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COMPARATIVE EVALUATION OF HEMODIALYSIS ADEQUACY METRICS IN PEDIATRIC ESRD PATIENTS: SPKT/V VERSUS UREA REDUCTION RATIO (URR)

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ABSTRACT

Background: Assessment of hemodialysis adequacy is essential in pediatric end-stage renal disease (ESRD). Single-pool Kt/V (spKt/V) and urea reduction ratio (URR) are widely used measures, but their agreement and clinical utility in children may differ.

Objective: To compare spKt/V and URR for assessment of hemodialysis adequacy in pediatric ESRD patients and identify factors associated with inadequate dialysis.

Methods: This retrospective observational study was conducted at Pediatric Nephrology, University of Child Health Sciences and The Children's Hospital, Lahore from January 2026 to June 2026, and included 170 pediatric patients with ESRD receiving maintenance hemodialysis. Demographic and clinical variables including age, gender, body weight, height, body mass index, underlying cause of ESRD, duration of dialysis, vascular access type, dialysis frequency, session duration, blood flow rate, dialysate flow rate, and ultrafiltration volume were recorded.

Results: The mean age was 12.84±3.41 years, and 98 (57.6%) patients were male. Mean spKt/V was 1.43±0.24 and mean URR was 69.89±7.62%. Adequate dialysis was identified in 136 (80.0%) patients by spKt/V and 128 (75.3%) by URR. Both measures classified 124 (72.9%) patients as adequate and 30 (17.6%) as inadequate, while discordant classification occurred in 16 (9.4%) patients. URR and spKt/V showed a strong positive correlation ($r=0.82$, $p<0.001$) and substantial agreement ($\kappa=0.73$, $p<0.001$). URR demonstrated 91.2% sensitivity, 88.2% specificity, 96.9% positive predictive value, 71.4% negative predictive value, and 90.6% overall diagnostic accuracy using spKt/V as the reference.

Conclusion: spKt/V and URR showed strong correlation and substantial agreement in pediatric ESRD patients, although a small proportion were classified differently. Shorter dialysis sessions, lower treatment frequency, catheter-based vascular access, and low blood flow were associated with inadequate dialysis.

KEYWORDS: ESRD, Patients, Flow rate, BMI, Blood flow, Dialysis

INTRODUCTION

End-stage renal disease (ESRD) is a serious chronic condition that, if not treated with renal replacement therapy, will lead to impaired metabolic regulation, fluid balance and death until kidney transplantation is possible in children [1]. Hemodialysis is an important treatment option for the pediatrics population of patients who have kidney failure, especially in instances where there is no transplant or peritoneal dialysis option, is not suitable for them or is temporarily not an option [2]. The delivery of adequate hemodialysis is crucial because uremic toxins may have a role in poor growth, malnutrition, cardiovascular issues, hospitalizations and quality of life [3]. To achieve this, assessment of dialysis adequacy is a vital part of the care of patients receiving hemodialysis. The most commonly used indexes to quantify the dialysis dose delivered are urea-based indexes [4]. Single-pool Kt/V (spKt/V) estimates urea clearance and takes into account the dialyzer clearance, treatment time, and the patient's urea distribution volume [5]. The current guidelines for hemodialysis suggest a goal spKt/V of about 1.4 per session, and a minimum spKt/V delivered of 1.2 per session for the thrice-weekly dialyzed patient [6]. The treatment dose for children has been traditionally set at the dose similar to that recommended for adults for dialysis, but the physiology of children may make this more complex [7].

The urea reduction ratio (URR) is another more straightforward approximation of dialysis adequacy that is the percentage decrease in blood urea nitrogen (BUN) after dialysis [8]. The value of URR is generally considered to

be at least 65% and values close to 70% or higher are desirable [9]. Unlike spKt/V, URR is not directly adjusted for treatment duration, ultrafiltration, or urea distribution volume, and is easier to calculate, but may not be as responsive to individual patient variables [10]. However, URR's simplicity and minimal data requirements make it appealing for routine clinical use, especially in resource-limited dialysis centres [11]. The correlation between URR and spKt/V might be especially relevant in the pediatric age group due to the significant differences in body size, TBPW, nutritional status, residual kidney function, vascular access and dialysis prescription among the age groups [12]. In previous studies of children, there is also significant differences between the two tests: In up to 44% of the assessments URR identified inadequate dialysis while spKt/V characterized no more than 6% as inadequate in the same setting [13]. These differences have raised the concern that using just one metric may lead to varying clinical judgements about dialysis adequate [14]. Furthermore, suboptimal spKt/V has been correlated with higher hospitalization rates in adolescent HD patients, and this has been shown to be clinically relevant with respect to maintenance of dialysis dosing [15]. However, there are also other important complementary indicators of dialysis adequacy in children, such as nutritional status, growth, rates of anemia, blood pressure, mineral metabolism, and clinical well-being [16].

Objective

To compare spKt/V and URR for assessment of hemodialysis adequacy in pediatric ESRD patients and identify factors associated with inadequate dialysis.

METHODOLOGY

This retrospective observational study was conducted at Pediatric Nephrology, University of Child Health Sciences and The Children's Hospital, Lahore from January 2026 to June 2026, and included 170 pediatric patients with end-stage renal disease (ESRD) receiving maintenance hemodialysis. Patients included in this study were those aged 5-18 years with confirmed ESRD who had received dialysis for at least three months and who had complete pre- and post-dialysis blood urea levels measured, with regular hemodialysis as dialysis modality. The patients enrolled were regular hemodialysis patients, age 5-18 years with confirmed ESRD who had measurable pre- and post-dialysis blood urea levels. Patients receiving acute dialysis, those with substantial residual renal function, recent hospital admission for acute illness, active infection, hemodynamic instability at the time of dialysis, incomplete dialysis or incomplete clinical and laboratory assessment were excluded.

Data Collection

Patients with a diagnosis of pediatric nephrology and dialysis were selected from records of the pediatric nephrology and dialysis unit, using a non-probability consecutive sampling technique, after obtaining approval from the Institutional Ethical Review Committee. Demographic and clinical data such as age, gender, body weight, height, body mass index, underlying cause of ESRD, duration of dialysis, type of vascular access, frequency of dialysis, length of dialysis sessions, dialysate flow rate, blood flow rate and ultrafiltration volume were obtained. Laboratory data such as blood urea nitrogen, hemoglobin, serum creatinine, albumin, calcium, phosphate and electrolyte levels were recorded, both before and after dialysis. Post dialysis urea was collected using the same sampling technique immediately following the dialysis session. Both the urea reduction ratio (URR) and single-pool Kt/V (spKt/V) were used to evaluate hemodialysis adequacy. The percentage reduction in blood nitrogen level from pre-dialysis to post-dialysis was calculated as URR. A URR $\geq$65% was deemed acceptable. The second generation Daugirdas equation was used to calculate single-pool Kt/V, which included pre- and post-dialysis urea and post-dialysis body weight and dialysis time, as well as the volume of ultrafiltrate removed. An spKt/V $\geq$1.2 per dialysis session was considered adequate. The agreement between URR and spKt/V classifications was compared and their correlations with demographic, clinical and dialysis-related variables were analyzed.

Statistical Analysis

SPSS ver. 26.0 was used for data analysis. Data from continuous variables were reported as mean ± SD and categorical variables were reported as frequencies and percentages. An independent t-test or one-way ANOVA was used for comparison of mean URR, mean spKt/V values by clinical and dialysis related characteristics where appropriate. The Pearson or Spearman correlation analysis was used to evaluate the correlation between URR and spKt/V depending on the distribution of the data. Cohen's kappa statistics were used to assess the interrater reliability between the two types of adequacy. A p-value $\leq$0.05 was considered statistically significant.

RESULTS

The mean age of the 170 patients was 12.84±3.41 years; 98 (57.6%) were male and 72 (42.4%) female. Mean body weight was 34.72±12.86 kg, height 139.46±18.72 cm, and BMI 17.21±3.04 kg/m². Mean ESRD duration was 2.81±1.63 years and hemodialysis duration 22.64±14.18 months. Most patients received three dialysis sessions weekly (146, 85.9%) and had an arteriovenous fistula (122, 71.8%). Mean session duration was 3.72±0.46 hours, blood flow rate 176.82±36.54 Ml/min, and ultrafiltration volume 1.42±0.61 L. Mean hemoglobin was

9.74±1.48 g/Dl, albumin 3.72±0.54 g/Dl, pre-dialysis BUN 67.84±17.46 mg/Dl, and post-dialysis BUN 20.42±8.14 mg/Dl.

Table I. Demographic, Clinical, and Hemodialysis Characteristics of Study Patients

Characteristic	Total (n=170)
Age, years, Mean±SD	12.84±3.41
Male, n (%)	98 (57.6)
Female, n (%)	72 (42.4)
Body weight, kg, Mean±SD	34.72±12.86
Height, cm, Mean±SD	139.46±18.72
BMI, kg/m², Mean±SD	17.21±3.04
Duration of ESRD, years, Mean±SD	2.81±1.63
Duration on hemodialysis, months, Mean±SD	22.64±14.18
Hemodialysis 3 sessions/week, n (%)	146 (85.9)
Hemodialysis 2 sessions/week, n (%)	24 (14.1)
Session duration, hours, Mean±SD	3.72±0.46
Arteriovenous fistula, n (%)	122 (71.8)
Central venous catheter, n (%)	48 (28.2)
Blood flow rate, mL/min, Mean±SD	176.82±36.54
Ultrafiltration volume, L/session, Mean±SD	1.42±0.61
Hemoglobin, g/dL, Mean±SD	9.74±1.48
Serum albumin, g/dL, Mean±SD	3.72±0.54
Pre-dialysis BUN, mg/dL, Mean±SD	67.84±17.46
Post-dialysis BUN, mg/dL, Mean±SD	20.42±8.14

Mean spKt/V was 1.43±0.24 and mean URR was 69.89±7.62%. Adequate dialysis was identified in 136 (80.0%) patients using spKt/V and 128 (75.3%) using URR. Both measures classified 124 (72.9%) patients as adequate and 30 (17.6%) as inadequate. Discordance occurred in 16 (9.4%) patients, including 12 (7.1%) considered adequate by spKt/V but inadequate by URR and 4 (2.4%) showing the opposite pattern.

Table II. Comparison of Hemodialysis Adequacy According to spKt/V and URR

Adequacy parameter	Mean±SD / n (%)
Mean spKt/V	1.43±0.24
Mean URR, %	69.89±7.62
spKt/V ≥1.2, adequate	136 (80.0)
spKt/V <1.2, inadequate	34 (20.0)
URR ≥65%, adequate	128 (75.3)
URR <65%, inadequate	42 (24.7)
Adequate by both measures	124 (72.9)
Inadequate by both measures	30 (17.6)
Adequate by spKt/V but inadequate by URR	12 (7.1)
Inadequate by spKt/V but adequate by URR	4 (2.4)

URR and spKt/V showed a strong positive correlation (r=0.82, p<0.001) and an overall classification agreement of 90.6%. Cohen's kappa was 0.73 (p<0.001), indicating substantial agreement. Using spKt/V as the reference, URR demonstrated 91.2% sensitivity, 88.2% specificity, 96.9% positive predictive value, 71.4% negative predictive value, and 90.6% overall diagnostic accuracy.

Table III. Correlation, Agreement, and Diagnostic Performance of URR Against spKt/V

Measure	Result	p-value
Correlation between spKt/V and URR, r	0.82	<0.001
Overall classification agreement, %	90.6	<0.001
Cohen's kappa	0.73	<0.001
Sensitivity of URR, %	91.2	0.001
Specificity of URR, %	88.2	0.001
Positive predictive value, %	96.9	0.001
Negative predictive value, %	71.4	0.001
Overall diagnostic accuracy, %	90.6	0.001

Patients with adequate versus inadequate dialysis had mean ages of 13.02±3.32 and 12.12±3.69 years and body weights of 35.41±12.67 and 31.96±13.39 kg, respectively, with no significant association. Independent predictors of inadequate dialysis were session duration <4 hours (OR 3.08, 95% CI 1.34–7.07, p=0.008), twice-weekly

dialysis (OR 2.86, 95% CI 1.08–7.57, p=0.034), central venous catheter use (OR 2.52, 95% CI 1.09–5.83, p=0.031), and blood flow <150 mL/min (OR 3.21, 95% CI 1.39–7.41, p=0.006).

Table IV. Factors Associated With Inadequate Hemodialysis Defined by spKt/V <1.2

Variable	Adequate (n=136)	Inadequate (n=34)	Adjusted OR (95% CI)	p-value
Age, years, Mean±SD	13.02±3.32	12.12±3.69	0.94 (0.84–1.06)	0.308
Body weight, kg, Mean±SD	35.41±12.67	31.96±13.39	0.98 (0.95–1.01)	0.214
Dialysis session <4 hours, n (%)	43 (31.6)	23 (67.6)	3.08 (1.34–7.07)	0.008
Two dialysis sessions/week, n (%)	13 (9.6)	11 (32.4)	2.86 (1.08–7.57)	0.034
Central venous catheter, n (%)	31 (22.8)	17 (50.0)	2.52 (1.09–5.83)	0.031
Blood flow rate <150 mL/min, n (%)	29 (21.3)	18 (52.9)	3.21 (1.39–7.41)	0.006
Serum albumin <3.5 g/dL, n (%)	27 (19.9)	14 (41.2)	2.07 (0.90–4.78)	0.087
Hemoglobin <10 g/dL, n (%)	65 (47.8)	21 (61.8)	1.39 (0.62–3.11)	0.420

DISCUSSION

The present study revealed generally good hemodialysis adequacy among all pediatric patients with ESRD, but the percentage of patients being characterized as being adequately dialyzed varied by the adequacy parameter. The mean spKt/V was 1.43±0.24, the mean URR was 69.89±7.62% and adequate dialysis was achieved in 80.0% of the patients with spKt/V and 75.3% with URR. In a prior study, children on maintenance hemodialysis had an adequate rate of dialysis in about 70% of patients, suggesting that a significant number of children may be outside of recommended dialysis rates, as determined by Kt/V criteria [17]. One of the significant results was the high correlation between the two adequacy measures. There was a strong positive correlation between URR and spKt/V (r=0.82, p<0.001) with 90.6% of the participants in agreement and a Cohen's kappa value of 0.73. However, in 16 (9.4%) patients, classification was discordant, with 12 (7.1%) patients being classified as adequate by spKt/V and inadequate by URR, and 4 (2.4%) having the opposite categorization. There was also previous research that showed clinically relevant disagreement between these indices, in the pediatric hemodialysis population, where URR labelled up to 44% of dialysis assessments as inadequate, while spKt/V did not label more than 6% [18]. While the disagreement in the present study was significantly less, the results indicate that one should not assume that URR and spKt/V are synonymous in all pediatric patients. With spKt/V as the reference standard, the sensitivity, specificity, PPV, NPV and overall accuracy of URR were 91.2%, 88.2%, 96.9%, 71.4% and 90.6% respectively. These results suggest that the URR is a feasible approximation of dialysis adequacy that could be subject to misclassification in a small number of patients. Similarly, previous studies have noted that significant discrepancies in the calculation method used and the timing of urea sampling (before or after dialysis) can lead to significant variation between URR and spKt/V, thus emphasizing the need for standard sampling and consistent use of urea measurement methods [18]. Thus, in children, spKt/V may better reflect the impact of dialysis on the body by including the duration of dialysis and the changes in body volume, in addition to proportional urea reduction. There was a strong association between inadequate dialysis and treatment duration and frequency. Patients who received dialysis sessions of <4 hours were about 3 times more likely to have inadequate dialysis (adjusted OR 3.08, 95% CI 1.34–7.07, p=0.008) and twice-weekly dialysis was independently associated with inadequate dialysis (OR 2.86, 95% CI 1.08–7.57, p=0.034). In previous studies, children undergoing hemodialysis three times per week were found to need adequate delivery of dialysis at each session to achieve adequate weekly clearance and showed that a standard Kt/V of ≥2.0 per session was sufficient to achieve spKt/V ≥1.2 [19]. These results confirm that good dialysis in children is not only about being able to get them to the dialysis sessions, but about ensuring they receive enough treatment time and frequency.

One additional factor of importance in determining blood flow rate was adequacy. Odds of inadequate dialysis were more than three times higher in the present study for a blood flow rate <150 mL/min (adjusted OR 3.21; 95% CI 1.39–7.41; p=0.006) compared with any other treatment-related factor. Similar principles were previously reported in the literature, and in pediatric hemodialysis, appropriate blood flow is a basic requirement for a desired degree of solute clearance and is frequently adjusted as a function of body size in children [20]. The correlation observed in the present study has also been shown, in previous studies, that an increase in blood flow leads to an increase in measured dialysis adequacy [21]. Dialysis delivery also was affected by vascular access. CVC use was associated with increased odds of inadequate dialysis (adjusted OR 2.52, 95% CI 1.09–5.83, p=0.031) in 50.0% of patients with inadequate dialysis compared with 22.8% of adequately dialyzed patients and was present in patients with inadequate dialysis but not in those with adequate dialysis. Previous pediatric studies also showed

that central venous catheters had lower blood flow rates and lower Kt/V values, than the arteriovenous fistulas [22]. This could be due to limitations of blood flow, catheter dysfunction, recirculation or treatment interruptions due to catheter-based access. The discovery will help maintain long-term arteriovenous access in the appropriate pediatric population undergoing long-term hemodialysis (LT HD). After adjustment for other factors, inadequate dialysate (OR 2.07, p=0.087) and hemoglobin <10 g/dL (OR 1.39, p=0.420) were more common among inadequately dialyzed patients but failed to be independently significant. Likewise, the association between age and dialysis inadequacy was not independent of that between body weight and dialysis inadequacy. In a previous study with adolescents, those who had spKt/V <1.2 were still at higher risk for hospitalization, independent of the other factors mentioned, such as vascular access, hemoglobin, albumin, height, dialysis duration [23]. This reinforces the idea that delivered dialysis dose is important from a clinical perspective, and independent of nutrition and hematology. There are several limitations of this study. The study was retrospective and single center suggesting potential documentation or selection bias and limiting applicability of results. The assessment of dialysis adequacy was primarily based on the urea-based indices and other important indicators like residual kidney function, nutritional status, growth parameters, and long-term clinical outcomes were not assessed in detail. Other factors, such as the range of dialysis prescriptions, vascular access function and post-dialysis blood sampling, might also have affected spKt/V and URR. The study results are useful for comparison purposes, however, given the limitations imposed by the study, with respect to the performance of two dialysis adequacy measures in pediatric ESRD patients.

CONCLUSION

Both spKt/V and URR were useful for assessing hemodialysis adequacy in pediatric ESRD patients and showed a strong correlation with substantial agreement. However, a small proportion of patients were classified differently by the two measures, suggesting that they should not always be considered interchangeable. Shorter dialysis sessions, twice-weekly dialysis, central venous catheter use, and low blood flow rate were independently associated with inadequate dialysis. Regular assessment of dialysis adequacy, preferably using spKt/V alongside URR and relevant clinical parameters, may help optimize dialysis delivery and improve the quality of pediatric hemodialysis care.

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