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Assessment of Left and Right Atrial Functions in Children on Regular Hemodialysis: A Speckle Tracking Imaging Study

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ABSTRACT

Background: For children with chronic renal disease, cardiovascular disease is the predominant cause of morbidity and mortality. Clinically evident illness is often preceded by early, mild cardiac dysfunction. Two-dimensional speckle tracking echocardiography (2D-STE), which measures left and right atrial mechanics, provides sensitive indicators of subclinical cardiac damage.

Aim: This study aimed to employ 2D speckle tracking imaging to evaluate the left and right atrial functions of pediatric chronic kidney disease (CKD) patients receiving regular hemodialysis.

Patients and methods: 22 children with end-stage renal disease (ESRD) receiving regular hemodialysis and 22 age- and sex-matched healthy controls participated in this case-control study. All participants received clinical evaluation, 2D-STE, tissue Doppler imaging and conventional echocardiography. LA and RA reservoir, conduit and contractile strain characteristics were measured. The relationship between atrial strain, ventricular wall thickness and dialysis duration was also examined.

Results: Hemodialysis patients had significantly lower weight, height, and BSA compared with controls ($p<0.001$). Conventional echocardiography showed increased interventricular septal and posterior wall thickness with normal LV systolic function. LA strain was significantly impaired in all phases in both 4- and 2-chamber views ($p<0.001$), with the 2-chamber view more sensitive. RA strain was reduced, especially in reservoir and contractile phases ($p<0.001$). Duration of dialysis and ventricular hypertrophy were negatively correlated with LA reservoir and conduit strain ($p<0.05$), suggesting progressive atrial dysfunction. **Conclusion:** 2D Speckle tracking echocardiography is a very sensitive & noninvasive tool for early detection of subtle cardiac diastolic impairment in pediatric CKD patients on dialysis by detecting significant reduction in LA & RA strain values.

Keywords: Chronic kidney disease, Hemodialysis, Pediatric cardiology, Left atrial strain, Right atrial strain, Speckle tracking echocardiography, Subclinical diastolic dysfunction.

INTRODUCTION

Cardiovascular disease (CVD) is highly prevalent among children living with chronic kidney disease (CKD), and the two conditions are tightly interconnected. CKD markedly worsens both the immediate and long-term outlook of patients with cardiovascular disorders. Conversely, CVD significantly aggravates the clinical course of renal patients, to the extent that individuals with CKD are statistically more likely to die from a cardiovascular event than to progress to dialysis. In fact, nearly 39% of deaths among those undergoing dialysis are attributed to cardiovascular causes (1).

Numerous studies have emphasized the prognostic impact of several cardiac abnormalities in CKD, including left ventricular (LV) hypertrophy, systolic impairment of both LV and right ventricle (RV), mechanical dyssynchrony and abnormalities in LV diastolic performance (2, 3).

Yet, despite the recognized burden of cardiac disease in CKD, current risk-prediction tools tend to underestimate cardiovascular risk in this population. This has driven the search for newer, more sensitive markers capable of identifying CKD patients at heightened risk of adverse cardiac outcomes. One such emerging marker is left atrial (LA) strain, which has recently gained recognition as an important diagnostic and prognostic measure in general cardiac populations (4).

Alterations in LA strain occur before classical echocardiographic signs of diastolic dysfunction (DD) become evident. In patients with heart failure with preserved ejection fraction (HFpEF), LA strain particularly the reservoir strain component has shown strong prognostic value and can independently forecast adverse cardiovascular events (5).

Despite technological progress in renal replacement therapy, mortality from cardiovascular causes among children with CKD has shown minimal improvement over the past several decades. Because the left atrium interacts dynamically with the left ventricle and mirrors changes in LV filling pressures, it serves as an especially sensitive marker of diastolic function. Two-dimensional speckle tracking echocardiography (2D-STE) has recently been validated as a dependable technique for evaluating LA strain in a variety of clinical conditions.

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Physiologically, the LA contributes to optimal LV filling through three key functions: Acting as a reservoir during LV systole, functioning as a conduit in early diastole, and operating as a booster pump in late diastole. Importantly, reductions in LA reservoir strain appear earlier than alterations in LA volume, making it a preferred parameter for detecting subclinical diastolic dysfunction [6].

Traditionally, the right side of the heart has received far less attention and has often been labeled the "forgotten heart." Although its importance is increasingly acknowledged, many aspects of right-sided cardiac physiology remain insufficiently understood. Speckle tracking echocardiography (STE) has expanded our ability to study atrial mechanics, including reservoir, conduit, and booster phases of RA function [7, 8].

RV dysfunction is now recognized as a meaningful contributor to morbidity and mortality in numerous conditions. However, the right atrium (RA) is still commonly perceived as a passive chamber, leading to limited understanding of its pathological relevance. Through 2D-STE, RA strain analysis offers a noninvasive window into RA mechanical behavior and may provide valuable insights into right-sided cardiac involvement in disease [9].

The study aimed to assess the phasic functions of both the left and right atria in children maintained on regular hemodialysis, utilizing speckle tracking imaging as a sensitive tool for identifying subtle myocardial and atrial mechanical abnormalities.

PATIENTS AND METHODS

This is a case-control study that was conducted over one year, from July 2024 to July 2025, in the Cardiology Department, Menoufia University Hospital, Egypt. It included children with ESRD on regular hemodialysis referred from the Pediatric Nephrology Unit for echocardiographic assessment. 44 children were enrolled and divided into two groups. Group 1 consisted of 22 children with ESRD on regular hemodialysis and group 2 consisted of 22 age and sex-matched healthy children free from cardiac or systemic diseases.

Inclusion criteria: The hemodialysis group included children between 6 and 18 years of age, with a minimum duration of dialysis of two months and at least three sessions per week, each lasting three to four hours. Patients had to be complication-free regarding acute dialysis-related complications for at least 30 days before inclusion in the study.

Exclusion criteria: Structural or congenital heart disease, overt heart failure, sustained arrhythmias, and diabetes mellitus.

All subjects underwent history taking, thorough clinical examination including full cardiac examination. Duration of dialysis, and regular medications were noted. Body surface area (BSA) was calculated by Mosteller's formula. Blood pressure was measured for all children and compliance with anti-hypertensive therapy was reviewed in the hemodialysis group. In all participants, standard investigations were performed including ECG, conventional echocardiography and 2D speckle tracking echocardiography. Echocardiographic assessment was carried out on a GE Vivid 9 (Horton, Norway) machine. The protocol followed the recommendations of the American Society of Echocardiography.

Systolic performance was evaluated using left ventricular ejection fraction (LV EF) and fractional shortening obtained from M-mode imaging. Diastolic function was assessed with pulsed-wave Doppler by measuring the early transmitral inflow velocity (E), late atrial inflow velocity (A) and calculating the E/A ratio. Tissue Doppler imaging (TDI) was applied at the basal septal mitral annulus to obtain early (E′) and late (A′) diastolic velocities, followed by computation of the E/E′ ratio.

2D-STE was carried out from apical four- and two-chamber views. For each patient, three consecutive cardiac cycles were captured during a breath-hold and stored for later analysis. The endocardial borders of both the LA and RA were manually outlined at end-systole, carefully excluding pulmonary veins, systemic veins, and atrial appendages. The GE Vivid E9 2D strain software then automatically tracked myocardial speckles throughout the cardiac cycle. Using this analysis, strain measurements for the reservoir, conduit, and contractile phases of both atria were obtained (Figure 1).

Figure (1): LA strain of a patient (A) 4C view & (B) 2C view showing decreased values in all phases of LA strain.

Ethical approval: This study was approved by the Cardiology Department, Menoufia University Hospital, Egypt (IRB No: 3/2023PEDI7). Parental consents were obtained. The study adhered to the Helsinki Declaration throughout its execution.

Statistical analysis

Data were analyzed using SPSS version 20. Categorical data were given as frequencies and numerical data as mean ± SD or median (IQR). Normality was tested with Shapiro–Wilk. Group differences were assessed using Chi-square, t-test, or Mann–Whitney. Spearman's correlation evaluated non-parametric associations. Significance was set at $P \leq 0.05$.

RESULTS

Patients and controls were comparable in age and sex ($p > 0.05$), confirming proper matching. Pediatric hemodialysis patients had significantly lower weight, height, and BSA than healthy controls ($p < 0.001$), reflecting the impact of chronic kidney disease and dialysis on growth and somatic development (Table 1).

Table (1): Baseline demographics and anthropometric characteristics

Parameter	Cases (n=22)	Controls (n=22)	Test	p-value
Sex, n (%)			χ^2	
Male	13 (59.1)	11 (50.0)	0.367	0.545
Female	9 (40.9)	11 (50.0)		
Age (years)			t	
Min–Max	7.0–15.0	6.0–14.0	0.798	0.430
Mean ± SD	10.68 ± 1.80	10.18 ± 2.32		
Median (IQR)	10.5 (10–11.5)	10 (8–12)		
Weight (kg)			t	<0.001*
Min–Max	18.2–31.8	23–44	6.667*	
Mean ± SD	23.74 ± 4.20	34.95 ± 6.68		
Median (IQR)	22.5 (20.5–26.0)	37 (29–40)		
Height (cm)			t	<0.001*
Min–Max	106–140	120–158	6.443*	
Mean ± SD	121.6 ± 9.38	141.7 ± 11.22		
Median (IQR)	120 (115–126)	144.5 (134–150)		
BSA (m^2)			t	<0.001*
Min–Max	0.75–1.12	0.88–1.40	6.767*	
Mean ± SD	0.90 ± 0.11	1.18 ± 0.16		
Median (IQR)	0.89 (0.81–0.93)	1.22 (1.05–1.30)		

Hemodialysis patients showed significantly increased interventricular septal thickness and posterior wall thickness (p<0.001) and reduced mitral annular plane systolic excursion (MAPSE) (p<0.05) compared to controls. Tricuspid annular plane systolic excursion (TAPSE) was also significantly lower (p<0.001) in dialysis group. FS was not significantly different, denoting preserved global LV function (Table 2).

Table (2): Conventional 2D Echocardiographic parameters in patients and controls

Parameter	Cases (n=22)	Controls (n=22)	Test	p-value
IVSd (cm)	0.81 ± 0.16	0.63 ± 0.07	U=78.50	<0.001*
IVSd z-score	2.96 ± 1.59	0.03 ± 0.66	U=14.50	<0.001*
LVPWDd (cm)	0.83 ± 0.15	0.68 ± 0.07	U=101.0	0.001*
LVPWDd z-score	2.30 ± 1.24	0.21 ± 0.43	U=29.50	<0.001*
LVEDD (cm)	3.92 ± 0.42	4.09 ± 0.18	t=1.792	0.084
LVESD (cm)	2.50 ± 0.36	2.60 ± 0.16	t=1.187	0.245
EF (%)	65.95 ± 5.74	68.55 ± 1.34	t=2.063*	0.049*
FS (%)	36.09 ± 4.36	36.17 ± 2.35	t=0.077	0.939
MAPSE (cm)	1.06 ± 0.19	1.21 ± 0.17	U=151.0*	0.029*
TAPSE (cm)	1.80 ± 0.23	2.06 ± 0.20	t=4.117*	<0.001*
E (m/s)	0.99 ± 0.20	1.07 ± 0.16	U=188.5	0.202
A (m/s)	0.70 ± 0.18	0.70 ± 0.10	U=208.0	0.410
E/A ratio	1.41 ± 0.28	1.49 ± 0.16	U=180.5	0.141

Mitral annular early diastolic velocity (E) was significantly lower in the patient group (p=0.004), indicating early diastolic impairment. The E/E` ratio and LAVI were slightly higher but not statistically significant, suggesting maintained filling pressures and atrial volume despite subclinical dysfunction (Table 3).

Table (3): Tissue Doppler imaging and left atrial volume index (LAVI)

Parameter	Cases (n=22)	Controls (n=22)	Test	p-value
E` septal (m/s)	0.11 ± 0.03	0.13 ± 0.01	U=120.0*	0.004*
E/E` septal	8.75 ± 1.85	8.03 ± 0.77	U=177.5	0.129
LAVI (ml/m²)	29.17 ± 10.39	25.82 ± 1.62	U=221.5	0.629

LA strain parameters were significantly reduced in patients across reservoir, conduit, and contractile phases in both 4-chamber and 2-chamber views (p<0.001), indicating left atrial deformation and early diastolic dysfunction (Table 4).

Table (4): Left atrial strain analysis (Reservoir, conduit and contractile phases)

LA Strain Parameter	Cases (n=22)	Controls (n=22)	Test	p-value
Reservoir 4C (%)	24.86 ± 7.11	41.41 ± 3.08	t=10.011	<0.001*
Conduit 4C (%)	17.32 ± 5.50	30.23 ± 1.82	t=10.453	<0.001*
Contractile 4C (%)	7.82 ± 3.92	11.32 ± 2.17	U=105.5*	0.001*
Reservoir 2C (%)	21.59 ± 8.01	37.41 ± 3.76	t=8.384	<0.001*
Conduit 2C (%)	14.86 ± 6.67	27.59 ± 2.86	U=27.5*	<0.001*
Contractile 2C (%)	6.91 ± 4.73	9.86 ± 1.86	t=2.727*	0.011*

RA strain values were significantly lower in the patient group, with marked reduction in reservoir and contractile phases (p<0.001) and moderate reduction in the conduit phase (p=0.002). These findings suggest that chronic hemodialysis affects both right and left atrial mechanics, likely due to volume overload and ventricular-atrial interactions (Table 5).

Table (5): Right atrial strain analysis (Reservoir, conduit and contractile phases)

RA Strain Parameter	Cases (n=22)	Controls (n=22)	Test	p-value
Reservoir 4C (%)	25.36 ± 10.34	36.50 ± 2.54	t=4.908*	<0.001*
Conduit 4C (%)	18.32 ± 7.91	24.45 ± 2.04	t=3.525*	0.002*
Contractile 4C (%)	6.82 ± 5.35	12.05 ± 1.84	t=4.333	<0.001*

The dialysis duration demonstrated a clear adverse association with left atrial (LA) deformation indices in the two-chamber view. A highly significant negative correlation was observed between dialysis duration and LA conduit strain (2C%)**,** indicating that longer time on dialysis was strongly linked to impaired LA conduit function ($p < 0.001$). Additionally, a significant negative correlation was found between dialysis duration and LA reservoir strain (2C%)**,** suggesting that prolonged dialysis also compromises LA reservoir performance ($p < 0.05$) **(Figure 2).**

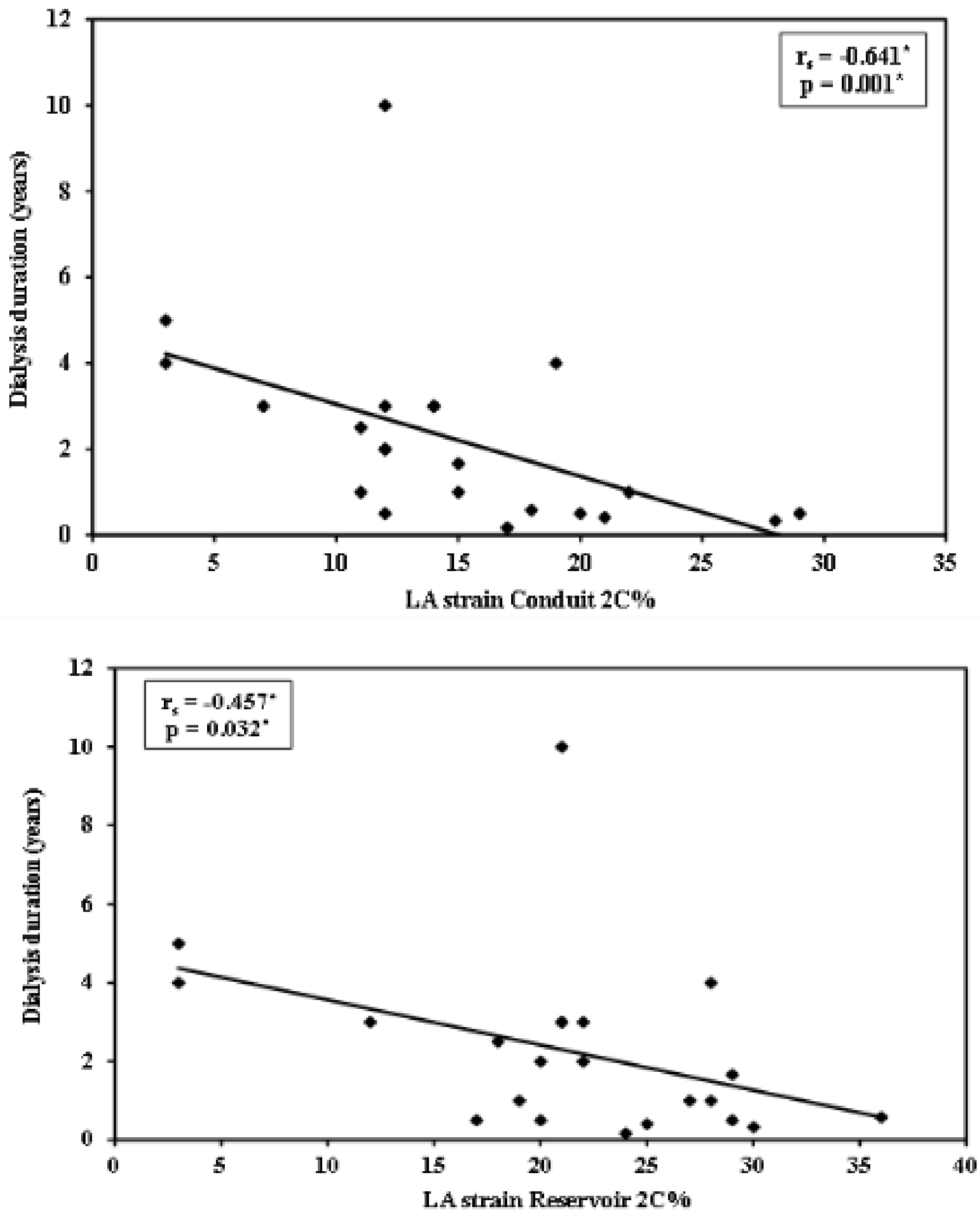

Fig (2): Correlation between dialysis duration and left atrial strain parameters (Conduit 2C% and reservoir 2C%) in the cases group.

The increased left ventricular wall thickness was associated with impaired left atrial deformation. Specifically, IVSd showed a significant negative correlation with LA conduit 2C% strain ($p < 0.05$). Likewise, LVPWDd exhibited a significant inverse relationship with both LA reservoir and conduit 2C% strains ($p < 0.05$). Although IVSd also showed a negative correlation with right atrial strain, this association did not reach statistical significance (Figure 3).

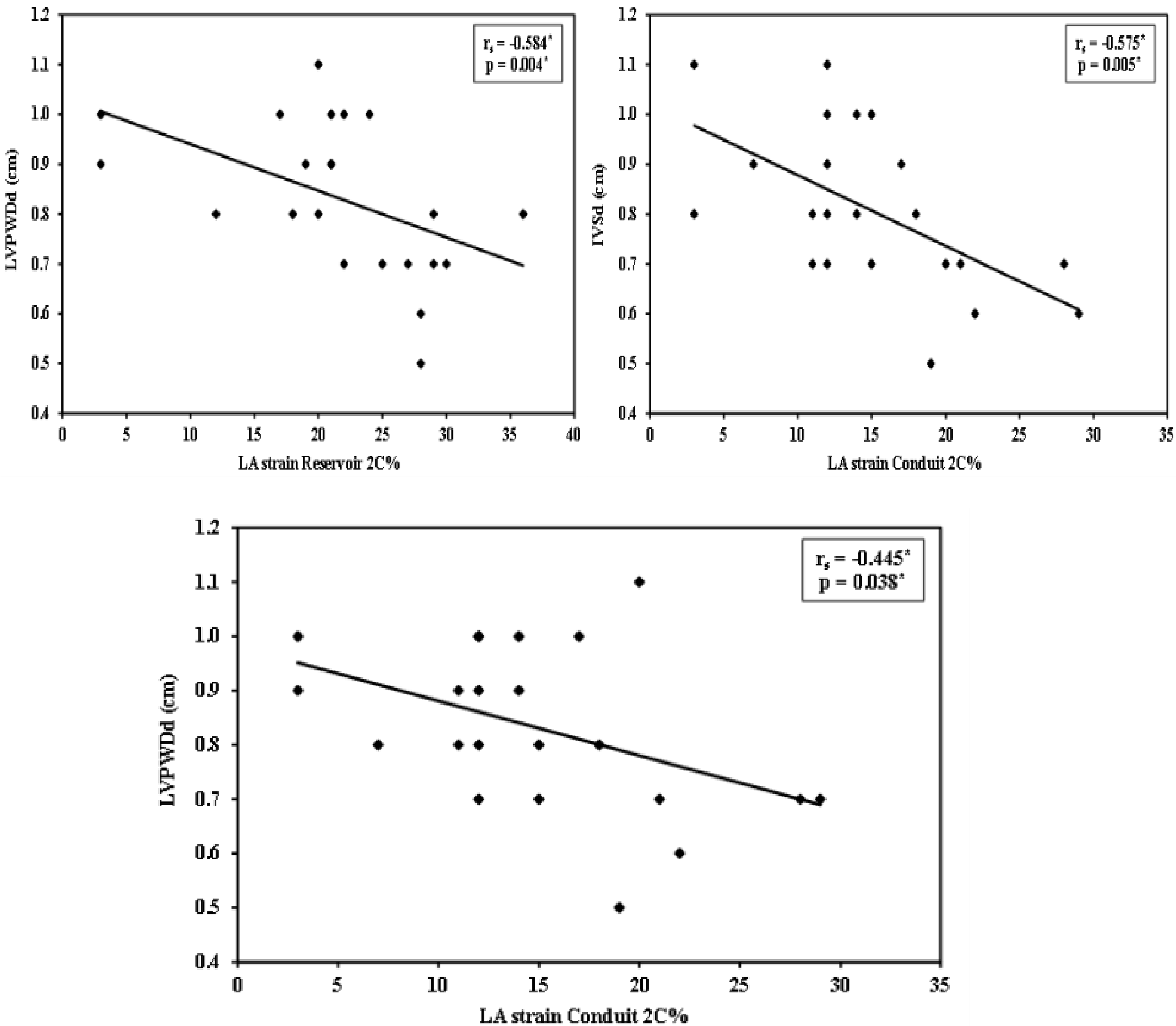

Figure (3): Correlation between left ventricular wall thickness parameters (LVPWDd and IVSd) and LA strain (Reservoir and Conduit 2C%) in the cases group.

DISCUSSION

Children with CKD die primarily from cardiovascular problems, yet early indicators of dysfunction are frequently overlooked. 2D speckle tracking echocardiography can identify early myocardial deterioration prior to traditional methods by measuring left and right atrial strain. In order to detect early cardiac abnormalities and direct prompt therapies, this study assessed LA and RA function in 22 pediatric CKD patients receiving regular hemodialysis compared to 22 healthy controls. There was a significant difference in mean weight and height between the groups, reflecting impaired growth in CKD patients, which is consistent with the North American Pediatric Transplant Cooperative Study, where over 35% of children had height < 3rd percentile or a median height standard deviation score (HtSDS) below −1.88 [10].

Traditional echocardiography showed no significant difference in fractional shortening between dialysis patients and controls. Similarly, **Edwards *et al.*** [11] reported comparable LV ejection fraction and systolic tissue Doppler velocities in early-stage CKD, indicating that despite abnormal systolic deformation linked to poor cardiovascular prognosis, conventional systolic function measures remain preserved.

Interventricular septal thickness in diastole and left ventricular posterior wall thickness in diastole were significantly different in the patient group compared to the control group in our study. This is consistent with a research by **Van Huis *et al.*** [12] that included 33 age-matched controls, 17 transplant patients, and 19 children receiving dialysis. According to the findings, dialysis and transplant patients had significantly thicker interventricular and left ventricular posterior walls than healthy controls. Additionally, our research showed that while there was no change in E/E, E was much lower in the dialysis group than in the control group. This aligns with the same research conducted by **Van Huis *et al.*** [12].

Our study found no significant difference in LA maximum volume between patients and controls, although it was slightly larger in patients. This aligns with **Penachio *et al.*** [13] who reported similar LA diameter and volume in 55 pediatric CKD patients and 55 controls despite lower LA reservoir strain in patients. However, it contrasts with **Bansal *et al.*** [14] who observed increased LA volume after dialysis in 417 adults from the CRIC study.

Reservoir phase, conduit phase and contractile phase were all lower in the dialysis group than in the control group, which was a statistically significant difference between the two groups in our investigation on LA strain. These results point to aberrant LV relaxation that raises LV filling pressures and a stiff or noncompliant LV that raises LVEDP during LV diastole. Therefore, despite minimal cardiac symptoms and normal LV FS%, our study's findings showed that children with CKD receiving regular hemodialysis had subclinical diastolic dysfunction. Our findings align with **Penachio *et al.*** [13] who reported that pediatric CKD patients with left ventricular hypertrophy had increased left atrial stiffness and reduced LA reservoir strain compared to healthy controls. **Calleja *et al.*** [15] reported that in 53 ESRD patients, LA reservoir, conduit, and contractile functions were reduced compared to 85 controls, indicating diastolic dysfunction. Similarly, **Tanasa *et al.*** [16] highlighted that LA strain is valuable in dialysis patients for detecting early myocardial involvement, predicting systolic and diastolic dysfunction, and forecasting adverse cardiovascular events.

In our study, all RA strain phases (reservoir, conduit, and contractile) were lower in patients than in controls, with a statistically significant difference. This aligns with **Ünlü *et al.*** [17] who observed significant changes in RA reservoir longitudinal strain before and after hemodialysis in end-stage kidney patients. Additionally, **Khani *et al.*** [18] study evaluated how kidney transplantation (KTx) affected the right heart chambers in individuals with end-stage renal disease (ESRD). This prospective longitudinal trial included 49 adult KTx candidates. According to the study, RA conduit strain was found to be a predictor of RA conduit strain after KTx, while RA reservoir strain prior to KTx revealed to be an independent predictor of RA reservoir strain following KTx. The results of this study showed that right cardiac function significantly improved after KTx. Additionally, strain analysis can offer important information for forecasting right heart function following KTx.

In addition, our research revealed a highly significant negative association (p value < 0.001) between the length of dialysis and LA conduit 2C strain in the patient group. Moreover, there was a strong negative association (p value < 0.05) between the length of dialysis and the LA reservoir 2C strain in the patient group, indicating that long-term dialysis had substantial cardiovascular effects. This is in line with a study by **Calleja *et al.*** [15], which found that changes in LA volume indicate a bad prognosis in CKD and ESRD and that LA dilates when exposed to high LV filling pressures over time, reflecting the degree and duration of diastolic dysfunction.

Moreover, our study found a significant negative correlation between IVSd and LA conduit 2C strain (p value < 0.05) as well as between LVPWd and LA 2C reservoir & conduit phases in the patient group (p value < 0.05) indicating a significant impact of uremic cardiomyopathy on these patients' diastolic function. This is in line with a research by **Penachio *et al.*** [13], which found that patients with concentric hypertrophy had higher LA stiffness index and lower LA reservoir and conduit strain than patients with normal LV geometry. Additionally, this is consistent with **Penachio *et al.*** [13] findings that LVH was linked to higher LA stiffness index, filling index and reduced LA reservoir strain.

CONCLUSION

2D Speckle tracking echocardiography is a very sensitive & noninvasive tool for early detection of subtle cardiac diastolic impairment in pediatric CKD patients on dialysis by detecting significant reduction in LA & RA strain values.

DECLARATIONS

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REFERENCES

1. **Mitsnefes M (2012):** Cardiovascular disease in children with chronic kidney disease. J. Am. Soc. Nephrol., 23 (4): 578-585.
2. **Khan A, Fayad F, Kim C *et al.* (2025):** Right Ventricular Dysfunction and Adverse Clinical Outcomes in Peripartum Cardiomyopathy: A Meta-Analysis. JACC Adv., 4 (9): 102047.
3. **Pastorini G, Anastasio F, Feola M (2023):** What Strain Analysis Adds to Diagnosis and Prognosis in Heart Failure Patients. J. Clin. Med., 12 (3): 836.
4. **Gan G, Kadappu K, Bhat A *et al.* (2021):** Left Atrial Strain Is the Best Predictor of Adverse Cardiovascular Outcomes in Patients with Chronic Kidney Disease. J. Am. Soc. Echocardiogr., 34 (2): 166-175.
5. **Singh A, Addetia K, Maffessanti F *et al.* (2017):** LA Strain for Categorization of LV Diastolic Dysfunction. JACC Cardiovasc. Imaging, 10 (7): 735-743.
6. **Wen W, Huang F, Liu Y *et al.* (2025):** Advanced Echocardiographic Approaches for Assessing Cardiac Dysfunction in Chronic Kidney Disease: Current Techniques and Future Perspectives. Clin. Interv. Aging, 20: 1495-1505.
7. **Avcı Demir F, Bingöl G, Uçar M *et al.* (2024):** Left Atrial Coupling Index Predicts Heart Failure in Patients with End Stage Renal Disease. Medicina, 60 (8): 1195.
8. **Truong V, Palmer C, Young M *et al.* (2020):** Right Atrial Deformation Using Cardiovascular Magnetic Resonance Myocardial Feature Tracking Compared with Two-Dimensional Speckle Tracking Echocardiography in Healthy Volunteers. Sci. Rep., 10 (1): 5237.
9. **Comunale G, Peruzzo P, Castaldi B *et al.* (2021):** Understanding and recognition of the right ventricular function and dysfunction via a numerical study. Sci. Rep., 11 (1): 3709.
10. **Furth S, Stablein D, Fine R *et al.* (2002):** Adverse clinical outcomes associated with short stature at dialysis initiation: a report of the North American Pediatric Renal Transplant Cooperative Study. Pediatrics, 109 (5): 909-913.
11. **Edwards N, Hirth A, Ferro C *et al.* (2008):** Subclinical abnormalities of left ventricular myocardial deformation in early-stage chronic kidney disease: the precursor of uremic cardiomyopathy? J. Am. Soc. Echocardiogr., 21 (12): 1293-1298.
12. **Van Huis M, Schoenmaker N, Groothoff J *et al.* (2016):** Impaired longitudinal deformation measured by speckle-tracking echocardiography in children with end-stage renal disease. Pediatr. Nephrol., 31 (9): 1499-1508.
13. **Penachio F, Diniz M, Laurino R *et al.* (2024):** Speckle-Tracking: Incremental Role in Diastolic Assessment of Pediatric Patients with Chronic Kidney Disease. Arq. Bras. Cardiol., 121 (3): e20230131.
14. **Bansal N, Roy J, Chen H *et al.* (2018):** Evolution of Echocardiographic Measures of Cardiac Disease from CKD to ESRD and Risk of All-Cause Mortality: Findings from the CRIC Study. Am. J. Kidney Dis., 72 (3): 390-399. doi: 10.1053/j.ajkd.2018.02.363
15. **Calleja A, Rakowski H, Williams L *et al.* (2016):** Left atrial and ventricular systolic and diastolic myocardial mechanics in patients with end-stage renal disease. Echocardiography, 33 (10): 1495-1503.
16. **Tanasa A, Burlacu A, Popa C *et al.* (2021):** A Systematic Review on the Correlations between Left Atrial Strain and Cardiovascular Outcomes in Chronic Kidney Disease Patients. Diagnostics (Basel), 11 (4): 671.
17. **Ünlü S, Şahinarslan A, Gökalp G *et al.* (2018):** The impact of volume overload on right heart function in end-stage renal disease patients on hemodialysis. Echocardiography, 35 (3): 314-321.
18. **Khani M, Moradi A, Ghadirzadeh E *et al.* (2024):** Improvement in right heart function following kidney transplantation in ESRD patients: insights from speckle tracking echocardiography analysis. Int. J. Cardiovasc. Imaging, 40 (6): 1329-1340.