001$), blood pressure ($p = 0.009$), urea ($p < 0.001$), hematocrit ($p = 0.013$), and post-dialysis BUN ($p = 0.009$) had an inverse and significant correlation with URR [Table 3]. Both parameters were significantly higher in women than in men (URR: $p = 0.02$ and KT/V: $p = 0.021$).

Table 1: Mean and standard deviation of BP and biochemical tests

Variable	Mean (SD)		*p
	Before dialysis	After dialysis	
Systolic BP**	138.72 (22.10)	128.23 (25.72)	<0.001
Diastolic BP	74.21 (12.89)	72.54 (11.63)	0.06
Urea	106.84 (26.45)	43.64 (13.62)	<0.001
Cr	7.55 (1.82)	2.86 (0.82)	<0.001
Na	134.47 (2.17)	134.88 (3.05)	0.003
K	4.64 (0.73)	3.20 (0.38)	<0.001
P	5.80 (1.35)	2.77 (0.65)	0.011
Hb	10.02 (1.37)	10.51 (1.67)	<0.001
HCT***	33.32 (4.31)	34.38 (4.81)	<0.001
BUN****	49.78 (12.38)	20.39 (6.36)	<0.001

*The results of *t*-test; BP**=Blood pressure; HCT***=*Hematocrit*; BUN****=Blood urea nitrogen

Table 2: Comparison of dialysis adequacy in dialysis machines used in samples

Dialysis machines	*KT/V Mean (SD)	**URR Mean (SD)
Fresenius 4008 S	1.07 (20)	58.58 (7.31)
Fresenius 4008 B	1.16 (0.29)	61.47 (8.48)
B. Braun	1.10 (0.15)	59.69 (4.59)
ATF.1022	1.04 (0.30)	57.25 (9.14)
Total	1.08 (0.25)	58.97 (7.65)
ANOVA test	F=0.47	P=0.70
	F=0.67	P=0.57

*KT/V=K (urea clearance), T (dialysis time), and V (urea distribution volume); **URR=Urea reduction ratio

Table 3: Correlation between dialysis adequacy indices (KT/V and URR) and the studied variables

	Variables	***r	p
KT/V*	Weight	−0.45	<0.001
	Urea after dialysis	−0.52	<0.001
	Cr after dialysis	−0.47	<0.001
	K after dialysis	−0.47	<0.001
	P after dialysis	−0.34	0.013
	BUN after dialysis	−0.52	<0.001
URR**	Weight	−0.46	<0.001
	Urea after dialysis	−0.61	<0.001
	Cr after dialysis	−0.32	0.02
	K after dialysis	−0.57	<0.001
	P after dialysis	−0.4	0.003
	BUN after dialysis	−0.52	<0.001

*KT/V=K (urea clearance), T (dialysis time), and V (urea distribution volume); **URR=Urea reduction ratio; ***r=Pearson's correlation coefficient

Discussion

The findings of this study indicate that the type of hemodialysis machine did not significantly affect the adequacy of dialysis, aligning with some similar studies[13,24] and contrasting with other studies, such as Iman's study.[25] Perhaps the reason for this discrepancy can be attributed to the difference in machine types between the two studies or the year of manufacture and technology updates.

Considering the criteria for dialysis adequacy, the mean dialysis adequacy (KT/V) in the participants was 1.21, and the URR was 58.97. Only 17.06% of patients had an acceptable URR above 65%, and 21.60% of patients had good dialysis adequacy or KT/V above 1.20. These results are consistent with the results of most studies conducted in Iran.[11,13,26] For instance, in Alipour *et al.*,[26] less than half of patients had the desired adequacy (22.75% of patients with a KT/V index more than 1.2 and 19.43% of patients with a URR index more than 65%).

In contrast, Zareei *et al.*[27] reported an average KT/V of 1.28 (0.43), with over half of the patients (64%) having a KT/V $\geq$ 1.2. These variations might be explained by differences in the dialysis machines across centers, their year of manufacture, duration of patient dialysis sessions, type of vascular access, type of filter, and the machine pump speed. A systematic review of Iranian patients undergoing hemodialysis showed that the mean KT/V index was 1.11, which was lower than the accepted value of $\geq$1.2, for optimal dialysis adequacy in Iran. Although the minimum acceptable KT/V in Iran is lower than in countries such as Egypt (1.5), Thailand (1.8), and Spain (1.9).[18]

Accordingly, this indicates suboptimal and poor adequacy of dialysis in patients undergoing hemodialysis. Achieving the minimum KT/V targets has been shown to improve patient morbidity and mortality.[16] Data from different studies show that for every 0.1 increase in KT/V, the mortality rate decreases by approximately 7%, and for every 5% increase in URR, the mortality rate decreases by 11%.[28] This can be attributed to the low-level equipment in dialysis units and their inadequate filters, lack of adequate vascular access, insufficient dialysis duration, and poor personnel skills.

In terms of biochemical variables, there was a significant inverse relationship with dialysis adequacy in this study, such that increased dialysis efficiency was associated with decreased levels of blood biochemical variables (K, P, Cr, UR, and BUN). This is consistent with the studies of Correa and Lee *et al.*[29,30] and this outcome aligns with one of the primary objectives of dialysis[30] and the definition of dialysis adequacy.[31]

Regarding other demographic variables, our results, in line with those of Zareei *et al.*,[27] showed no significant association between demographic data (occupation, education, and marital status), frequency and duration of dialysis sessions, and KT/V. However, KT/V targets may be achieved by altering many different aspects of the HD prescription, including dialysis frequency, duration, blood flow rate, dialysate flow rate, and dialyzer size.[25] Our study found that dialysis adequacy significantly varied by gender, being higher in women, which is consistent with findings from other similar studies.[32,33] This difference may be explained by the smaller physical stature of women when using similar filters and identical dialysis conditions or may be related to sex-related physiological differences between men and women.

Although in this study, the type of hemodialysis machine did not significantly affect the adequacy of dialysis, there were limitations, such as short-term assessment, conducting the study in two centers, limited sample size, and generalizability, and limitation to four types of dialysis machines.

Conclusion

Most patients in this study did not receive adequate dialysis, and the machine type did not significantly affect the outcomes. A comprehensive review of the factors influencing dialysis adequacy is crucial, focusing on the technology used, personnel training, and patient care practices. We recommend conducting more extensive studies to explore the various factors influencing dialysis adequacy across a broader patient population and different healthcare settings to enhance treatment effectiveness and improve patients' quality of life.

Acknowledgments

This study is the result of a research project with code 402000066. The authors are grateful to all patients, specialists, and personnel of the Dialysis Department of Pastor Hospital and Sepehr Dialysis Center

Financial support and sponsorship

Bam University of Medical Sciences (MUBAM)

Conflicts of interest

Nothing to declare.

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