ESC European Society of Cardiology

European Heart Journal - Imaging Methods and Practice (2024) **2**, qyae027
https://doi.org/10.1093/ehjimp/qyae027

ORIGINAL ARTICLE

Left atrial and ventricular deformation: alterations and predictive value of echocardiography parameters in end-stage renal disease patients after kidney transplantation

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Received 28 December 2023; accepted after revision 26 March 2024; online publish-ahead-of-print 18 April 2024

Abstract

Aims

End-stage renal disease (ESRD) patients are prone to alterations in cardiac haemodynamics specifically on the left ventricle (LV) and left atrial (LA) functions usually due to factors like uraemia, fluid overload, and inflammation. While studies on LV function in ESRD exist, research on LA function is limited. Successful kidney transplant (KTx) is believed to reverse pathological cardiac remodelling, and monitoring changes in cardiac strain before and after transplantation may guide pre- and post-transplant care. This study has two main objectives: to investigate alterations in LA and LV strain and other echocardiographic parameters after KTx and to identify independent factors predicting impaired strain parameters post-KTx.

Methods and results

We conducted a prospective cohort study of 49 ESRD patients who underwent KTx. Echocardiography was performed at baseline and at 3 months after KTx. LV end-diastolic volume, LV end-systolic volume, LV end-diastolic diameter, LV ejection fraction (LVEF), E/e′, maximum LA volume index (LAVi), LV global longitudinal strain (LVGLS), and all LA strain values, including booster (LASb), conduit (LAScd), and reservoir (LASr), improved significantly after KTx ($P < 0.05$). Regarding independent predictors of impaired LA and LV strains, pre-KTx values of LVEF, LAVi, and NT-proBNP were associated with LVGLS impairment after KTx; pre-KTx values of LAVi and LVEF were associated with LASr impairment after KTx.

Conclusion

The present study provided valuable evidence on the effects of KTx on uraemic cardiomyopathy demonstrated by LA strain and LV strain improvements and indicated pre-KTx LVEF and LAVi as significant independent predictors of LVGLS and LASr impairment after KTx.

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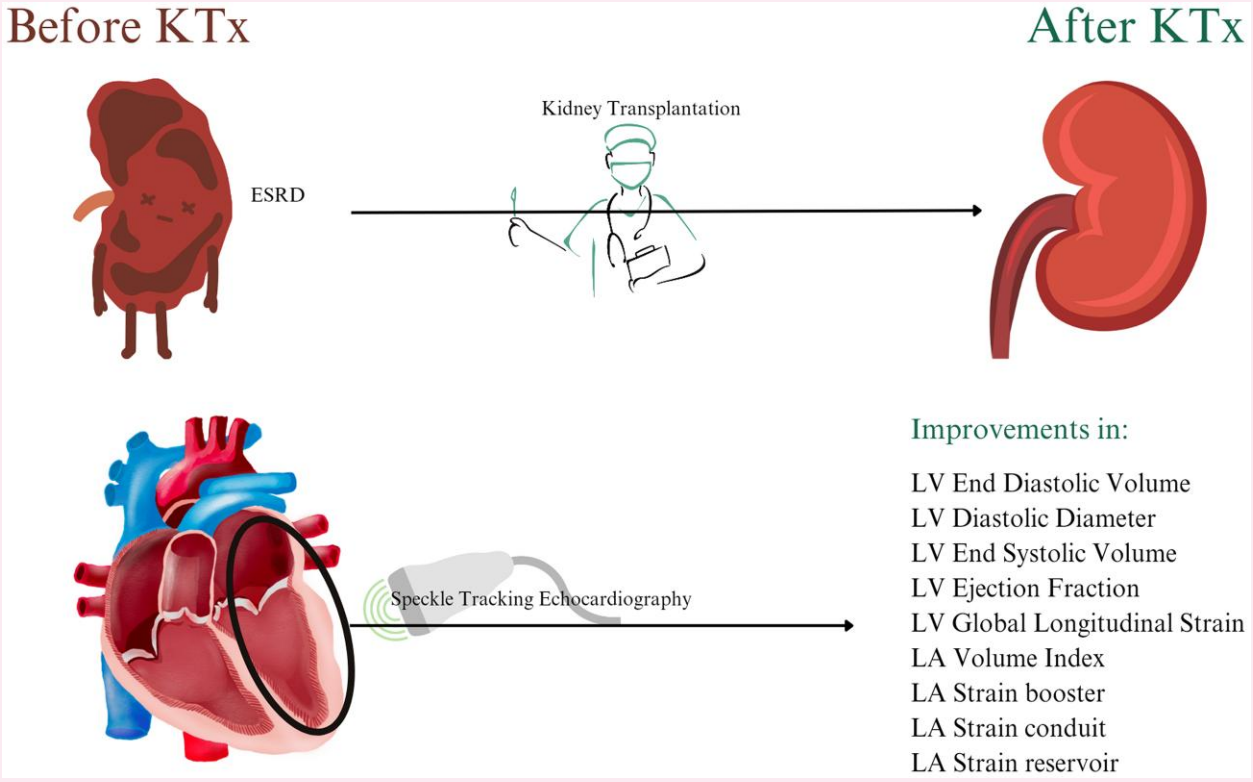
Graphical Abstract



Keywords kidney transplantation • speckle tracking echocardiography • left ventricular global longitudinal strain • left atrial strain • strain • transthoracic echocardiography

Introduction

Patients with end-stage renal disease (ESRD) face a higher risk of cardiovascular mortality.[1] This higher risk is due to not only the higher prevalence of conventional risk factors but also by uraemia, electrolyte abnormalities, and haemodynamic factors[1,2] These factors have been found to impact the left ventricle (LV) resulting in structural and functional changes in the heart.[1,3]

LV hypertrophy (LVH) is a frequent finding in patients with ESRD and is directly linked to uraemia through fluid and pressure overload and activation of the renin–angiotensin–aldosterone system, in addition to chronic inflammation.[4,5] Considering the effects of uraemia on LV, an exploration of the left atrial (LA) function is also necessary; however, studies on LA function in ESRD patients are limited. Uraemia may also be connected with alterations in LA function, which is believed to be due to increased LV filling pressures, diastolic dysfunction, and pulmonary hypertension.[6,7] Thus, it is essential to monitor the structure and function of the LV and LA in ESRD patients to highlight and manage these alterations and prevent further cardiovascular problems. LA structure and function are dependable indications of diastolic function and sensitive predictors of cardiovascular outcomes.[8,9] Conventionally, these parameters were evaluated by chamber volumes in two-dimensional echocardiography. However, strain analysis, a novel sensitive technique for functional analysis of the heart chambers, has recently developed which enables medical professionals to identify malfunctions early. The novelty and increased sensitivity of strain parameters make them valuable tools for detecting subtle changes in cardiac mechanics.[10,11] By evaluating strain parameters, we aimed not only to assess the impact of kidney transplantation on cardiac function but also to determine if strain analysis contributes unique and valuable information compared with conventional echocardiographic parameters.

Successful kidney transplantation (KTx) may reverse pathological cardiac remodelling by reducing uraemic and haemodynamic abnormalities.[6,12] LA function screening may identify patients who may benefit new pharmacologic and non-pharmacologic therapies. It is uncertain, however, whether LA malfunction is reversible after successful KTx.

By monitoring changes in left cardiac strain before and after transplantation, physicians can estimate the impact of KTx on cardiac function and adjust pre- and post-transplant care based on those patients who would benefit from KTx the most. Post-KTx LA and LV strains and their predictive value for other structural and functional parameters have not been thoroughly investigated.

Cardiac and renal systems have a complex interplay and both affect each other with various mechanisms. Moreover, some immunosuppressive medications that are used in the recipients may cause worsening of hypertension, hyperlipidaemia, diabetes mellitus, cardiac toxicity, or heart failure.[13,14] Thus, due to the fact that these patients are at heightened risk of cardiovascular diseases, prediction of cardiac dysfunction for further risk stratification and close cardiac monitoring of high-risk patients is of important essence.

Although some recent studies have investigated LV function in ESRD patients, the studies on LA function in ESRD patients are limited; therefore, LA function has yet to be well characterized. Therefore, this study aimed mainly at two objectives: first, to investigate if LA and LV strain and other structural and functional echocardiographic parameters are significantly altered after KTx and, second, to identify independent factors in predicting these strain parameters after KTx.

Methods

Study population and design

This was a single-centre prospective longitudinal study of adult KTx candidate ESRD patients referred to Shahid Modarres Hospital, Tehran, Iran, between March 2022 and March 2023. Patients were included if the following criteria were fulfilled: (i) over 18 years old, (ii) consent to participate, and (iii) candidate for an allograft KTx from a nonrelative individual. Patients were excluded if any of the following criteria existed: (i) significant heart valve comorbidities (e.g. severe mitral regurgitation), (ii) coronary artery disease, (iii) pacemaker, (iv) KTx from a cadaver, (v) arrhythmia, and (vi) unsuccessful or non-functional KTx based on nephrologist consultation. All patients underwent KTx and received a standard medical regimen post-transplant. Baseline characteristics were recorded at enrolment and presented in *Table 1*.

Echocardiography and speckle tracking

All echocardiographic data were gathered by transthoracic echocardiography (TTE) using an EPIQ CVx 3D cardiology ultrasound system (Philips, USA) and X5–1 probe (Philips, USA) at 60–80 frames per s and 1.6–3.2 Hz by one experienced echocardiography specialist. All echocardiography images were stored to undergo offline analysis blindly at another time by TomTec Auto Strain Image Arena version 4.6 software.

Initially, each patient's echocardiographic study was performed 24 h prior to the KTx. All patients were subsequently referred for follow-up echocardiography 3 months after the KTx or later if not possible at the time of the due date (up to 3.5 months). Three-dimensional LV ejection fraction (3D-LVEF), LV end-diastolic diameter (LVEDD), LV end-diastolic volume (LVEDV), and LV end-systolic volume (LVESV) were measured and recorded using the dynamic heart model of TOMTEC software (*Figure 1*). Other echocardiographic parameters, such as posterior wall thickness (PWT), diastolic interventricular septum thickness (IVSd), and LV stroke volume (LVSV), were also measured. Additionally, the maximum LA volume index (LAVi) and LA volume were calculated using the biplane [apical two-chamber (A2C) and apical four-chamber (A4C)] view in the end-diastolic and end-systolic phases, respectively. The peak velocity of early mitral valve inflow (E) and peak early diastolic velocity of the mitral annulus (e′), in addition to the E/e′ ratio, were obtained using Doppler imaging and tissue Doppler imaging (TDI-PW), respectively, for the assessment of diastolic function (*Figure 2*).

LA strain was recorded and measured offline in both A2C and A4C views at three scales of reservoir (LASr), conduit (LAScd), and booster (LASb or LASct) using autostrain LA at the end-diastolic reference point (*Figure 3*). For each scale, the mean of both A2C and A4C strains in each patient was recorded. Furthermore, imaging records were optimized and modified using tracking revision under the supervision of an echocardiography specialist. A4C, three-chamber (A3C), and A2C views were recorded and analysed using the autostrain LV function to measure each patient's LV global longitudinal strain (LVGLS) values. Then, the average value of LV strain in all views was recorded for data analysis (*Figure 4*). All imaging protocols were as per the American Society of Echocardiography (ASE) guidelines.[15,16]

Patients were also stratified into normal or impaired groups based on their strain analyses. Patients with LVGLS $\leq -16\%$ were recognized as the normal LVGLS group,[17] whereas normal values for atrial strains were defined as LASr $\geq 39\%$ and LAScd $\geq 23\%$.[18]

Moreover, to evaluate inter- and intra-rater variability as an indicator of method reproducibility, 29 randomly selected patients underwent speckle tracking echocardiography (STE) to measure the LVGLS after KTx by the first assessor and another cardiologist. Both cardiologists were blind to the previous echocardiographic measurements of patients.

Statistics

Descriptive statistics were utilized to summarize the data, including frequencies and percentages for categorical variables and means and standard deviations for continuous variables. The normality of data distribution and equality of variances were assessed by Kolmogorov–Smirnov's and Levene's tests, respectively. The inter-rater and intra-rater reliability of measurements were evaluated via the intraclass correlation coefficient (ICC), employing a two-way fixed model of absolute agreement. In accordance with the recommendation by Koo and Li,[19] ICC values were interpreted as follows: ICC < 0.5 showing poor correlation, $0.5 \leq$ ICC < 0.75 indicating moderate correlation, $0.75 \leq$ ICC < 0.9 representing good correlation, and ICC ≥ 0.9 signifying excellent correlation. Paired samples *t*-test or Wilcoxon test (in case of non-normally distributed data) were conducted to compare continuous variables. Spearman or Pearson correlation coefficients were calculated to evaluate correlations between changes (Δ) in echocardiographic measurements. Additionally, logistic regression analysis was employed to identify pre-KTx

Table 1 Baseline characteristics

Variable		Frequency (percent)	Variable	Mean ± SD
Gender	Male	31 (63.3)	Age (years)	40.76 ± 11.63
	Female	18 (36.7)	Hb (g/dL)	11.31 ± 1.57
HTN (yes/no)		34 (69.4)	Calcium (mg/dL)	8.69 ± 0.66
DM (yes/no)		10 (20.4)	NT-proBNP (pg/mL)	461.32 ± 219.53
AVF (yes/no)		28 (57.1)	Dialysis duration (months)	24.82 ± 21.3
FH of IHD (yes/no)		5 (10.2)	Height (m)	1.74 ± 0.07
Smoking (yes/no)		9 (18.4)	BMI (kg/m^2)	24.71 ± 1.78
Cause of ESRD	HTN	20 (40.8)		
	DM	10 (20.4)		
	Glomerulonephritis	5 (10.2)		
	Hereditary causes	3 (6.1)		
	Urological causes	3 (6.1)		
	Unknown	8 (16.3)		

HTN, hypertension; DM, diabetes mellitus; AVF, arteriovenous fistula; FH of IHD, family history of ischaemic heart disease; ESRD, end-stage renal disease; Hb, haemoglobin; BMI, body mass index.

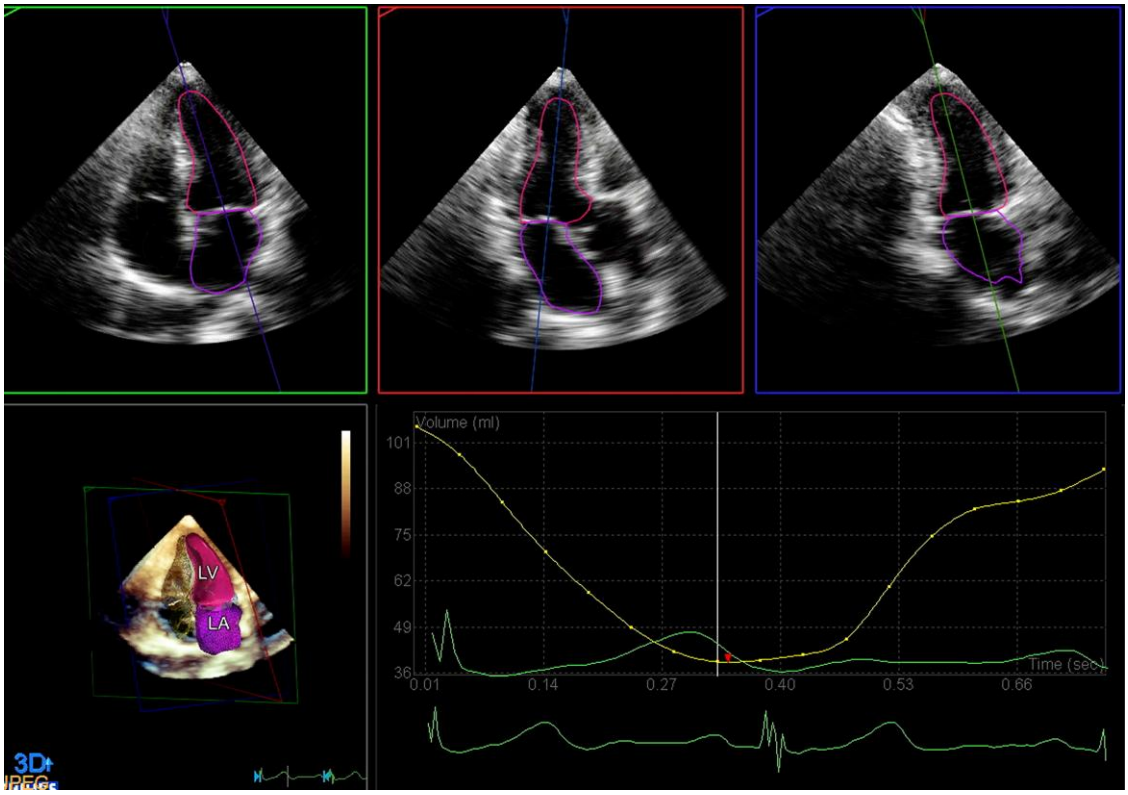


Figure 1 Philips automated 3D dynamic heart model. The software traces the end-diastolic and end-systolic LV endocardial borders, allowing for precise volume calculations and EF. Additionally, the system boasts operator-correction capabilities to address any potential errors.

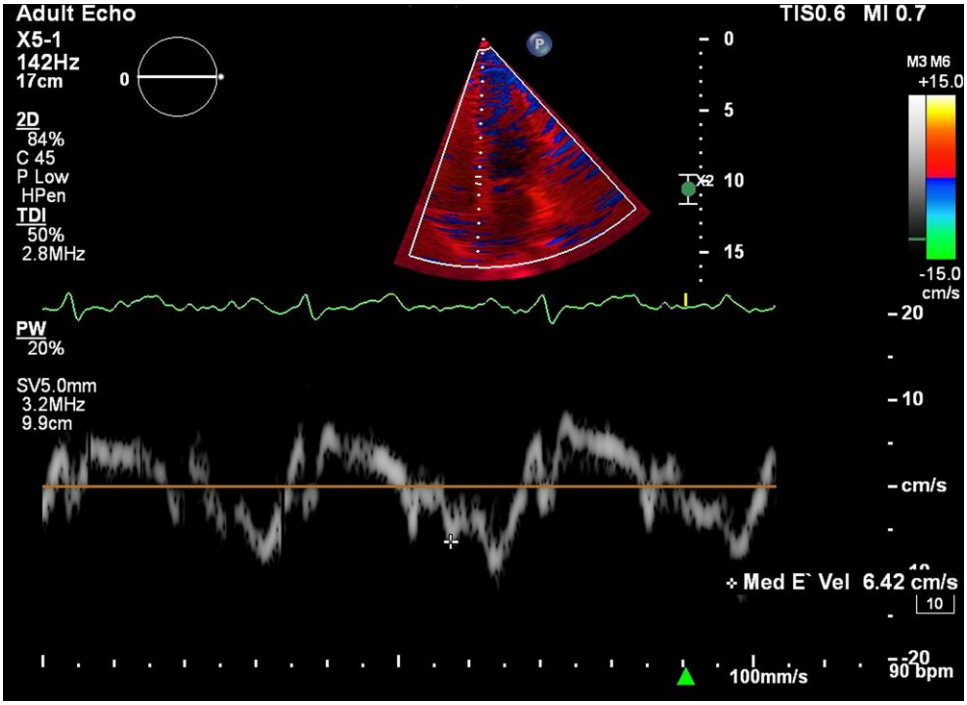


Figure 2 Exploring diastolic function: Tissue Doppler echo in four-chamber view reveals the septal E′ velocity, providing valuable insights into the heart's relaxation phase. E′ is 6.42 cm/s in this patient.

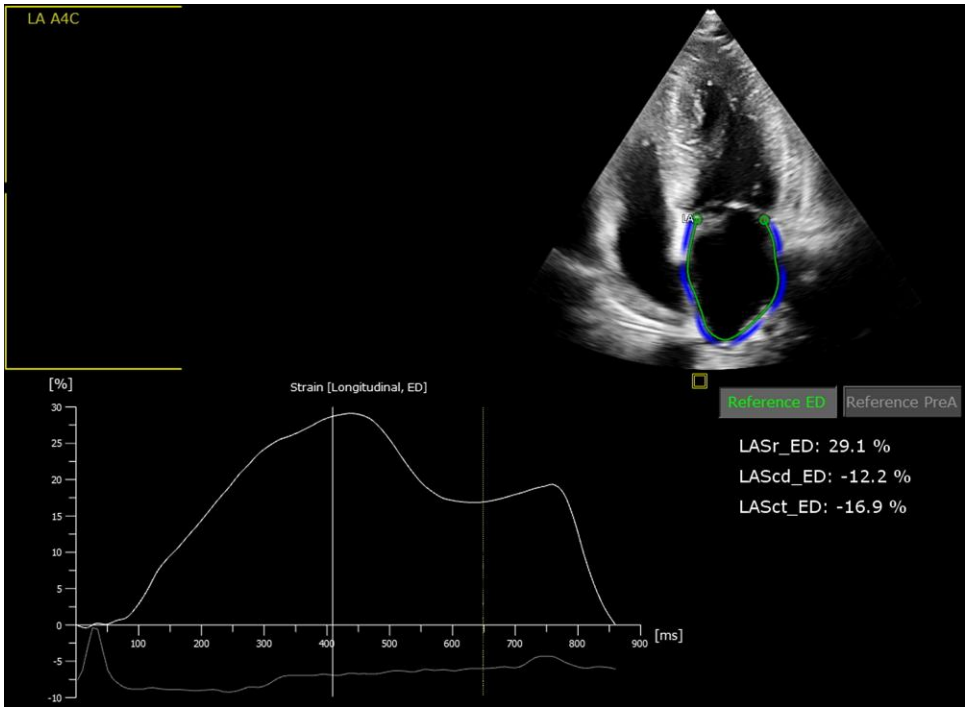


Figure 3 Unveiling LA strain; discovering the three components of LA strain with zero point at end of diastole. LA strain was measured using STE in both the four-chamber and two-chamber LA focus views. The zero point was set at the end of the diastole, and the software tracked the speckles (tiny myocardial tissue markers) throughout the cardiac cycle to quantify the strain percentage in each phase. Three separate values were reported for each phase, representing the LA strain during the reservoir, conduit, and contractile phases, respectively. The unit of strain is expressed in percentage (%), with more negative values indicating better LA function in each phase.

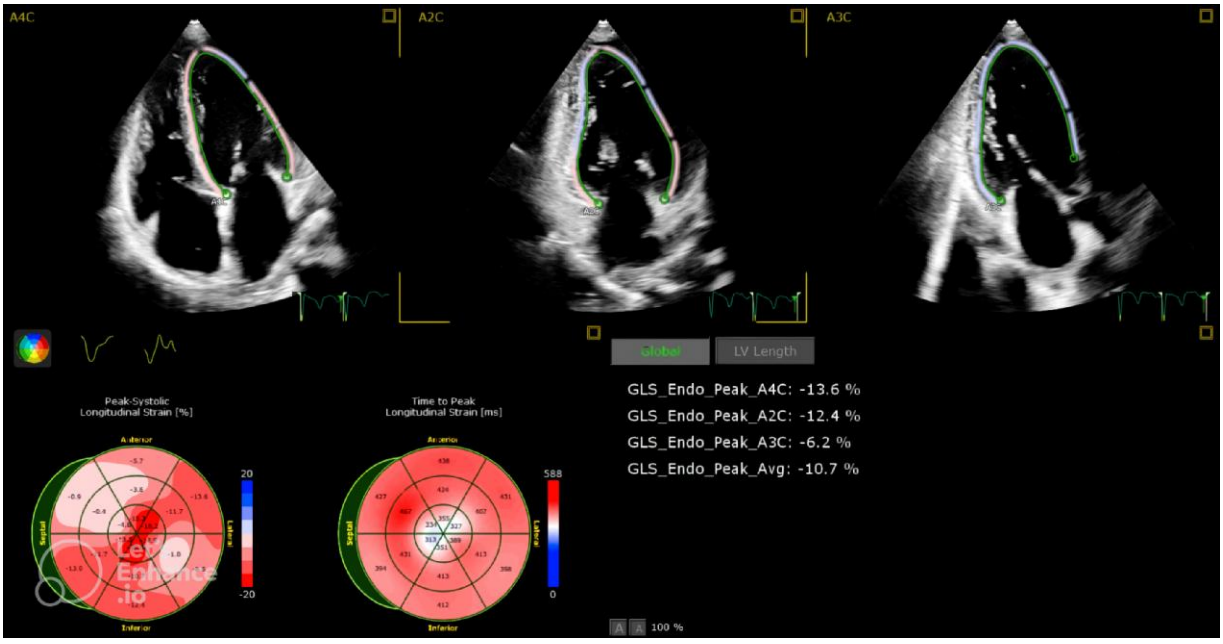


Figure 4 Assessing LVGLS with STE: a comprehensive view from four-chamber, three-chamber, and two-chamber views. This image captures LVGLS analysis using Philips vendor's advanced speckle tracking technology in an ESRD patient before KTx. The speckle tracking software precisely analyses myocardial tissue movement based on speckle patterns within the cardiac images obtained from four-chamber, three-chamber, and two-chamber views. By tracking these speckles throughout the cardiac cycle, it quantifies LV strain during systole and diastole. The LV strain values are expressed as negative percentages (%) in figure.

Table 2 Comparison of the study echocardiographic variables before and after KTx

Variable	Before KTx (mean ± SD)	After KTx (mean ± SD)	*P*-value
Ventricular parameters			
LVEDV	131.36 ± 44.04	123.99 ± 40.89	<0.001
LVESV	60.46 ± 25.94	55.41 ± 23.11	<0.001
LVEDD	54.46 ± 9.42	53.12 ± 9.2	<0.001
LVSV	70.9 ± 21.67	69.97 ± 20.79	0.717
3D-LVEF	56.13 ± 6.73	57.36 ± 8.78	0.045
LVGLS	−18.37 ± 3.77	−20.22 ± 3.23	<0.001
IVSd	11.14 ± 2.33	10.83 ± 1.33	0.074
e′	10.54 ± 14.48	8.01 ± 6.46	0.973
E/e′	11.84 ± 1.83	10.61 ± 2.82	<0.001
Atrial parameters			
LAVi	14.24 ± 5.47	12.27 ± 4.92	0.003
LA volume	27.34 ± 11.45	23.57 ± 10.14	0.003
LASr	31.26 ± 8.09	35.54 ± 7.97	<0.001
LAScd	16.7 ± 6	18.23 ± 6.11	0.002
LASb	14.42 ± 5.93	17.33 ± 5.42	0.002

LVEDV, left ventricle end-diastolic volume; LVESV, left ventricle end-systolic volume; LVEDD, left ventricle end-diastolic diameter; LVSV, left ventricle stroke volume; LVEF, left ventricle ejection fraction; LVGLS, left ventricle global longitudinal strain; IVSd, interventricular septum thickness; LAVi, left atrial volume index; LASr, left atrial reservoir strain; LAScd, left atrial conduit strain; LASb, left atrial booster strain.

Table 3 Correlation analysis of changes in study variable with ΔLVGLS and Δ3D-LVEF pre- and post-KTx

Variable	Δ3D-LVEF		ΔLVGLS	
	r	*P*-value	*r*	*P*-value
ΔLVEDV	−0.069	0.640	−0.090	0.536
ΔLVESV	−0.554	<0.001	0.159	0.275
ΔLVGLS	−0.338	0.018	NA	NA
ΔLVSV	0.476	0.001	−0.430	0.002
Δ3D-LVEF	NA	NA	−0.338	0.018
ΔLAVi	−0.077	0.597	0.073	0.618
ΔLASr	0.186	0.201	−0.095	0.515
ΔLAScd	0.129	0.378	−0.227	0.117
ΔLASb	0.299	0.037	−0.270	0.06

KTx, kidney transplant; LVEDV, left ventricle end-diastolic volume; LVESV, left ventricle end-systolic volume; LVGLS, left ventricle global longitudinal strain; LVSV, left ventricle stroke volume; LVEF, left ventricle ejection fraction; LAVi, left atrial volume index; LASr, left atrial reservoir strain; LAScd, left atrial conduit strain; LASb, left atrial booster strain; NA, not applicable.

factors associated with post-KTx impairment of LVGLS, LASr, and LAScd. Statistically significant variables in the univariate analysis were included in the multivariate analysis. To avoid multicollinearity between variables in the multivariate model, the variance inflation factor (VIF) was calculated, and variables with a VIF larger than 10 were excluded from the final multivariate analysis. IBM SPSS Statistics for Windows version 24 (Armonk, NY, USA) was utilized, with statistical significance defined as *P*-values < 0.05.

Ethics

The Research Ethics Committee of Shahid Beheshti University of Medical Sciences reviewed and approved this study (ethics code: IR.SBMU.retech.1401.291). Informed consent was obtained from each patient for experimentation after providing adequate information regarding the aims and methods of the present research.

Results

Baseline characteristics

Of the 49 study participants, 31 (63.3%) were male. Thirty-four patients (69.4%) had a history of hypertension, and 10 patients (20.4%) had a history of diabetes. Patients were between 18 and 65 years old, with a mean age of 40.76 ± 11.63 years and a mean dialysis duration of 24.82 ± 21.3 months. Additionally, HTN (40.8%), DM (20.4%), and glomerulonephritis (10.2%) were identified as the main causes of ESRD among our study participants. The baseline characteristics of the patients are summarized in *Table 1*.

Echocardiographic variables before vs. after KTx

Our findings showed that E/e′, LVEDV, LVESV, LVEDD, LA volume, and LAVi decreased significantly after the intervention, while other variables, including LASr, LASb, LAScd, LVGLS, and 3D-LVEF, significantly improved. Meanwhile, only e′, IVSd, and LVSV did not differ significantly before and after KTx ($P > 0.05$) (*Table 2*).

Correlation analysis of changes in study variables pre- and post-KTx

Table 3 demonstrates correlations between changes in study variable values with ΔLVGLS and Δ3D-LVEF. Strong and moderate correlations were found between ΔLVGLS and Δ3D-LVEF ($r = -0.33$, $P = 0.018$) and ΔLVSV ($r = -0.43$, $P = 0.002$), in addition to between Δ3D-LVEF and ΔLVEDV ($r = -0.55$, $P < 0.001$), ΔLVSV ($r = 0.47$, $P = 0.001$), and ΔLASb ($r = 0.29$, $P = 0.037$) (*Table 3*) (*Figure 5*).

Regarding the correlation between changes in study variables and changes in LA strain, ΔLASr, ΔLA volume, ΔLVSV, and ΔLVEDV were significantly correlated with ΔLAVi; ΔLASb, ΔLAVi, and ΔLA volume were significantly correlated with ΔLASr; and ΔLASr was significantly correlated with ΔLASb. ΔLAScd was significantly correlated with ΔLA volume, while no significant correlations with either LV strain or LA strain parameters were observed (*Table 4*).

Factors associated with LVGLS impairment after kidney transplantation

In this investigation, univariate regression analysis demonstrated significant associations between pre-KTx measures and post-KTx LVGLS impairment, including LVEF (OR: 0.84), LAVi (OR: 1.24), E/e′ (OR: 1.70), LVEDV (OR: 1.03), LVESV (OR: 1.05), and NT-proBNP (OR: 1.01). Subsequent multivariate regression analysis confirmed the association between pre-KTx values of LVEF (OR: 0.85), LAVi (OR: 1.24), and NT-proBNP (OR: 1.01) with LVGLS impairment after KTx (*Table 5*).

Factors associated with LASr impairment after kidney transplantation

Utilizing univariate regression analysis, we identified associations between pre-KTx LAVi (OR: 1.27), LVEF (OR: 0.76), e′ (OR: 0.34),

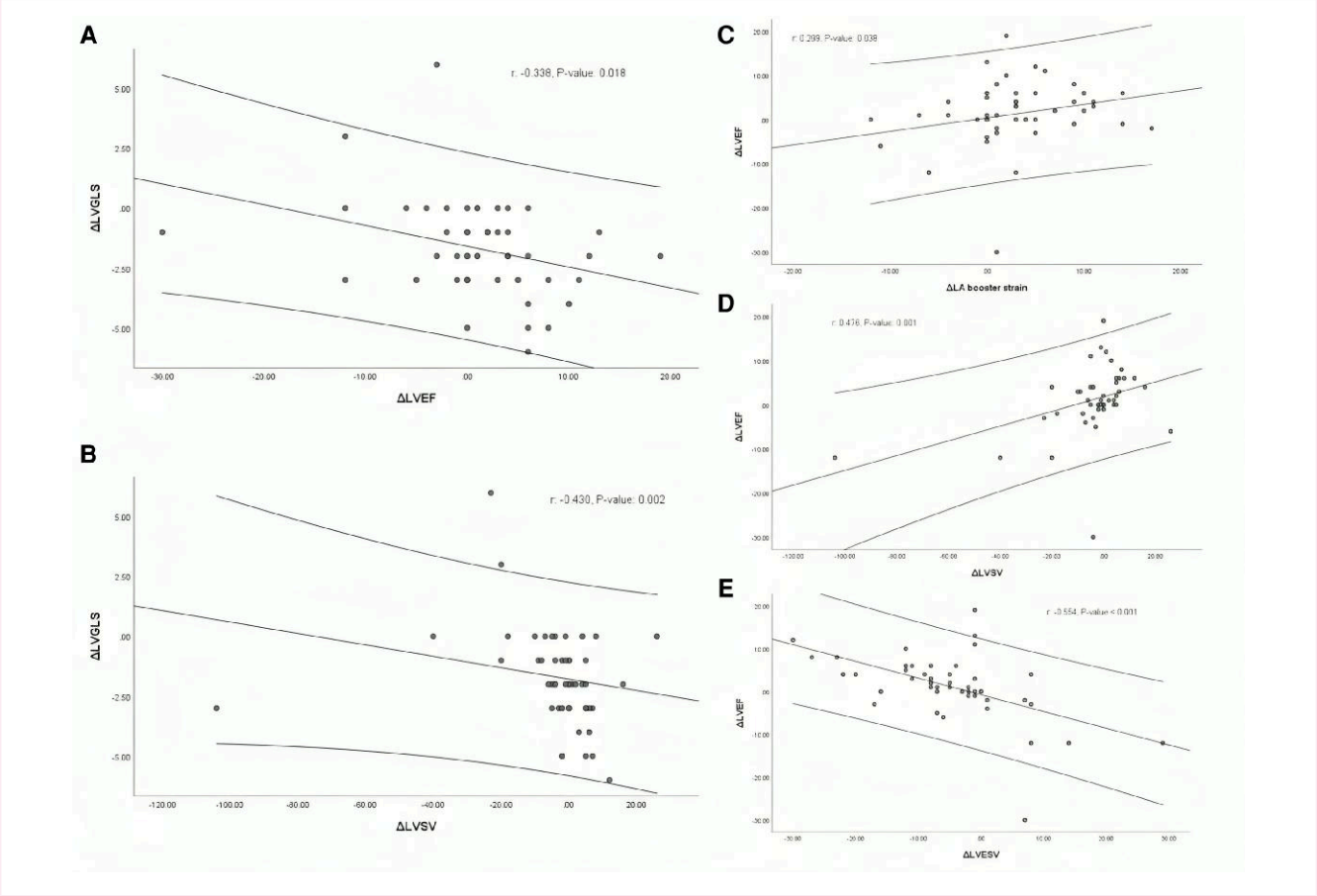


Figure 5 Correlation diagram of significant correlations. Correlations between changes in LVGLS and (*A*) Δ3D-LVEF and (*B*) ΔLVSV, in addition to changes in 3D-LVEF and (*C*) ΔLASb, (*D*) ΔLVSV, and (*E*) ΔLVESV.

Table 4 Correlation analysis of changes in study variable with ΔLASr, ΔLAScd, ΔLASb, and ΔLAVi pre- and post-KTx

Variables	ΔLASr		ΔLAScd		ΔLASb		ΔLAVi	
	r	*P*-value	*r*	*P*-value	*r*	*P*-value	*r*	*P*-value
ΔLASr	NA	NA	0.130	0.375	0.621	<0.001	−0.478	0.001
ΔLAScd	0.130	0.375	NA	NA	−0.115	0.431	−0.118	0.420
ΔLASb	0.621	<0.001	−0.115	0.431	NA	NA	−0.207	0.153
ΔLAVi	−0.478	<0.001	−0.118	0.421	−0.207	0.153	NA	NA
ΔLA volume	−0.337	0.018	−0.323	0.024	−0.197	0.174	0.997	<0.001
ΔLVSV	−0.039	0.789	0.165	0.258	−0.032	0.828	0.145	0.321
ΔLVGLS	−0.219	0.131	−0.239	0.098	−0.263	0.068	0.003	0.983
ΔLVEDV	−0.153	0.295	0.102	0.487	−0.219	0.131	0.409	0.004
ΔLVESV	−0.110	0.450	−0.133	0.361	−0.195	0.180	−0.009	0.950
Δ3D-LVEF	0.185	0.203	0.159	0.274	0.248	0.086	0.082	0.577

LASr, left atrial reservoir strain; LAScd, left atrial conduit strain; LASb, left atrial booster strain; LAVi, left atrial volume index; KTx, kidney transplant; LVSV, left ventricle stroke volume; LVGLS, left ventricle global longitudinal strain; LVEDV, left ventricle end-diastolic volume; LVESV, left ventricle end-systolic volume; LVEF, left ventricle ejection fraction; NA, not applicable.

Table 5 Association between demographics and pre-KTx echocardiographic measurements with post-KTx LVGLS impairment

Pre-KTx measurements	Univariable analysis				Multivariable analysis				
	OR	95% CI		*P*-value	OR	95% CI		*P*-value	VIF
		Upper	Lower			Lower	Upper		
LVEF	0.846	0.733	0.975	0.021	0.857	0.743	0.989	0.037	4.6
LAVi	1.244	1.053	1.469	0.010	1.244	1.002	1.545	0.048	1.8
NT-proBNP	1.011	1.003	1.018	0.005	1.011	1.001	1.021	0.035	1.8
E/e′	1.700	1.018	2.839	0.042	1.150	0.582	2.272	0.688	1.2
LVEDV	1.031	1.009	1.054	0.005[a]					24.7
LVESV	1.057	1.018	1.097	0.003[a]					37.0
Age	1.061	0.981	1.146	0.137					
Hb	0.843	0.520	1.367	0.488					
Ca	2.247	0.617	8.188	0.220					
Male gender	4.958	0.557	44.103	0.151					
Hypertension	3.630	0.405	12.512	0.249					
Diabetes mellitus	2.914	0.562	15.120	0.203					
AVF	2.591	0.467	14.382	0.276					
FH of IHD	4.222	0.580	30.752	0.155					
Smoking	1.619	0.269	9.748	0.599					
BMI	1.436	0.908	2.269	0.121					
e′	1.015	0.973	1.060	0.490					
Fractional shortening	0.928	0.792	1.088	0.356					
LVEDD	1.116	0.979	1.273	0.110					
S′	0.801	0.485	1.321	0.384					

KTx, kidney transplant; LVGLS, left ventricle global longitudinal strain; OR, odds ratio; CI, confidence interval; VIF, variance inflation factor; LVEF, left ventricle ejection fraction; LAVi, left atrial volume index; LVEDV, left ventricle end-diastolic volume; LVESV, left ventricle end-systolic volume; Hb, haemoglobin; Ca, calcium; AVF, arteriovenous fistula; FH of IHD, family history of ischaemic heart disease; BMI, body mass index; LVEDD, left ventricle end-diastolic diameter.
[a]LVEDV and LVESV were excluded from the multivariable analysis due to multicollinearity.

LVEDV (OR: 1.03), LVESV (OR: 1.08), and NT-proBNP (OR: 1.001) and post-KTx LASr impairment. In the multivariate regression analysis, only the association between post-KTx LASr impairment and pre-KTx values of LAVi (OR: 1.13) and LVEF (OR: 0.64) remained statistically significant (*Table 6*).

Factors associated with LAScd impairment after kidney transplantation

Univariate regression analysis demonstrated a significant association between post-KTx LAScd impairment and pre-KTx measurements of LAVi (OR: 1.67), LVEDV (OR: 1.02), and LVESV (OR: 1.08). Owing to potential collinearity between LVEDV and LVESV, these variables were excluded from the multivariate model, precluding a multivariate analysis (*Table 7*).

Inter- and intra-rater reliability of measurements

Our evaluation showed excellent inter-rater (ICC 0.98; 95% CI 0.97–0.99) and intra-rater (ICC 0.98; 95% CI 0.96–0.99) agreement regarding LVGLS measurements of patients after KTx. Similar robust agreements were observed for LASr (inter-rater ICC 0.97, 95% CI 0.94–0.99, and intra-rater ICC 0.98, 95% CI 0.94–0.99) and LAScd (inter-rater ICC 0.96, 95% CI 0.90–0.99, and intra-rater ICC 0.99, 95% CI 0.95–1.00) measurements in KTx patients.

Discussion

The present study aimed to investigate changes in LA and LV strain by STE before and after KTx. Our findings showed that all LV and LA strain values improved significantly after KTx. In addition, we observed significant improvements in other echocardiographic variables after KTx, including LVEDV, LVESV, LVEDD, 3D-LVEF, LAVi, LA volume, and E/e′. However, IVSd modification post-KTx had borderline statistical significance, which was expected because septal thickness changes at a slower rate compared with other echocardiographic parameters, and more time is required to observe significant modifications.

Previous studies have indicated that in pathological conditions, LA strain values show greater sensitivity and tend to deviate from normal earlier than volumetric parameters or other traditional measures of LV filling pressure such as E′; however, in our study, we observed significant improvements in all measured LA volumetric and functional values following KTx in ESRD patients. These findings suggest that in ESRD patients, the previous associations between LA strain values and disease conditions may not fully apply. Further research is needed to elucidate the implications of these improvements and their relevance in the context of patient outcomes.[20]

In our study, we identified independent predictors of impaired LA and LV strains after KTx. 3D-LVEF, LAVi, and NT-proBNP were found to be independent predictors of impaired post-KTx LVGLS. 3D-LVEF and LAVi were independent predictors of impaired post-KTx LASr. Lastly, only LAVi was identified as the independent predictor of impaired post-KTx LAScd. Our findings suggest that for settings where

Table 6 Association between demographics and pre-KTx echocardiographic measurements with post-KTx LASr impairment

Pre-KTx measurements	Univariable analysis				Multivariable analysis				
	OR	95% CI		*P*-value	OR	95% CI		*P*-value	VIF
		Lower	Upper			Lower	Upper		
LAVi	1.273	1.054	1.538	0.012	1.130	1.009	1.503	0.037	2.0
LVEF	0.768	0.618	0.956	0.018	0.643	0.436	0.949	0.026	4.7
e′	0.347	0.151	0.797	0.013	0.993	0.941	1.049	0.808	1.1
NT-proBNP	1.007	1.001	1.014	0.015	1.001	0.993	1.006	0.910	1.9
LVEDV	1.036	1.009	1.064	0.009[a]					25.9
LVESV	1.086	1.023	1.153	0.007[a]					39.1
Age	1.046	0.956	1.144	0.331					
Hb	0.696	0.387	1.251	0.226					
Ca	2.063	0.578	7.362	0.265					
Male gender	2.769	0.285	26.864	0.380					
Hypertension	1.867	0.191	18.273	0.592					
Diabetes mellitus	1.969	0.213	18.163	0.550					
AVF	3.333	0.344	32.272	0.299					
FH of IHD	9.111	0.973	17.363	0.053					
Smoking	3.524	0.495	15.095	0.209					
BMI	1.189	0.703	2.010	0.518					
E/e′	1.499	0.875	2.569	0.140					
Fractional shortening	0.857	0.706	1.042	0.121					
LVEDD	1.167	0.989	1.377	0.067					
S′	0.507	0.251	1.027	0.059					

KTx, kidney transplant; LASr, left atrial reservoir strain; OR, odds ratio; CI, confidence interval; VIF, variance inflation factor; LAVi, left atrial volume index; LVEF, left ventricle ejection fraction; LVEDV, left ventricle end-diastolic volume; LVESV, left ventricle end-systolic volume; Hb, haemoglobin; Ca, calcium; AVF, arteriovenous fistula; FH of IHD, family history of ischaemic heart disease; BMI, body mass index; LVEDD, left ventricle end-diastolic diameter.
[a]LVEDV and LVESV were excluded from the multivariable analysis due to multicollinearity.

strain analysis is not available, LAVi and LVEF can offer valuable insights as predictor variables.

The clinical impact of our findings stem from our interest in understanding the impact of KTx on cardiac function, particularly in less resourceful areas where advanced methodologies such as STE may not always be readily available for follow-up assessments. While STE offers valuable insights into myocardial mechanics, its adoption may be limited by factors such as the availability of professional operators and advanced imaging devices. Therefore, as one of our objectives, the team decided to determine pre-operation factors that can be independently associated with post-operation strain measurements. By such analysing, we sought to identify predictors of impaired haemodynamics post-KTx from factors of the pre-KTx echocardiography. In this approach, we can identify patients that are more probable to have impaired haemodynamics on the first echo (before KTx). This approach aligns with the practical realities faced by clinicians in resource-constrained settings, where the rational distribution of resources is paramount.

This section compares our findings with the results of previously published studies. Zapolski *et al.*[21] studied KTx candidates to evaluate changes in their LA indices after KTx. Their results were consistent with our findings, showing that LAVi was significantly reduced after KTx. However, regarding LV volumetric indices, their results demonstrated that although both LVEDV and LVESV were reduced 3 months after KTx, only the reduction in LVEDV was statistically significant. In the present study, we also followed up with our patients for 3 months, and our findings showed that both LVEDV and LVESV were significantly reduced after KTx. Additionally, inconsistent with our results, Zapolski *et al.* showed that LVEF does not significantly differ between pre- and post-KTx. In the present study, LVEF was calculated using a 3D dynamic heart model, and the difference was statistically significant between pre- and post-KTx.

Yildirim *et al.*[22] recently published a study comparing LA strain parameters between 75 KTx patients and 75 age- and gender-matched haemodialysis patients. After adjustments for blood pressure, haemoglobin, and LVEF, they found significant differences regarding LASr and LAScd between the two study groups; however, LASb was not significantly different. Additionally, they found significant positive weak correlations between LVEF, LASr, and LASb ($r = 0.262$ and 0.309, respectively) but not with LAScd. In the present study, we found significant improvements in all echocardiographic strain parameters, including LVGLS, LASr, LASb, and LAScd, after KTx; however, inconsistent with the results of Yildrim *et al.*, we did not find a significant correlation between LVEF and LASr and LAScd. Nevertheless, consistent with their results, we found significant moderate positive correlations between changes in LASb and changes in LVEF ($r = 0.299$).

Lassen *et al.*[23] followed up with 33 patients 6 months after KTx and observed the effects of this intervention on the LVGLS, E/e′, and E/e′ strain rate using STE. Their findings demonstrated reversed cardiac remodelling after KTx observed as decreased LV filling pressure assessed by E/e′ strain rate; however, their results did not show any significant modifications in E/e′ following KTx (9.9 vs. 10.3). Nevertheless, our results showed significant changes in E/e′ after KTx. This could be partially due to differences in underlying conditions of our patients.

Table 7 Association between demographics and pre-KTx echocardiographic measurements with post-KTx LAScd impairment

Pre-KTx measurements	Univariable analysis				Multivariable analysis				
	OR	95% CI		*P*-value	OR	95% CI		*P*-value	VIF
		Lower	Upper			Lower	Upper		
LAVi	1.679	1.016	2.776	0.043	1.679	1.016	2.776	0.043	1.7
LVEDV	1.028	1.001	1.057	0.050[a]					19.1
LVESV	1.080	1.011	1.153	0.022[a]					18.3
LVEF	0.690	0.472	1.009	0.056					
NT-proBNP	1.019	0.999	1.040	0.065					
Age	1.051	0.936	1.180	0.397					
Hb	0.816	0.395	1.686	0.582					
Ca	3.028	0.420	21.810	0.271					
Male gender	1.286	0.108	15.237	0.842					
Hypertension	1.143	0.096	13.664	0.916					
Diabetes mellitus	2.056	0.167	25.257	0.573					
AVF	1.538	0.130	18.192	0.733					
FH of IHD	2.667	0.984	14.187	0.414					
Smoking	1.431	0.886	14.011	0.262					
BMI	1.102	0.570	2.130	0.772					
E/e′	1.452	0.765	2.757	0.254					
e′	0.334	0.104	1.080	0.067					
Fractional shortening	0.779	0.601	1.009	0.059					
LVEDD	1.189	0.966	1.465	0.103					
S′	0.432	0.179	1.041	0.061					

KTx, kidney transplant; LAScd, left atrial conduit strain; OR, odds ratio; CI, confidence interval; VIF, variance inflation factor; LAVi, left atrial volume index; LVEDV, left ventricle end-diastolic volume; LVESV, left ventricle end-systolic volume; LVEF, left ventricle ejection fraction; Hb, haemoglobin; Ca, calcium; AVF, arteriovenous fistula; FH of IHD, family history of ischaemic heart disease; BMI, body mass index; LVEDD, left ventricle end-diastolic diameter.
[a]LVEDV and LVESV were excluded from the multivariable analysis due to multicollinearity.

Gong *et al.*[24] followed up with 79 ESRD patients, including 39 KTx and 40 patients on haemodialysis. Their study showed that LV strain significantly improved 12 months after KTx, whereas no significant change was observed in the haemodialysis group. Additionally, LV strain improvement was parallel to LVEF improvement, and LV strain was significantly correlated with LVEDV and LVESV. Consistent with their findings, our results showed a significant correlation between LV strain and 3D-LVEF; however, we found no significant correlation between LV strain and LVESV or LVEDV.

Hamidi *et al.*[25] assessed 25 ESRD patients 1 month after KTx with STE and found significant improvements in LVEF and four-chamber LV strain; however, the changes in E/e′, e′, and two-chamber LV strain were not statistically significant. The present study found significant improvements in 3D-LVEF and LV strain after KTx. In the present study, we reported the mean LV strain values measured by apical four-chamber, three-chamber, and two-chamber views, while Hamidi *et al.* reported LV strain values measured in apical two-chamber and four-chamber views separately.

Limitations

The study of the parameters only at a single time point restricts our ability to capture the dynamic trajectories of these measurements over time. Additionally, we acknowledge that our study does not delve into the direct clinical impact of the observed alterations in measurements. While these limitations are inherent to the design of our study, we believe they provide valuable insights for future research directions. Consideration of long-term follow-up and incorporation of clinical outcomes in subsequent studies would be essential to address these limitations and provide a more holistic understanding of the implications of our findings.

Conclusion

LVEDV, LVESV, LVEDD, 3D-LVEF, LVGLS, E/e′, LAVi, LA volume, and all LA strain values, including LASb, LAScd, and LASr, improved significantly after KTx. Our findings suggest that in the settings of patient recovery, strain values may not be more sensitive than simple volumetric parameters. Thus, where strain analysis is not available, other obtainable echocardiographic parameters, such as LA volume and IVSd, could provide valuable insights as predictor variables.

Author contributions

A.B., F.B., M.K., and T.A. designed the study. A.M. worked on proper statistical analysis of the data. T.A., S.P.S.M.S., and E.P. collected the data. E.G. wrote the first draft of the manuscript. All authors contributed to the preparation of the final draft and reviewed the manuscript.

Consent

Informed consent was obtained from each patient for experimentation after providing adequate information regarding the aims and methods of the present research.

Funding

None declared.

Conflict of interest: None declared.

Data availability

Data will be shared on reasonable request to the corresponding author.

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