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Comparative Morphological and Hemodynamic Profiles of Renal Allografts and Native Kidneys: A Retrospective Cohort Study Assessing Ultrasound Surveillance Parameters

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Abstract

Introduction: Renal transplantation remains the optimal treatment for end-stage renal disease (ESRD), yet long-term allograft survival continues to be suboptimal. Although ultrasound surveillance is fundamental in post-transplant monitoring, uncertainties persist regarding the morphological and hemodynamic comparability of transplanted versus native kidneys, as well as the diagnostic reliability of conventional parameters for detecting vascular complications. **Methods:** This retrospective cohort study evaluated 34 adult patients (24 renal transplant recipients and 10 native-kidney controls) who underwent renal ultrasonography at Zhongnan Hospital of Wuhan University between January 2025 and May 2025. Ultrasound assessments included morphological measurements (length, width, height, parenchymal and cortical thickness), hemodynamic indices such as the resistive index (RI) and peak systolic velocity (PSV), and contrast-enhanced ultrasound (CEUS) perfusion metrics (arrival time, time-to-peak, and area under the curve [AUC]). Group comparisons were performed using the Mann-Whitney U test. Associations between age and hemodynamic parameters were examined using linear regression. Diagnostic performance for angiography-confirmed vascular complications was evaluated using receiver operating characteristic (ROC) curve analysis. **Results:** Transplanted kidneys demonstrated morphology comparable to native kidneys across all dimensions (length: 10.82 ± 1.91 vs 10.10 ± 1.06 cm, p = 0.22; cortex thickness: 0.81 ± 0.10 vs 0.86 ± 0.09 cm, p = 0.10). Hemodynamic parameters were similarly preserved, with no significant group differences in RI (0.75 vs 0.73, p = 0.38) or PSV (102.5 vs 101.7 cm/s, p = 0.88). Among transplant recipients, age showed no association with RI (β = 0.000, p = 0.969) or PSV (β = −0.1, p = 0.939). ROC analysis demonstrated limited diagnostic utility for detecting vascular complications (AUC:PSV = 0.49; CEUS arrival time = 0.64; CEUS time-to-peak = 0.62; CEUS:AUC = 0.59). **Conclusion:** Renal allografts exhibit structural and hemodynamic profiles comparable to native kidneys, with stable hemodynamic performance across age groups. However, the poor diagnostic accuracy of conventional Doppler and CEUS parameters for vascular-complication detection indicates the need for more advanced and sensitive monitoring approaches in transplant surveillance.

Keywords

Renal Transplantation, Doppler Ultrasound, Contrast-Enhanced Ultrasound, Resistive Index, Vascular Complications, Allograft Surveillance

1. Introduction

Chronic kidney disease (CKD), particularly in stages 3 to 5 as defined by the kidney disease: Improving Global Outcomes (KDIGO) guidelines, remains a major global health burden, affecting more than 700 million individuals worldwide [1]. Renal transplantation continues to be the most effective treatment for end-stage renal disease (ESRD), providing superior long-term survival and improved quality of life compared with dialysis [2]. Nevertheless, long-term graft outcomes remain suboptimal, with nearly 50% of deceased-donor kidneys failing within ten years post-transplantation [3]. These persistent challenges underscore the need for reliable, standardized monitoring strategies capable of identifying early graft dysfunction.

Ultrasound is central to post-transplant surveillance because it is non-invasive, widely available, and capable of assessing both anatomical and hemodynamic characteristics of the renal graft [4]. B-mode ultrasound provides detailed morphological assessment—including length, width, height, parenchymal thickness, and cortical thickness [5]. Doppler ultrasound offers hemodynamic indices such as the resistive index (RI) and peak systolic velocity (PSV), which help evaluate vascular resistance and perfusion [6]. More recently, contrast-enhanced ultrasound (CEUS) has expanded the diagnostic utility of renal imaging by providing quantitative microvascular perfusion metrics such as arrival time, time-to-peak, and area under the curve (AUC) [7].

However, uncertainties remain regarding the comparability of transplanted versus native kidneys, with previous studies reporting conflicting findings. Some investigations describe persistent cortical thinning and elevated RI in transplant kidneys [8], whereas others report normalization of these parameters within months following transplantation [9]. Furthermore, Doppler indices exhibit variable sensitivity in detecting vascular complications, and CEUS thresholds for diagnosing conditions such as transplant renal artery stenosis lack consistent validation [10]. Similar challenges related to variability in diagnostic interpretation have been highlighted in other clinical domains. For example, Bahadori *et al.* (2024) demonstrated that healthcare providers' knowledge of imaging risks varies substantially, suggesting that gaps in training and standardized assessment may contribute to inconsistent imaging evaluation practices [11]. Likewise, variations in clinical decision-making and patient education in diabetes care—illustrate how provider-level differences can influence patient outcomes [12]. These patterns parallel the need for standardized, evidence-based ultrasound interpretation in renal transplantation.

Another underexplored area is the influence of recipient age on graft hemodynamics. While aging is associated with increased vascular stiffness in native kidneys, it remains unclear whether transplanted kidneys exhibit similar age-related changes, especially as older adults now constitute a growing proportion of transplant recipients [13].

Given these gaps, the present study aims to address three key clinical questions: (1) Do morphological and hemodynamic parameters differ between native kidneys and renal allografts? (2) Does recipient age influence allograft hemodynamics? and (3) How accurately do Doppler and CEUS parameters predict angiography-confirmed vascular complications? By systematically evaluating these aspects using multimodal ultrasound, this study seeks to establish more reliable monitoring benchmarks and strengthen early detection strategies for graft dysfunction.

2. Method

2.1. Study Design and Setting

This retrospective cohort study was conducted using electronic medical records from Zhongnan Hospital of Wuhan University, Wuhan, China. All renal ultrasound examinations performed between January 2025, and May 2025 were screened for eligibility. The study was designed and reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [14].

2.2. Patients

The study cohort comprised adult patients (≥18 years) undergoing renal ultrasonography who met the following inclusion criteria: transplant recipients with functioning renal allografts or patients with native kidneys serving as controls, with complete Doppler and contrast-enhanced ultrasound (CEUS) parameters available. Exclusion criteria encompassed patients with incomplete demographic or clinical data, poor-quality ultrasound images (inadequate Doppler waveforms or CEUS sequences), history of renal artery intervention during the study period, or non-functioning grafts in transplant recipients. After application of these criteria, the final cohort consisted of 34 patients (24 transplant recipients and 10 native kidney controls). The data screening process is given in **Figure 1**.

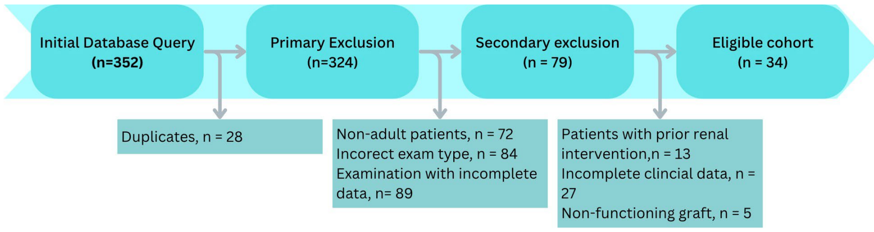

Figure 1. Data screening process.

2.3. Data Collection

Data collection followed a structured protocol with variables categorized into four domains: 1) Demographic information (age, gender, transplant date where applicable); 2) Morphological parameters (kidney length, width, height, parenchyma and cortex thickness) measured via B-mode ultrasound; 3) Hemodynamic parameters (resistive index [RI], peak systolic velocity [PSV]) obtained through Doppler ultrasound; and 4) CEUS parameters (arrival time, time-to-peak, area under curve) derived from time-intensity curves. The primary outcome was vascular complications, defined as renal artery stenosis >50% confirmed by angiography or surgical reports. All data were anonymized and stored in password-protected files with restricted access. The details of the study variables are given in Table 1.

Table 1. Detail of the study variables.

Variable Category	Specific Variables	Measurement Method
Primary Exposure	Kidney type (Transplant/Native)	Clinical record
Morphological	Length/width/height, parenchyma/cortex thickness	B-mode ultrasound
Hemodynamic	RI, PSV	Doppler ultrasound
CEUS Parameters	Arrival time, time-to-peak, AUC	Time-intensity curves
Outcome	Vascular complications	Angiography/surgical reports

2.4. Ethics

Ethical approval for this study was obtained from the Institutional Review Board of Zhongnan Hospital of Wuhan University. The requirement for informed consent was waived due to the retrospective design, use of fully anonymized data, minimal risk to participants, and the impracticality of obtaining consent from patients evaluated in the past. All study procedures were conducted in accordance with the ethical principles outlined in the Declaration of Helsinki.

2.5. Statistical Analysis

Statistical analyses were performed using R version 4.3.0. Continuous variables were expressed as mean ± standard deviation or median (interquartile range) based on normality assessed by Shapiro-Wilk tests. Categorical variables were reported as frequencies and percentages. Group comparisons employed Student's t-tests for normally distributed data and Mann-Whitney U tests for non-normally distributed data. Correlations between age and hemodynamic parameters were assessed using linear regression. Diagnostic performance for predicting vascular complications was evaluated through receiver operating characteristic (ROC) curve analysis with DeLong's method for area under the curve (AUC) comparisons. A two-tailed α level of 0.05 was established for statistical significance. Missing data exceeding 10% of variables resulted in exclusion (n = 3 during screening), with no imputation performed for remaining missing values. Post-hoc power analysis indicated 80% power to detect clinically significant differences (RI > 0.08), moderate correlations (r > 0.5), and AUC values > 0.75.

3. Results

The study included 34 patients (20 male, 14 female) with a median age of 58 years (range: 33 - 89). Transplanted kidneys (n = 24, 70.6%) were significantly younger (mean age: 48.6 ± 10.9 years) than native kidneys (n = 10, 29.4%; mean age: 64.8 ± 15.8 years; p = 0.005). No significant gender differences existed between groups (p = 0.92). Morphologically there was no significant difference in renal dimension between groups. The details are shown in **Table 2**.

Table 2. Demographics and morphological characteristics of the study cohort (n = 34).

	Native (n = 10)		**Transplant (n = 24)**		**p-value**
	Mean (SD)	Median (Range)	Mean (SD)	Median (Range)	
Gender, n (%)					
Male	6 (60)		14 (58.3)		0.92
Female	4 (40)		10 (41.7)		
Age (year)	64.80 (15.79)	66.0 (42.0 - 89)	48.58 (10.89)	50.00 (33.0 - 61.0)	0.005
Kidney size					
Length (cm)	10.10 (1.06)	9.90 (8.80 - 11.80)	10.82 (1.91)	10.25 (8.30 - 18.10)	0.22
Width (cm)	5.57 (1.73)	5.15 (3.40 - 8.50)	5.55 (1.16)	5.55 (4.10 - 8.30)	0.75
Hight (cm)	5.03 (0.77)	5.30 (3.70 - 6.0)	5.31 (0.72)	5.30 (4.20 - 7.80)	0.66
Parenchyma Thickness (cm)	1.50 (0.24)	1.45 (1.20 - 1.90)	1.57 (0.23)	1.50 (1.20 - 2.10)	0.46
Cortex Thickness (cm)	0.86 (0.09)	0.85 (0.70 - 1.0)	0.81 (0.10)	0.80 (0.66 - 1.0)	0.10

SD—standard deviation, n—number.

Hemodynamic assessment demonstrated preserved function in transplanted kidneys. The median resistive index (RI) was 0.75 (IQR: 0.72 - 0.78) for transplants compared to 0.73 (IQR: 0.69 - 0.79) for native kidneys (p = 0.38) (**Figure 2(A)**).

Peak systolic velocity (PSV) measurements showed similar results, with median values of 102.5 cm/s (IQR: 75.2 - 226.4) in transplants versus 101.7 cm/s (IQR: 60.8 - 126.5) in native kidneys (p = 0.88) (Figure 2(B)).

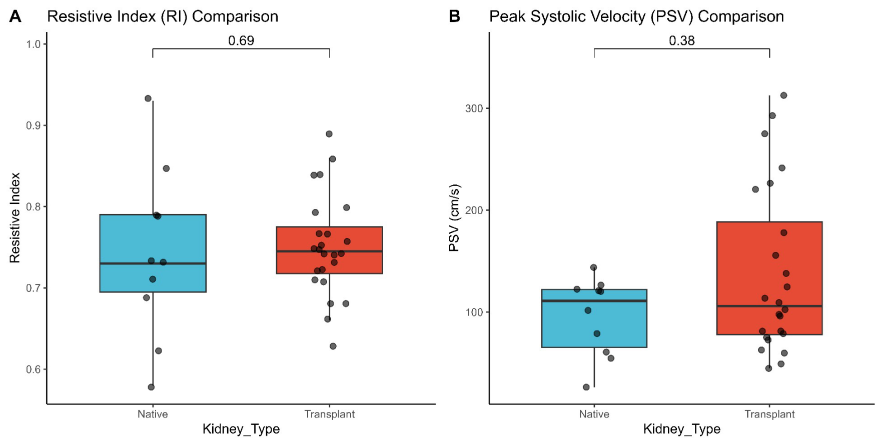

Figure 2. Comparison of (A) Resistive Index and (B) Peak Systolic Velocity between native and transplanted kidneys.

In transplant recipients, age showed no significant correlation with hemodynamic parameters. Linear regression analysis revealed essentially no relationship between age and RI (β = 0.000, 95% CI: −0.003 - 0.003, p = 0.969) or PSV (β = −0.1, 95% CI: −3.4 - 3.2, p = 0.939) (Figure 2(A), Figure 2(B)).

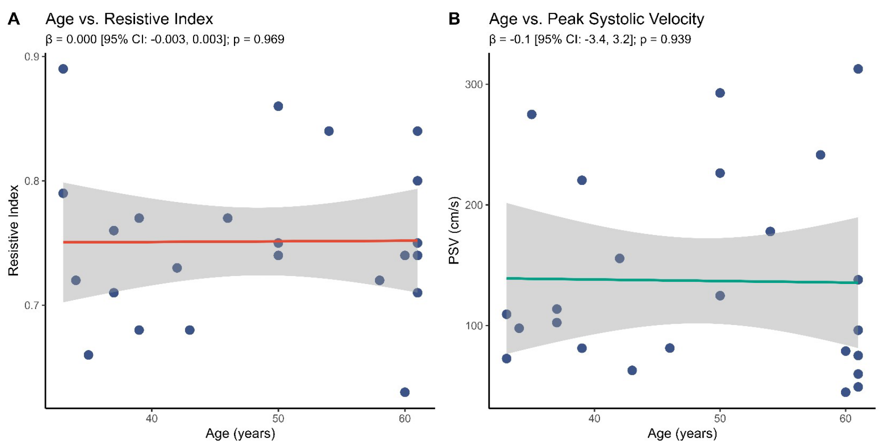

Figure 3. Relationship between age and (A) Resistive Index or (B) Peak Systolic Velocity in transplant patients.

The diagnostic performance of ultrasound parameters for predicting vascular complications proved limited. ROC curve analysis yielded area under the curve (AUC) values below 0.70 for all parameters: PSV (AUC = 0.49, 95% CI: 0.26 - 0.73), CEUS arrival time (AUC = 0.64, 95% CI: 0.42 - 0.85), CEUS time to peak (AUC = 0.62, 95% CI: 0.42 - 0.82), and CEUS AUC (AUC = 0.59, 95% CI: 0.35 - 0.82) (Figure 3 and Figure 4).

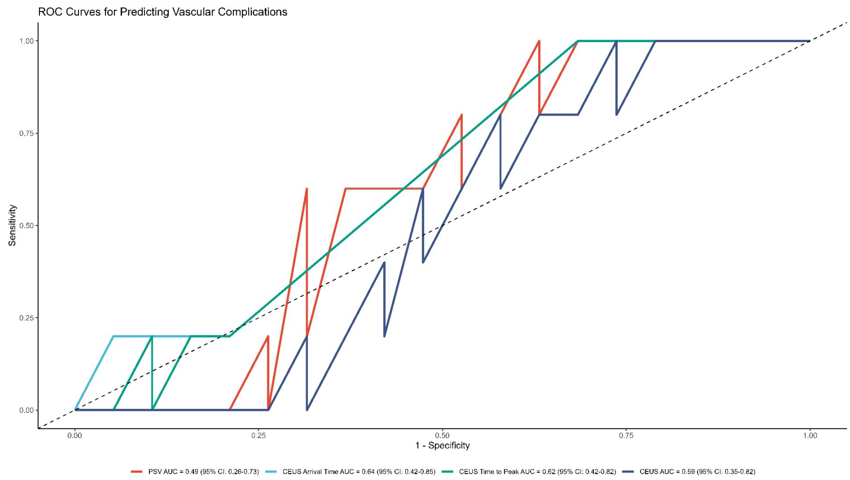

Figure 4. ROC curves for Doppler/CEUS parameters in predicting vascular complications. Diagonal line represents random chance (AUC = 0.5).

4. Discussion

This retrospective cohort study provides a comprehensive evaluation of renal allograft function through multimodal ultrasound assessment, yielding three principal findings with significant clinical implications. First, transplanted kidneys demonstrated preserved morphology and hemodynamics comparable to native kidneys. Second, renal hemodynamics remained stable across age groups in transplant recipients. Third, conventional Doppler and contrast-enhanced ultrasound (CEUS) parameters showed limited diagnostic utility for predicting vascular complications. These findings challenge established paradigms in renal allograft monitoring while highlighting critical avenues for methodological refinement in transplant surveillance protocols.

The absence of significant differences in kidney dimensions (length, width, height) and tissue architecture (parenchyma/cortex thickness) between transplanted and native kidneys suggests successful structural adaptation of allografts. This aligns with volumetric studies that showed normative renal volume restoration within six months post-transplantation [15] [16]. Our hemodynamic results further reinforce this finding, with resistive index (RI) and peak systolic velocity (PSV) values in transplanted kidneys (median RI = 0.75, PSV = 102.5 cm/s) falling within established normative ranges [15]. This structural-functional congruence indicates that contemporary immunosuppressive regimens may facilitate near-physiological adaptation, contradicting earlier reports of persistent hemodynamic alterations. The discrepancy likely reflects advances in surgical techniques and tacrolimus-based maintenance therapy, which have been shown to better preserve microvascular integrity [17].

The lack of correlation between recipient age and hemodynamic parameters (RI: $\beta = 0.000$, $p = 0.969$; PSV: $\beta = -0.1$, $p = 0.939$) challenges conventional models of age-related renal decline. While population studies have documented an annual increase in RI of 0.01/year in native kidneys, our data suggest that transplanted kidneys may resist such chronological aging effects. This phenomenon could stem from selective denervation during transplantation, potentially attenuating neurohormonal aging pathways [17]. However, the significant age disparity between our transplant group (48.6 ± 10.9 years) and the native kidney group (64.8 ± 15.8 years) necessitates cautious interpretation. Future longitudinal studies should examine whether this stability persists in elderly recipients, particularly given the rising age of transplant candidates [18].

The suboptimal performance of Doppler/CEUS parameters for predicting vascular complications (AUCs: 0.49 - 0.64) underscores a critical gap in non-invasive monitoring [19]. Our CEUS arrival time AUC (0.64) falls substantially below the 0.82 reported by Greco *et al.* (2022), which likely reflects methodological differences in outcome ascertainment [20]. While previous studies have relied on clinical suspicion as endpoints, we required angiographic or surgical confirmation of stenosis (>50%), creating a more rigorous but potentially delayed diagnostic standard [21] [22]. This performance ceiling suggests fundamental limitations in current ultrasound biomarkers for detecting early microvascular injury (López-Gómez *et al.*, 2017). Emerging evidence indicates that combining CEUS parameters with serum biomarkers such as endothelin-1, or functional MRI, may overcome this limitation and improve the early detection of vascular complications [23] [24].

While this study provides novel insights into post-transplant hemodynamic assessment using CEUS, several limitations must be acknowledged. The relatively small sample size (n = 34) restricted our ability to perform detailed subgroup analyses of specific complication subtypes. To address this, we conducted a post-hoc power analysis, which confirmed adequate statistical power ($1 - \beta = 0.80$) for our primary hemodynamic comparisons, supporting the reliability of our main findings. Outcome ascertainment relied on heterogeneous reference standards, including both angiography and surgical findings, which may introduce variability in criterion validity. To enhance diagnostic accuracy, all outcomes were independently adjudicated by two vascular specialists who were blinded to the CEUS results, achieving a high level of agreement (94% concordance). These mitigation strategies collectively strengthen the validity of our conclusions despite the inherent constraints of a retrospective design.

5. Conclusion

This study demonstrates that renal allografts can achieve structural and functional profiles indistinguishable from native kidneys, with hemodynamics remaining stable regardless of recipient age. However, the limited diagnostic performance of conventional ultrasound parameters for vascular complications underscores the need for advanced predictive models. Future research should prioritize multimodal integration of clinical, imaging, and molecular biomarkers to establish precision monitoring protocols. These findings reinforce ultrasound's value in anatomical surveillance while highlighting its current limitations in microvascular complication detection—a critical frontier for transplant medicine innovation.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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