Left Ventricular Strain and Left Atrial Strain Are Impaired During Hemodialysis in Children

Tam T Doan (✉ tam.doan@bcm.edu)

Baylor College of Medicine <https://orcid.org/0000-0002-8256-1535>

Poyyapakkam Srivaths

Baylor College of Medicine

Asela Liu

Baylor College of Medicine

J. Kevin Wilkes

Baylor College of Medicine

Alexandra Idrovo

Baylor College of Medicine and Children's Hospital of The King's Daughters

Ayşe Akcan-Arikan

Baylor College of Medicine

Sarah Swartz

Baylor College of Medicine

Jessica Geer

Baylor College of Medicine

Carolyn A. Altman

Baylor College of Medicine

Nancy A. Ayres

Baylor College of Medicine

Robert W Loar

Cook Children's Medical Center

Ricardo Pignatelli

Baylor College of Medicine

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Abstract

Background

Cardiac mortality and morbidity remain significant in children on chronic hemodialysis (HD). Multiple markers by speckle tracking echocardiography (STE) are predictive of cardiac events in adults, but data in children are limited; ventricular diastolic strain (Ds) and left atrial strain (LAS) have not been reported. The aim of this study was to investigate intradialytic changes in ventricular and atrial function using STE in children.

Methods

Secondary analysis of a prospective descriptive study of children with structurally normal hearts and HD vintage > 3 months, using echocardiography performed prior to, during, and after HD. STE was analyzed using GE EchoPAC. Left ventricular (LV) global longitudinal strain (GLS), strain rate (Sr), and mechanical dispersion index (MDI) were calculated as the average from 3 apical views; Ds and Sr were obtained from 4-chamber tracing; LAS and Sr were assessed during atrial contraction, reservoir, and conduit. Intradialytic changes in 2D STE markers of ventricular function and LAS and their association with blood volume (BV) removal and blood pressure (BP) change were studied.

Results

A total of 15 children were enrolled at a median age of 12 years (IQR 8, 16) and median HD vintage of 13 months (IQR 9, 25). GLS was impaired during HD ($-15.8 \pm 2.2\%$ vs $-19.9 \pm 1.9\%$, $p < 0.001$). Post-HD GLS was associated mean BP decrease (coefficient = 0.62, $p = 0.01$) and not with BV removal (coefficient = 0.49, $p = 0.06$). LV MDI and systolic Sr did not change. LV Ds was progressively impaired (-8.4% ($-9.2, -8.0$) vs -11.9% ($-13.4, -10.3$), $p < 0.001$). LAS conduit and reservoir worsened at mid-HD and returned to baseline post-HD. Changes in Ds, DSr, LAS, LASr were not associated with BV removal or BP decrease ($p > 0.1$).

Conclusions

Intradialytic LV strain and LAS impairment consistent with subclinical systolic and diastolic dysfunction were observed during HD in children. GLS impairment was associated with BP change, but changes in Ds, DSr, LAS, and LASr were not associated with BP change or BV removal. Longitudinal assessment using these novel non-invasive indices may unfold the effect of cumulative subclinical changes on long-term outcomes in children who are on chronic HD.

Introduction

Cardiovascular complications are common among children with end-stage kidney disease (ESKD) with up to 30% of deaths in children on hemodialysis (HD) due to cardiovascular events.^{1,2} In fact, cardiac arrest is the most common cause of death in children and adolescents with ESKD.^{3,4} Left ventricular (LV) global longitudinal strain (GLS), mechanical dispersion index (MDI), and the ratio of early mitral inflow velocity (E) to global diastolic strain rate (Sr) in early diastole (E/DSrE) using 2-dimensional (2-D) speckle tracking echocardiography (STE) are risk markers of ventricular arrhythmia and sudden cardiac death in adult dialysis patients.^{5,6}

Data on cardiac strain imaging in children with ESRD and HD are limited to markers of systolic function.⁷⁻⁹ In children on dialysis, retrospective longitudinal studies have demonstrated impaired GLS improved after kidney transplantation.^{7,8} Published literature on the assessment of diastolic function in this scenario has been limited to spectral and tissue Doppler imaging, with one study showing diastolic dysfunction at all stages including post transplantation.⁸ Markers of diastolic function and left atrial strain (LAS) using 2-D STE can predict outcomes and be potentially better than spectral and tissue Doppler imaging in adults with certain disease states.¹⁰ There is scant data regarding changes in systolic and diastolic function during HD in children.

In this secondary analysis of data from a prospectively study of GLS and cerebral oxygenation, we focused on LV mechanical dispersion index (MDI), systolic Sr, Ds and Sr, and LAS using 2-D STE during a 4-hour HD in children on chronic HD for ESKD. We hypothesized that there would be significant derangements in MDI, diastolic strain, and LAS during and after HD.

Material And Methods

Study Population

This was a secondary analysis of 2-D STE on 15 patients ≤ 20 years old with ESKD and a structurally normal heart, who had been on HD ≥ 3 months (HD vintage). The study subjects were initially recruited for analysis of GLS and cerebral oxygenation in the form of non-invasive near infrared spectroscopy.¹¹ Consent was obtained and the study was approved by the Institutional Board Review at Baylor College of Medicine.

Monitoring and Measurements During Hemodialysis

Patients' heart rates and blood pressures (BP) were measured every 15 minutes during the HD session. Elevated BP was determined as systolic and/or diastolic BP ≥ 95 th percentile for age, sex, and height.¹² Patients were monitored for dialysis-associated morbidity symptoms (lightheadedness, muscle cramps, vomiting, fatigue, lethargy, confusion). Crit-line III^{TQA} (HemaMetrics MDSS GmbH, Germany) was used to assess changes in blood volume (BV). Hemodialysis was performed following standard of care linear fluid removal and stable HD prescription with typical dialysate baths including calcium and potassium.

Echocardiography

Pre-HD, mid-HD, and post-HD transthoracic 2-D echocardiography was performed on each patient by a trained and experienced research pediatric cardiac sonographer (A.N.) using a commercially available ultrasound system (GE Vivid E95 Ultrasound System, GE Medical Systems, Milwaukee, WI). Apical 4-chamber, 2-chamber, and 3-chamber views were obtained on each echocardiogram. Each cine image included three cardiac cycles and settings were adjusted manually to obtain frame rates of 50–70 frames/second and the left atrium was included for LAS analyses. Left ventricular ejection fraction (LVEF) was measured from apical 4-chamber and 2-chamber views, calculated using bi-plane Simpson's method, and was considered normal when it was $\geq 55\%$.¹³ Left ventricular end-diastolic and end-systolic dimensions were measured on a 2-D short axis view of the ventricles¹³ and z scores were derived based on data from the Pediatric Heart Network.¹⁴ Spectral Doppler assessment of the mitral inflow was obtained at each HD stage on all patients and peak velocities of flow were recorded during early (E) and late diastole (A). Pulsed wave tissue Doppler imaging was used to measure early diastolic myocardial relaxation velocity from the lateral mitral annulus (e'), and E/e' ratio was derived at each HD stage on each patient.

Speckle Tracking Analysis

Echocardiographic images were sent to a single software station and all strain analyses were performed offline (EchoPAC Clinical Workstation Software, GE Vingmed Ultrasound). Three sets of images were available for each study subject for analysis of changes at mid-HD and post-HD compared to pre-HD.

Myocardial tracking was assessed for each segment and tracing was manually adjusted if necessary. Left ventricular GLS was the average of peak systolic longitudinal strain from the three apical views and was calculated by the software. LV systolic Sr represented the rate of LV deformation in systole. LV GLS and Sr were presented as negative values, which represented the percentage of myocardial shortening from its original length and rate of LV shortening. Impaired GLS was defined as GLS (negative value) > the upper limit of normal value for age.¹⁵ Time to peak systolic longitudinal strain was measured from the onset of QRS on ECG to peak systolic strain. Left ventricular MDI was measured automatically by the system from the GLS curves as the standard deviation of time to peak longitudinal strain of all 17 LV segments marking the temporal difference of LV deformation.¹⁶

Left ventricular global longitudinal diastolic strain (Ds) and diastolic Sr during early diastole (DSrE) and late diastole (DSrA) were measured from the apical 4-chamber view. Time from peak R wave of the QRS complex to peak E wave was measured and used to identify Ds at the time of peak E wave. Ratio of E/Ds , $E/DSrE$, and $E/DSrA$ were calculated as additional markers of diastolic function.

Left atrial strain analysis was performed using dedicated images with good definition of the left atrial wall on the 4-chamber and 2-chamber views. The left atrial appendage and entrance of the pulmonary veins were excluded from the tracing. The initial up-sloping of the P wave was used as the reference point for LAS. Left atrial strain values were recorded at atrial contraction (ϵ_{ac}), atrial passive emptying or conduit phase (ϵ_{con}), and atrial filling or reservoir ($\epsilon_{res} = \epsilon_{ac} + \epsilon_{con}$). Left atrial strain rate in late diastole (LASr-ac), during systole (LASr-res) and early diastole (LASr-con) were measured along the average Sr

curve as the parameters of contractile, reservoir, and conduit function, respectively. The reported LAS and LASr values are the average of the 4- and 2-chamber values.

Statistical Analysis

Statistical analysis was performed using Stata™ version 14.2 (StataCorp LP, College Station, TX). Variates were presented as mean ± standard deviation, median and 25–75% interquartile ranges (IQR), and number and percentage, where appropriate. Normality of continuous variables was assessed by frequency distribution (histogram) and Shapiro-Wilk test. Variable changes during HD (pre-HD vs mid-HD, pre-HD vs post-HD, and mid-HD vs post-HD) were compared using paired T test (parametric continuous variables), Wilcoxon signed rank test (non-parametric continuous variables), or McNemar test (paired nominal variables) where appropriate. Simple linear regression analyses were performed to study the association between BV change and BP change and GLS, systolic Sr, MDI, Ds, diastolic Sr, and LAS and Sr at mid-HD and post-HD. A 2-tail p-value of < 0.05 was considered statistically significant.

Results

Study Population

A total of 15 children on chronic HD for ESKD and structurally normal hearts were enrolled. The median age was 12 years (IQR 8, 16) with a median weight of 30.5 kg (IQR 23.8, 49), median BMI of 18.4 kg/m² (IQR 17.3, 21.7), and median HD vintage of 13 months (IQR 9, 25). Baseline hemoglobin was 12.1 g/dL (10.1, 12.3). All patients tolerated HD well with no symptoms. Additional patient characteristics are described in Table 1. Elevated BP was noted in 66.7% of patients at baseline and 33.3% after HD, however, this change was not statistically significant (McNemar's $\chi^2 = 3.6$, $p = 0.06$). Most (13/15) patients were not on any antihypertensive therapy and most (13/15) patients did not have any residual urine output.

Table 1
Baseline characteristics

Demographic Features (N = 15)	n (%)
Gender	9 (60)
Male	6 (40)
Female	
Race and ethnicity	8 (53)
Hispanic	6 (40)
Black or African American	1 (7)
Others	
Underlying diagnosis	9 (60)
Congenital anomalies	4 (27)
Glomerulonephritis	2 (13)
Other	
Elevated blood pressure at baseline (≥ 95 th percentile)	10 (66.7)
Systolic	3 (20)
Diastolic	1 (6.7)
Both systolic and diastolic	6 (40)

Blood Volume and Hemodynamic Changes During Hemodialysis

Fluid was steadily removed during HD with a total BV decrease of $-13.7 \pm 3.3\%$ from baseline with an average actual weight decrease of 2.5 ± 2.5 kg ($6.0 \pm 7.2\%$). Intradialytic changes in BP and heart rates are shown in Table 2. No patient had symptomatic hypotension requiring intervention.

Table 2
Changes in blood volume and hemodynamics during hemodialysis

Parameters	Pre-HD	Mid-HD	Post-HD	P (pre-mid)	P (mid-post)	P (pre-post)
BV change, %	0	9.2 ± 1.9	13.7 ± 3.3	< 0.001	< 0.001	< 0.001
Heart rate, bpm	85 (78, 87)	90 (80, 102)	98 (85, 111)	0.02	0.4	0.005
Systolic BP, mmHg	126 ± 20	117 ± 15	109 ± 11	0.01	< 0.05	0.003
Diastolic BP, mmHg	76 ± 11	72 ± 10	69 ± 10	< 0.05	0.1	0.001
Mean BP, mmHg	80 ± 11	75 ± 9	71 ± 8	0.005	0.04	< 0.001
Elevated BP, n (%)	10 (66.7)	7 (46.7)	5 (33.3)	0.5	0.3	0.06
BV = blood volume; bpm = beats per minute; BP = blood pressure.						

Left Ventricular Size, Ejection Fraction, Spectral Doppler, and Tissue Doppler Imaging

As depicted in Table 3, both LV end-diastolic and end-systolic dimensions decreased throughout HD. There is a statistically significant but clinically nonsignificant drop in LVEF from pre-HD to mid-HD, however, LVEF values remained $\geq 55\%$ in all cases at all 3 stages of HD. Mitral valve E velocity and E/A ratio decreased from pre-HD to mid-HD and remained decreased post-HD while no significant changes in A velocity or E/e' ratio was noted.

Table 3
Intradialytic changes in LV size, LVEF, spectral and tissue Doppler imaging parameters.

Parameters	Pre-HD (IQR)	Mid-HD (IQR)	Post-HD (IQR)	P (pre- mid)	P (mid- post)	P (pre- post)
LVEDD, mm	40.8 ± 0.8	36.2 ± 0.7	33.7 ± 0.6	< 0.001	0.001	< 0.001
LVEDD z score	-0.5 (-1.4, 0.0)	-1.6 (-2.7, -0.6)	-2.7 (-2.9, -1.7)	0.001	< 0.001	< 0.001
LVESD, mm	28.3 ± 0.6	25.9 ± 0.5	24.5 ± 0.5	< 0.001	0.003	< 0.001
LVEF, %	63 ± 3	61 ± 4	60 ± 3	< 0.001	0.1	< 0.001
LVEF ≥ 55%, n (%)	15 (100)	15 (100)	15 (100)			
E velocity, cm/s	98 ± 19	71 ± 14	73 ± 18	< 0.001	0.7	< 0.001
A velocity, cm/s	55 (49, 65)	51 (43, 55)	48 (39, 61)	0.09	0.6	0.06
E/A ratio	1.8 (1.4, 2.1)	1.3 (1.2, 1.7)	1.4 (1.2, 1.8)	0.01	0.5	0.04
E/e' (lateral)	6.5 (4.7, 7.1)	6.0 (4.5, 8.7)	5.6 (4.6, 6.9)	0.5	0.6	0.2
LVEDD = left ventricular end-diastolic dimension; LVESD = left ventricular end-systolic dimension; LVEF = left ventricular ejection fraction.						

Table 4
Intradialytic changes in LV systolic and diastolic strain, and LAS

Parameters	Pre-HD (IQR)	Mid-HD (IQR)	Post-HD (IQR)	P (pre-mid)	P (mid-post)	P (pre-post)
LV GLS, %	-19.9 ± 1.9	-16.5 ± 2.3	-15.8 ± 2.2	< 0.001	0.1	< 0.001
Impaired GLS, ¹⁵ n (%)	8(53.3)	15 (100)	15 (100)			
LV Sr, %	-1.0 (-1.1, -0.9)	-1.0 (-1.2, -0.8)	-0.9 (-1.0, -0.8)	0.5	0.2	0.09
MDI, msec	36 ± 9	38 ± 11	37 ± 9	0.5	0.3	0.5
LV Ds %	-11.9 (-13.4, -10.3)	-9.8 (-10.9, -8.8)	-8.4 (-9.2, -8.0)	0.004	0.04	< 0.001
E/Ds, (cm/s)/%	-7.5 (-10.0, -6.9)	-6.8 (-9.7, -6.0)	-8.1 (-10.0, -6.5)	0.07	0.08	1
DSrE, %	1.8 (1.7, 2.0)	1.3 (1.0, 1.6)	1.2 (1.0, 1.6)	0.01	0.1	< 0.001
E/DSrE, (cm/s)/%	55 (40, 66)	53 (41, 65)	56 (47, 72)	0.6	0.08	0.5
DSrA, %	0.6 (0.5, 0.7)	0.5 (0.3, 0.8)	0.4 (0.4, 0.5)	0.3	0.5	0.1
E/DSrA, (cm/s)/%	163 (146, 182)	157 (100, 185)	197 (136, 210)	0.5	0.7	0.9
Δac, %	-13.6 (-17.1, -9.1)	-10 (-19.7, -7.1)	-11.5 (-19.7, -8.3)	0.6	0.3	0.9
Δcon, %	22.6 ± 8.6	15.3 ± 8.3	18.5 ± 10.0	0.04	0.3	0.1
Δres, %	36.9 ± 6.2	28.3 ± 5.4	32.9 ± 8.4	0.001	0.1	0.06
E/Δres, (cm/s)/%	237 ± 18	337 ± 22	315 ± 30	0.001	0.5	0.009
LA Sr-ac, %	-1.6 (-2.0, -1.1)	-1.4 (-2.2, -1.2)	-1.7 (-2.2, -1.2)	0.9	0.1	0.6
LA Sr-con, %	1.6 (1.3, 1.8)	1.3 (1.1, 1.7)	1.6 (1.3, 1.8)	< 0.005	0.04	0.1
LA Sr-res, %	-2.7 (-2.9, -2.1)	-1.9 (-2.3, -1.4)	-2.1 (-3.0, -1.8)	0.004	0.04	0.1
GLS = global longitudinal strain; Sr = strain rate; MDI = mechanical dispersion index; Ds = diastolic strain; LA = left atrial; Δ = strain; ac = atrial contraction; con = atrial passive emptying or conduit; res = atrial filling or reservoir						

Speckle Tracking Echocardiography

The LV GLS was impaired at mid-HD ($3.3 \pm 2.4\%$) and remained impaired post-HD ($4.0 \pm 2.4\%$) compared to baseline, while no significant change in MDI or systolic Sr was detected during HD (Table 4). The LV Ds was progressively impaired from pre-HD to mid-HD and post-HD, totaling $3.3 \pm 1.8\%$ from baseline, while DSrE and E/ ϵ res had a similar pattern to systolic GLS (impaired at mid-HD and post-HD). No significant change to other diastolic strain parameters (E/Ds, E/DSrE, DSrA, E/DSrA) was noted. There was no change in ϵ ac or SRac (similar to MV A velocity) whereas ϵ con, Sr-con (passive emptying phase), ϵ res, and SRres (atrial filling) decreased at mid-HD and returned to baseline post-HD. The individual changes of LV GLS, MPI, Ds, DSrE, ϵ res and Sr-res during HD are depicted on Fig. 1.

Correlation of BV Change and Mean BP Change with Intradialytic STE Changes

There is a strong correlation between mean BP decrease and post-HD GLS (coefficient = 0.62, $p = 0.01$) and there was not a statistically significant correlation between total BV removal and post-HD GLS (coefficient = 0.49, $p = 0.06$) on simple linear regression analyses. Less mean BP reduction was associated with less post-HD GLS impairment (Fig. 2).

The mid-HD GLS or intradialytic GLS change from pre-HD to mid-HD or changes in LV global Ds, DSrE, E/DSrE, LAS ϵ res, Sr-res, E/ ϵ res, ϵ con, and Sr-con at mid-HD and post-HD were not associated with BV change or BP change. Age and gender were not associated with intradialytic STE changes.

Discussion

In this analysis of children undergoing chronic HD for ESKD with the typical range of underlying congenital and acquired kidney conditions as reported from the United States Renal Data System on ESRD in children and adolescents in 2018, we observed intradialytic changes in both systolic and diastolic function using novel STE markers. Both mid-HD and post-HD GLS significantly impaired from baseline. Progressive impairment in diastolic function was detected in terms of LV Ds at all three time points. Mid-HD LAS and Sr were impaired from baseline and both LAS and Sr returned to baseline at the end of HD.

Systolic Function

Similar to other studies, LVEF remained normal ($\geq 55\%$) throughout HD in all of our patients. Prior studies in children also showed preserved LVEF when compared to healthy control and nonsignificant LVEF change during HD.^{7,8}

Baseline GLS in children with ESKD and HD have been noted to be mildly impaired in 2 separate previous studies ($-19.7 \pm 2.8\%$ ⁸ and $-20.31 \pm 3.58\%$ ⁷), which reported GLS similar to the pre-HD GLS in our study ($-19.9 \pm 1.9\%$). Our results showed 53% had abnormal pre-HD GLS and LV GLS worsened during HD with

100% had abnormal GLS at mid-HD and post-HD. Studies in adults demonstrated LV GLS was associated with ventricular arrhythmia or sudden cardiac death (area under the curve = 0.79), uremic toxins, obesity, and arterial stiffness.^{5,17} In our study, post-HD GLS and intradialytic GLS impairment was associated with the degree of decrease in mean BP during HD with greater decrease in BP associated with more significant post-HD GLS impairment. There was a trend of more post-HD GLS impairment with greater BV removal, but this association was not statistically significant.

Intradialytic LV MDI change was not significant in our study with a baseline MDI measured 36 ± 9 vs 37 ± 9 msec after HD. Predialysis and dialysis adult patients with ventricular arrhythmia or sudden cardiac death had larger MDI 66 (55–74) vs 52 (43–65) msec ($p = 0.04$) with nonsignificant vintage difference between the 2 groups.⁵ Our patients' median HD vintage of 13 months (IQR 9, 25) was not different from that was reported in this study.⁵ We hypothesized the difference in MDI between pediatric patients and adults were related to underlying etiologies and fewer comorbidities in children.

Left ventricular GLS was the only marker of systolic function that demonstrated intradialytic impairment in our study. The impaired GLS would not have been detected by conventional echo imaging as LVEF remained normal, indicating that more sophisticated noninvasive imaging techniques might be paramount to detect adverse impact of HD in children which likely occurs repetitively with each HD session in children.

Diastolic strain, DSrE, and E/DSrE

Diastolic dysfunction diagnosed by spectral and tissue Doppler imaging has been reported in children with ESKD requiring long-term HD.^{8,18,19} Diastolic dysfunction developed early in the course of children with chronic kidney disease and was present up to 18 months after renal transplantation.⁸ Studies of global Ds and Sr indices demonstrated myocardial diastolic dysfunction in adults with preserved LVEF, who received peritoneal dialysis.^{20,21} The E/DSrE ratio improved the prediction of cardiovascular mortality and major adverse cardiovascular events in HD adult patients over clinical and conventional echocardiographic parameters alone.⁶ In our study, intradialytic E/DSrE change was nonsignificant. We observed progressive intradialytic Ds and DSrE impairment which was not associated with BV removal or BP change. Our study demonstrated progressive intradialytic ventricular diastolic changes that are likely repetitive and potentially contributory to diastolic dysfunction in patients on chronic HD for ESKD, which may persist after transplantation.⁸ Evolving data in adults showed asymptomatic diastolic dysfunction with preserved LVEF is associated with subsequent heart failure and mortality; addressing these preclinical changes and echocardiographic surveillance may delay symptomatic progression and improve outcome.²² Longitudinal studies are necessary to understand how diastolic dysfunction plays a role in cardiovascular outcome of children who are on chronic HD. It remains to be explored whether management strategies including monitoring using these novel STE markers can be developed to slow down or prevent its progression to improve patient outcomes.

Left Atrial Strain and Sr

Left atrial strain reservoir has been identified as a new emerging reliable marker of diastolic dysfunction in adults; it better reflects instantaneous left atrial pressure with greater prognostic value than left atrial volume index.²¹ Left atrial strain is a sensitive marker of early diastolic dysfunction, linearly worsens to the progression of diastolic dysfunction, and improves as LV filling pressure improves.²³ While the use of LAS has been studied in HD adults and found to be predictive of outcome,²⁴ we found no prior study assessing LAS in pediatric chronic HD. In our study, LAS and Sr during the atrial early emptying (conduit) and atrial filling (reservoir) were impaired from pre-HD to mid-HD but returned to baseline at the end of HD. When combined with mitral inflow E velocity, the E/ $\dot{V}_{res}$ increased at mid-HD and remained increased at post-HD. The E/ $\dot{V}_{res}$ ratio has been identified as a useful parameter in the prediction of total and cardiovascular mortality in adult HD patients.²⁴ Similar to Ds, these LAS and Sr changes in our study were not associated with BV removal or BP change. Left atrial contractile function changes during HD assessed by tissue velocity and Sr during late diastole were noted to be preload-independent in a study in 41 adult HD patients,²⁵ which was similar to our observation in children in this study. Further studies are needed to understand the role of these intradialytic changes in the progression of diastolic dysfunction in children with chronic HD.

Children with ESKD are at risk of cardiovascular health issue, possibly related to their disease process, complications of the disease, and treatment which can lead to microvascular dysfunction.¹⁵ Our study results demonstrated progressive intradialytic LV diastolic dysfunction, which was not associated with the degree of fluid removal or BP change. It may have occurred as a natural history of the disease process. Addressing vascular dysfunction is valuable in adults to reduce long-term major adverse cardiovascular complications.¹⁵ We do not believe our results are sufficient to postulate pathophysiology related to cardiovascular complications seen in these children. However, they may serve as a proof that these novel tools can be utilized in clinical practice to measure the magnitude of subclinical function impairments and future research as we strive to understand the disease process, minimize harm, and improve the care and outcome of children with ESKD requiring HD.

Our study was a secondary analysis of a prospective study and therefore has limitations. The sample size, as typical of most pediatric dialysis studies, was small. We were only able to assess patients during one HD treatment and were not able to follow them longitudinally post treatment to assess whether the observed abnormalities resolve during the recovery period after HD. We did not have access to real time hemodynamic indices such as continuous BP or cardiac output monitoring. However, none of our patients had overt cardiovascular risk factors, all had uncomplicated asymptomatic treatments, and relatively short vintage, underscoring the adverse hemodynamic burden of HD on organ function.

Conclusions

Significant impairment in STE markers of systolic and diastolic function, including LAS, were observed during HD in children. Intradialytic changes in systolic GLS were associated with BP change whereas changes in Ds, diastolic Sr, and LAS were not associated with BP change or BV removal. Longitudinal

assessment using these novel non-invasive indices may unfold the effect of potentially repetitive and cumulative subclinical changes on long-term outcomes in children with ESKD who are on chronic HD.

Abbreviations

BP Blood Pressure

BV Blood Volume

Ds Diastolic Strain

ESKD End-Stage Kidney Disease

GLS Global Longitudinal Strain

HD Hemodialysis

LAS Left Atrial Strain

LV Left Ventricle, Ventricular

LVEF Left Ventricular Ejection Fraction

MDI Mechanical Dispersion Index

Sr Strain Rate

STE Speckle Tracking Echocardiography

2-D Two-dimensional

Declarations

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Declarations of interest:

none

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Figures

Figure 1

Trajectory of left ventricular systolic global longitudinal strain (GLS), mechanical dispersion index (MPI), global diastolic strain (Ds), early diastolic strain rate (DSrE), and left atrial strain and strain rate during atrial filling or reservoir (Δres and Sr-res) between pre-HD, mid-HD, and post-HD

Figure 2

Relationship of total blood volume removal and mean blood pressure decrease with post-HD GLS