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Original Article

Investigating the Acute Effects of Hemodialysis on Hemodynamic and Electrocardiographic Parameters

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ABSTRACT

Background and Aim: Changes in electrocardiographic parameters are reported after hemodialysis (HD). This study determines the alternations in electrocardiographic parameters, hemodynamics, and body weight post-HD.

Methods: Electrocardiography was evaluated pre- and post-dialysis in 20 patients (55% males) aged 16.25±6.25 years. Changes in electrocardiographic parameters were compared considering changes in weight (post-dialysis and between dialysis sessions), blood pressure (BP) indices, and the occurrence of intra-dialysis hypotension (IDH).

Results: A significant decrease was observed in weight, systolic, diastolic, and mean arterial BPs post-dialysis ($P<0.05$, for all). No substantial changes in durations of PR interval, QT interval corrected for heart rate, and QRS complex, as well as QT dispersion, were found post-dialysis ($P>0.05$ for all). Hemodynamic and electrocardiographic alternations were not significantly different between cases with adequate versus inadequate weight gain ($P>0.05$ for all). Meanwhile, dialysis-induced ventricular strain patterns (ST-T segment changes) were found in 20% of patients, including three cases with inadequate weight gain inter-dialysis. In one case, electrocardiographic findings of hyperkalemia resolved post-dialysis. Whereas, the left ventricular strain pattern appeared in one other case.

Conclusion: HD is associated with significant acute changes in systolic and diastolic BP and mean arterial pressure (MAP). These changes, if repeated frequently, can result in myocardial ischemia and infarction. HD protects the heart against hyperkalemia, and thereby arrhythmia; however, it causes ventricular strain patterns, which is a predictive of adverse cardiovascular outcomes. Evaluating the long-term complications of hemodynamic and electrocardiogram changes in pediatric HD cases is suggested.

Keywords: Child, Hemodialysis (HD), Hemodynamic changes, Electrocardiography

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Introduction

Cardiovascular diseases are the most common cause of death among dialysis patients [1]. Chronic kidney diseases (CKDs) increase the risk of coronary artery disease, heart failure, arrhythmias, and sudden cardiac death. Cardiovascular complications are among the most common etiology of mortality in dialysis patients [2].

Structural and functional cardiovascular abnormalities can develop in patients undergoing maintenance hemodialysis (HD) that make them prone to myocardial ischemia. Left ventricular hypertrophy, myocardial fibrosis, microvascular disease, accelerated atherosclerosis, and arteriosclerosis are cardiovascular changes that have been reported in CKD cases. Non-physiologic fluid removal, which results in hemodynamic instability and initiation of systemic inflammation is among the adverse effects of HD on the cardiovascular system [3]. Functional and structural abnormalities of the cardiovascular system in CKD patients predispose the myocardium to ischemic events. Asymptomatic dynamic ST-T changes which is an indicator of silent myocardial ischemia, have been found in 22% of HD patients [4].

The QT dispersion (QTd) is the difference between the maximum and minimum of the QT in different leads (minimum 10) on the same recording [1]. Increased QTc and QTcd have been reported in patients undergoing HD and peritoneal dialysis [5]. Alternations in left ventricular mass and its function are common in the CKD population [6]. Prolonged QTc is significantly more common in CKD compared to subjects without CKD. Prolonged QTc in CKD patients is associated with an increased risk of mortality [7].

Few studies in the pediatric population have evaluated the impacts of acute blood pressure (BP) and weight changes post-HD on electrocardiogram (ECG) parameters. Chronic inflammation is among the factors potentially affecting the function of the cardiovascular system in HD cases [8]. An increased risk of arterial fibrillation has been found in cases of hypokalemia, hypomagnesemia, and hyperphosphatemia [9]. Decreased serum potassium and increased serum magnesium are important risk factors for QTc prolongation [10]. A recent study found that hypotensive episodes were significantly more frequent with acetate than with citrate-based dialysis solution [11]. Electrolyte imbalances, frequently seen in HD patients account for the occurrence of arrhythmia [12].

Materials and Methods

Study design

A single-center cross-sectional study was performed on HD patients. Patients with a diagnosis of CKD stage 5 undergoing HD enrolled if they were placed on dialysis from ≥3 months before the study. The 12-lead ECGs were performed in identical conditions for all patients 10 min before and after HD sessions. Body weight (BW) was measured using digital weight scales, systolic and diastolic BPs were measured using arm BP monitors and defined as units of mm Hg, and heart rates (HRs) were measured pre-and post-HD; moreover, the mean arterial pressure (MAP) was calculated in pre and post-dialysis stages. MAP was calculated using the following formula: 1/3 systolic BP + 2/3 diastolic BP [13].

Intra-dialysis hypotension (IDH), a decrease in systolic BP ≥20 mm Hg or MAP ≥10 mm Hg is a frequent finding during HD, reported in 20%-55% of cases [14]. The QT interval, which is defined as the time of ventricular activity, including both depolarization and repolarization, is measured from the onset of the QRS complex to the end of the T wave (the return of the terminal T wave to the isoelectric baseline). Three successive QT interval measurements were performed in each of the 12 leads, and the mean values were calculated [15]. The maximum QT interval corrected for heart rate (QTC) using the Bazett formula was employed (QTC=QT/RR1/2) [16]. One examiner who had no information about the patients measured and reported ECG parameters.

Study participants

Patients undergoing HD in the dialysis section of an academic children's hospital enrolled after obtaining written consent. Those with congestive heart failure treated with digoxin were excluded from the study.

Exposure and outcomes

The exposure was undergoing maintenance HD for >3 months. The primary outcome of the study was to evaluate ECG and hemodynamic changes post-HD. The secondary outcome was to assess the impacts of hemodynamic changes, the occurrence of IDH, and interdialysis weight gain (adequate vs inadequate) on ECG parameters.

Sample size

The sample size was determined based on the census method, and all patients who fulfilled the inclusion criteria enrolled in the study.

Data analysis

Th one-sample Kolmogorov-Smirnov test was used to assess the normality of variables, and all variables had a normal distribution. The paired t-test was used to compare variables in pre- and post-HD. Moreover, the Fisher exact test was used for the comparison of patients with adequate versus inadequate weight gain inter-dialysis. Meanwhile, a $P<0.05$ was considered statistically significant.

Results

Baseline characteristics

In total, 11(55%) boys and 9(45%) girls in the age range of 8-28.25 years (16.25±6.25 years) were enrolled. They were placed on HD from 4 months to 14 years ago (45.3±47.5 months). The number of dialysis sessions was 2-3 (2.7±0.45) per week, and they were dialyzed for 3-4 (3.7±0.47) h in each session. Bicarbonate-based low calcium dialysate solutions (calcium concentration of 1.25 mmol/L) were applied for all patients. Dialysis schedules were standard (12 h/week) in nine (45%) patients. In seven (35%) cases, there was a history of previous renal transplantation. The etiologies of renal failure were vesicoureteral reflux (n=9 [45%]), neurogenic bladder (n=4 [20%]), idiopathic causes (n=4 [20%]), nephrotic syndrome (n=2 [10%]), and renal dysplasia (n=1 [5%]). The dialysis machines were Gambro and Fresenius, and different types of dialysis membranes were used based on weight (Table 1).

Hemodynamic, body weight, and electrocardiogram findings in pre- and post- HD

BW, systolic and diastolic BPs, and HRs were recorded in pre- and post-HD (Table 1). Severe fluctuations in systolic and diastolic BPs, BW, and HRs were detected. The weights of the patients decreased from 35.3±10.8 kg in pre-HD to 33.8±10.3 kg in post-HD, indicating a weight loss of 1.47±0.22 kg (P=0.0001). A decrease of 22.25±15.25 mm Hg in systolic BPs (P=0.001), 15.75±12.06 in diastolic BPs (P=0.001), and 12.45±25.68 mm Hg in MAP (P=0.001) were found post-HD (Table 2). The ranges of changes in systolic and diastolic BPs, BW, and HRs post-HD were 0 to 70 (22.25±15.25) mm Hg, 0 to 50 (-15.75±12.06) mm Hg, 0-3 (1.47±0.22) kg, and -6 to +13 (1.52±4.55) beats/min, respectively. In total, 18(90%) patients had either decreased (n=6 [30%]) or increased (n=12 [60%]) HRs post-HD.

ECG demonstrated changes in ST-T segment, QTC, and QRS complex durations, as well as PR interval. Sinus rhythm was the predominant rhythm (95%), and a single patient with sinus arrhythmia found a sinus rhythm post-dialysis. Atrial or ventricular hypertrophy was uncommon (25% and 5%, respectively).

Pre- and post-dialysis ECGs in 25% and 45% of patients demonstrated ST-T segment changes, respectively. ECG findings related to hyperkalemia were found in 6(30%) patients before HD and were resolved in four cases post-HD. The highest rate of changes in ECG parameters post-HD was in QTC duration (n=15 [75%]).

The QTC durations decreased in seven (35%) cases and increased in eight (40%) patients. PR-intervals and QRS complex durations decreased in 5 (25%) and 3 (15%) cases, respectively. Both factors increased in two (10%) patients, respectively. Dialysis resulted in a significant decrease in BW, systolic and diastolic BPs, as well as MAP.

Systolic and diastolic BPs remained constant in one (5%) and two (10%) patients, respectively. In addition, 1 (5%) case had no weight loss with dialysis (Table 1).

Although a significant decrease was detected in BW, as well as systolic and diastolic BPs, after HD, no significant change was observed in PR intervals, QTC, QTd, QRS complex durations, and HR ($P>0.05$ for all; paired t-test; Table 2). A weight gain of ≤5% and >5% inter-dialysis was defined as adequate and inadequate, respectively [17]. Applying a higher ultrafiltration rate is necessary to remove excess fluid and sodium in patients with inadequate weight gain inter-dialysis. Severe weight loss (>5% of BW) after HD results in rapid changes in systolic and diastolic BPs.

Patients with adequate versus inadequate weight gain inter-dialysis

Alternations in hemodynamic and ECG parameters were compared in patients with adequate versus inadequate weight gain inter-dialysis ($P>0.05$ for all variables; Table 3). As displayed in Table 3, patients with inadequate weight gain inter-dialysis had significantly more weight loss post-dialysis (2.42±0.64 kg vs 0.75±0.96 kg

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Table 1. Weigh and hemodynamic characteristics of enrolled cases pre- and post- dialysis

Patients	Weight (kg)		Systolic BP (mm Hg)		Diastolic BP (mm Hg)	
	Pre-HD	Post-HD	Pre-HD	Post-HD	Pre-HD	Post-HD
Case 1	62	60	170	140	120	90
Case 2	25.1	25	110	90	70	50
Case 3	41	38.5	110	90	60	50
Case 4	34	32.5	140	120	90	80
Case 5	37.7	35.6	130	100	80	60
Case 6	37	34	150	130	90	80
Case 7	25	25	100	100	60	60
Case 8	31	30	105	90	55	50
Case 9	48.4	46.5	105	100	70	70
Case 10	31.6	29.5	110	85	70	50
Case 11	24.2	23.2	140	130	90	80
Case 12	37.3	34.2	110	95	70	60
Case 13	36.6	34.5	160	90	100	50
Case 14	24.4	23.1	130	120	90	80
Case 15	22	21.9	130	110	80	70
Case 16	38.5	38.2	120	95	80	50
Case 17	47.5	46.5	150	130	90	80
Case 18	17.8	17.5	150	100	90	60
Case 19	47.5	46.3	150	130	90	80
Case 20	37. 5	34.6	110	90	70	50

HD: Hemodialysis; BP: Blood pressure.

in subjects with adequate weight gain; P=0.0001). Blood flow rates (cc/min and cc/kg/min) applied during the HD procedure were not significantly different between the two groups (P=0.154 and P=0.762, respectively).

Increased HR post-HD was found in 5(38.5%) cases with adequate and 1(14.3%) patient with inadequate weight gain (P=0.354; Fisher exact test). Moreover, 7 cases (53.8%) in the former and 5 patients (71.4%) in the latter groups had decreased HRs after dialysis (P=0.642). Nonetheless, 2 cases (10%) had no change in HR. Changes in HRs, diastolic and systolic BPs, and MAPs after dialysis were compared between cases with adequate versus inadequate weight gain inter-dialysis (P>0.05 for all; Table 3).

Ventricular strain patterns (ST-T segments changes) appeared in 4(20%) patients post-HD, including 3 cases with inadequate weight gain inter-dialysis.

Figures 1A and 1B and also Figures 2A and 2B illustrate the ECGs of two patients who had the highest increase and decrease in HRs in pre- and post-HD, respectively. The weight was 37 kg, which reached 34 kg after dialysis. The BP before HD was 150/90 mm Hg, which decreased to 130 /80 mm Hg after HD. The QTC duration decreased with HD (QTC duration in pre- and post-HD were 0.43 and 0.42 s) with no changes in PR-interval and QRS complex durations, but ST-T changes appeared post-HD in V5-V6 leads.

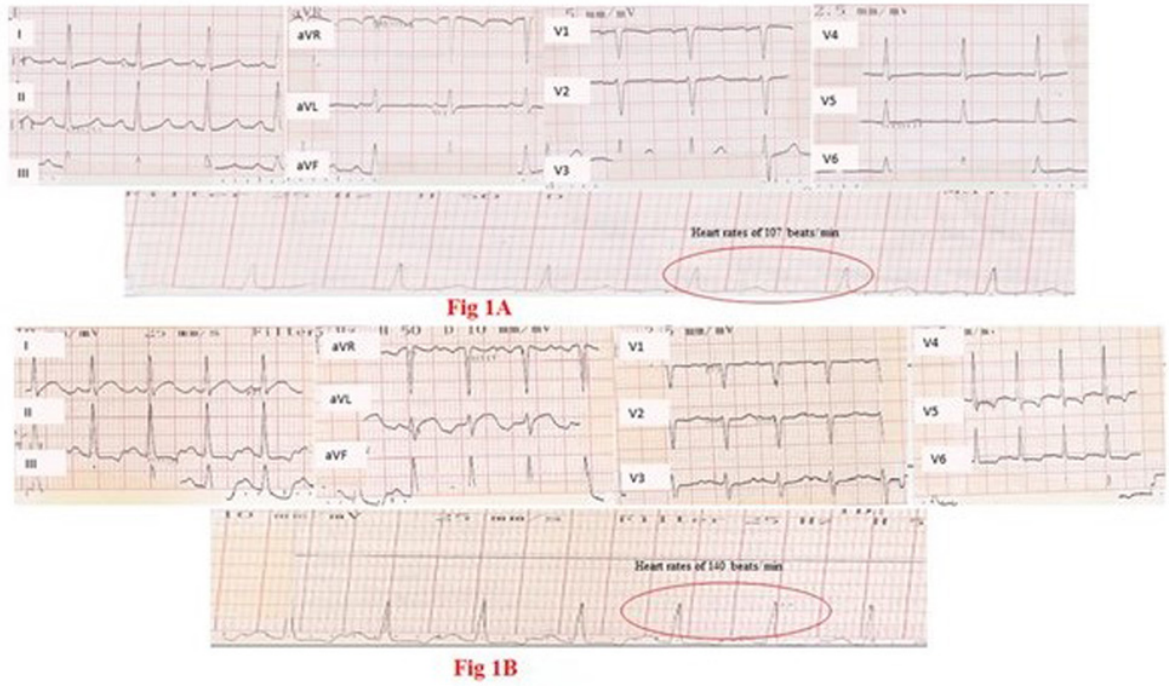

Figure 1. Electrocardiogram of a patient with the highest increase in heart rate after dialysis

A) Pre-dialysis, B) Post-dialysis

Notes: Heart rates in pre-HD and post-HD were 107 and 140 beats/min, respectively.

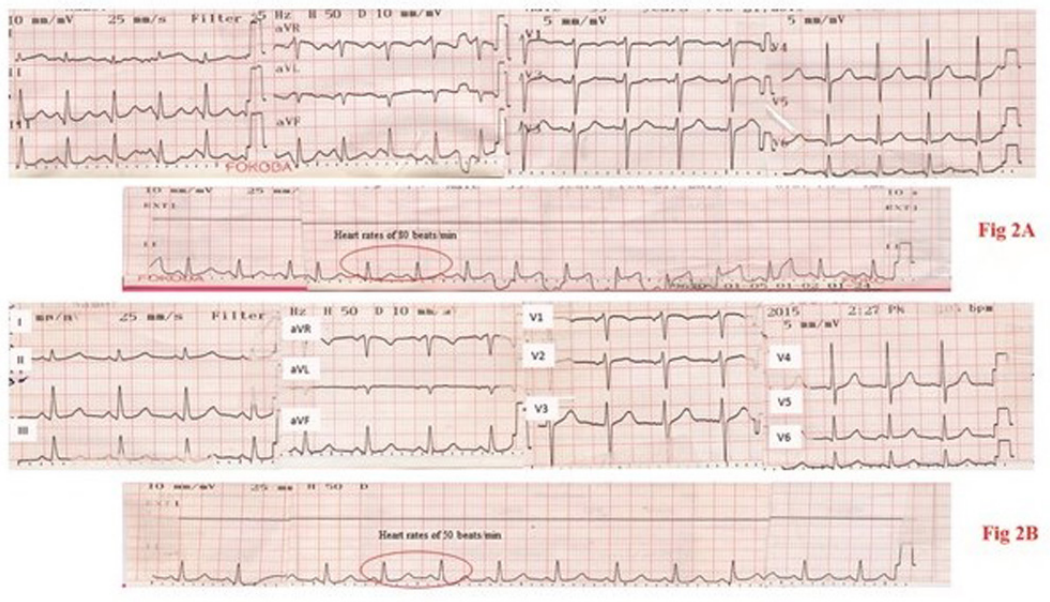

Figure 2. Electrocardiograms of a 12-year-old boy with the highest decrease in heart rate with dialysis

A) Pre-dialysis, B) Post-dialysis

Notes: Heart rates in pre-HD and post-HD were 80 beats/min and 50 beats/min, respectively. His weight was 24.4 kg, which reached 23.1 kg after dialysis. The BP before and after HD was 130/90 and 120/80 mm/Hg, respectively. The prolonged QTC duration (0.55 s) in pre-HD reached normal levels post-HD (0.44 s). No changes in PR interval and QRS complex duration were found after HD .

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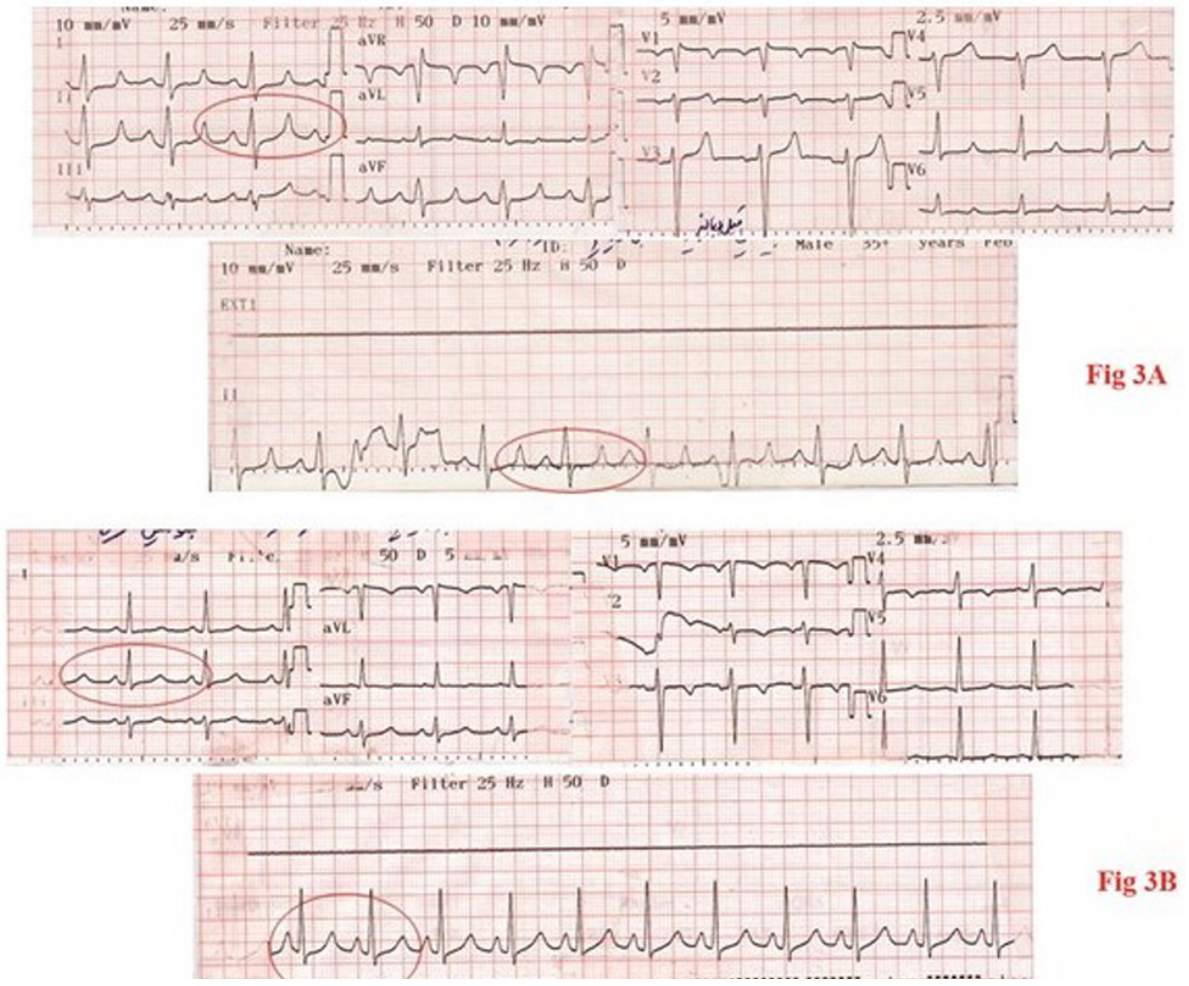

Figure 3. The electrocardiograms of an 8-year-old boy placed on dialysis 10 months before the study

A) Pre-dialysis, B) Post-dialysis

Notes: The patient had 1 kg weight loss with HD (24.2 kg in pre-HD and 23.2 kg in post-HD), BP and heart rate in pre-dialysis were 140/90 mm Hg and 85 beats/min, which reached 130/80 mm Hg and 100 beats/min respectively. Duration of the PR interval, QRS complex, and QTC all decreased with dialysis (0.16, 0.12, and 0.47 s pre-HD, which reached 0.12, 0.08, and 0.45 s post-HD, respectively). Electrocardiographic evidence of hyperkalemia, including tall T waves and prolonged PR intervals disappeared with dialysis.

Figure 3A presents the ECG of a patient with findings suggestive of hyperkalemia before HD. These changes were completely resolved post-dialysis (Figure 3B). Figures 4A and 4B display the ECGs of a patient with evidence of a left ventricular strain pattern after dialysis.

Discussion

This study found significant changes in systolic and diastolic BPs, MAP, and BW following HD; however, the changes in PR intervals, QTC, QTd, QRS complex durations, and HR were not significant. The appearance of ventricular strain pattern following HD was the main negative effect on heart electrophysiology that was observed. HD resulted in the resolution of ECG findings of hyperkalemia in a group of the patients, thus, it seems the HD protects the heart against hyperkalemia and arrhythmia.

Nguyen et al. found prolonged QT interval pre-dialysis in 44.3%, which increased to 77% one h after dialysis [18]. In our series, QTC durations decreased in 7(35%) cases and increased in 8(40%) patients after a 4-h dialysis.

In line with our findings, Astan et al. [19] reported a prolongation of QRS complex duration post-HD and suggested that it may be a marker for ventricular arrhythmias. The etiology of CKD can affect the prevalence of hypertension, left ventricular hypertrophy, and left atrial enlargement [20]. In our series, the most common eti-

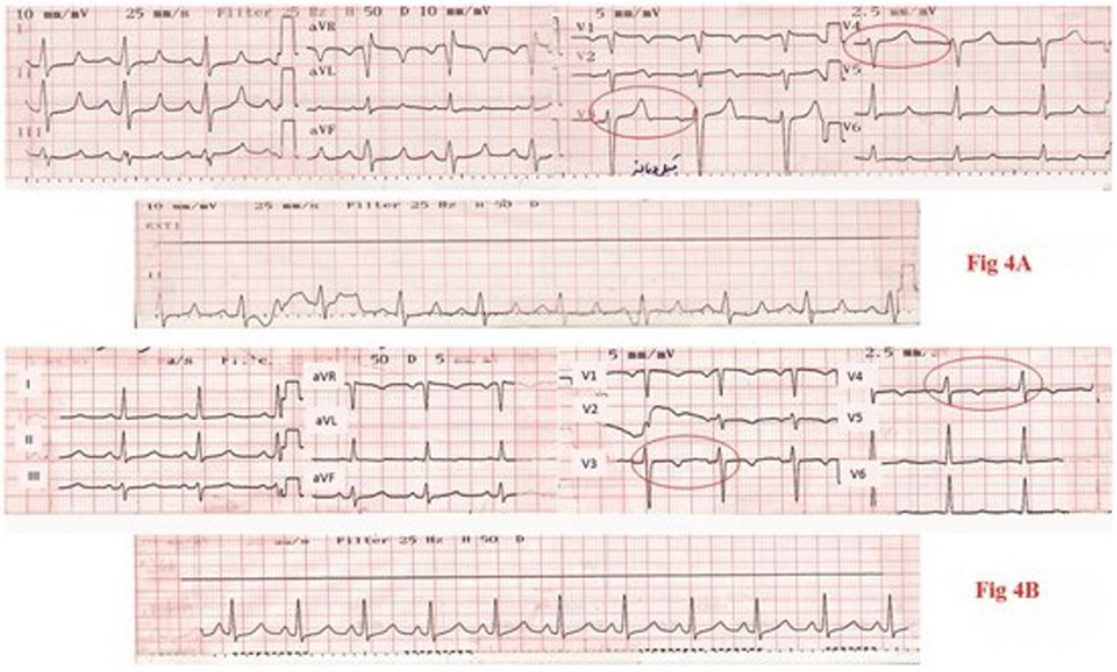

Figure 4. The electrocardiogram of a young female adult (28 years and 3 months) with a history of end-stage renal failure from 14 years ago

A) Pre-dialysis, B) Post-dialysis

Notes: Her BP and heart rate before HD were 110/70 mm Hg and 100 beats/min, respectively. She had a 2.1 kg weight loss with dialysis (31.6 kg in pre-HD and 29.5 kg in post-HD). BP decreased to 85/50 mm Hg post-HD with no change in heart rate. Changes in electrocardiogram after dialysis included prolongation of QRS duration (pre-HD=0.4 s that reached 0.46 s after HD) and appearance of inverted T waves on leads V3-V4 after dialysis.

Table 2. Hemodynamic and electrocardiographic changes after HD

Variables	Pre-HD	Post-HD	Pre- Post- HD	95% Confidence Interval	P*
Weight (kg)	35.3±10.8	33.8±10.3	1.47±0.22	1-1.94	0.0001
Systolic BP (mm Hg)	129±21.2	106.75±17.7	22.25±15.25	15-29.4	0.001
Diastolic BP (mm Hg)	80.75±15.6	65±14	15.75±12.06	10.1-21.4	0.001
MAP (mm Hg)	95.4±18.64	77.84±15.39	17.58±13.64	11.2-13.64	0.001
Heart rate (beats/m)	98.75±22.34	100.45±22.66	-1.52±4.55	-8.9-5.56	0.63
PR interval (s)	0.13±0.03	0.13±0.03	-0.006±0.005	0.018-0.006	0.316
QTC (s)	0.41±0.037	0.41±0.046	-0.002±0.04	-0.02-0.017	0.836
QTd (s)	0.072±0.03	0.06±0.04	0.006±0.52	-0.0177-0.0297	0.604
QRS complex duration (s)	0.084±0.01	0.083±0.009	0.015±0.003	-0.006-0.008	0.772

BP: Blood pressure; HD: Hemodialysis.

*Paired t-test.

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Table 3. Hemodynamic and electrocardiogram changes in patients with adequate versus inadequate weight gain inter-dialysis

Variables	Weight Gain Inter Dialysis	Pre- Post- HD	P*
Heart rates (beats/m)	Adequate[1] Inadequate[2]	4.53±-0.66 2.96±-2.28	0.405
Systolic BP (mm Hg)	Adequate Inadequate	20.38±12.49 25.71±20.08	0.471
Diastolic BP (mm Hg)	Adequate Inadequate	14.23±10.77 -18.57±14.6	0.458
Mean arterial BP (mm Hg)	Adequate Inadequate	15.25±12.29 20.99±16.32	0.428
QTC duration (s)	Adequate Inadequate	0.041±-0.01 0.051±0.01	0.357
QRS complex duration (s)	Adequate Inadequate	0.0015±0.017 0.0115±0	0.836
PR interval (mm)	Adequate Inadequate	0.029±-0.01 0.017±0.002	0.276
Weight loss (kg)	Adequate Inadequate	0.75±0.96 2.42±0.64	0.0001

HD: Hemodialysis; BP: Blood pressure.

*Paired t-test, [1]They included 13(65%) patients, [2]They included 7(35%) patients.

ology for CKD was vesicoureteral reflux (n=9 [45%]). In total, out of 20 enrolled cases, 5(25%) patients had atrial hypertrophy (AH), including 4(80%) subjects with vesicoureteral reflux and 1(20%) patient with renal dysplasia. Right AH, left AH, and both AH were found in 3(15%), 1(5%), and 1(5%) cases, respectively. Prolonged QT intervals were reported in 34% of cases pre-HD, and its frequency increased post-HD (46%). We noted prolonged QT intervals in pre- and post-HD in 35% and 40% of cases, respectively.

To prevent severe hemodynamic changes during dialysis, a weight gain ≤5% of total BW between dialysis sessions is considered adequate [17]. The weight loss during HD is due to the removal of excess sodium and fluid accumulated in extracellular (interstitial and intravascular) spaces inter-dialysis. Rapid changes in intravascular volume during HD can be assessed by measuring changes in systolic and diastolic BPs post-HD.

The amounts of intravascular depletion can differ in patients with similar weight loss. Rapid changes in BPs during HD can potentially induce acute myocardial ischemia. In our series, evidence of myocardial ischemia (ventricular strain pattern) appeared post-HD in 4(20%) cases, including 3 of 7(42.8%) cases with inadequate and one of 13(7.7%) subjects with adequate weight gain inter-dialysis (P=0.061, Fisher exact test). Moreover, 13 (65%) cases had a decrease of ≥20 mm Hg in systolic BPs and ≥10 mm Hg in MAP (consistent with definitions of IDH).

A recent study in adults undergoing HD showed that after compared to pre-HD, HR significantly increased, whereas, the duration of QRS complex and QTd (ventricular repolarization parameters) significantly decreased [21]. They excluded patients with underlying heart diseases (heart failure, a history of coronary artery diseases, and heart block). In contrast to this study, we did not find any significant changes in HRs or the durations of QRS complex and QTd in post compared to pre-HD. The difference in study population may account for different results.

The strain pattern is a marker for the presence of LVH on ECG. It is defined by ST depression and T-wave inversion. ECG strain is independently associated with all-cause mortality, and adverse cardiovascular events, [22]. Patients with CKD have high cardiovascular morbidity and mortality, and CKD worsens cardiovascular outcomes [23].

Control of total body volume and BP is critical in patients undergoing dialysis and impacts on cardiovascular complications [24]. We found evidence of right and left ventricle strain patterns post-HD in 4(20%) patients, indicating dialysis-induced myocardial ischemia. Ventricular strain pattern appeared in four of 7(71.4%) cases with inadequate and none of 13 patients with adequate weight gain inter dialysis (P=0.058). A physiologic response to decreased BP should be an increase in HR to maintain optimal cardiac output and protect vital organs against reduced perfusion. The lack of this physiologic response potentially can result in diminished cardiac output and hypo-perfusion injuries.

Conclusion

HD is associated with significant acute changes in systolic and diastolic BP, and MAP. These changes if repeated frequently can result in myocardial ischemia and infarction. Resolution of ECG findings of hyperkalemia was a positive effect of HD that was observed. This finding suggests that HD protects the heart against hyperkalemia, thus arrhythmia. However, HD resulted in ventricular strain patterns in a group of patients. This finding is predictive of adverse cardiovascular outcomes. Our study revealed that HD has no significant impact on QTC, QRS complex durations, QTd, and PR interval.

Nonetheless, there has remained a significant concern about whether repeated acute hemodynamic changes with HD can provoke cardiac ischemia and ventricular dysfunction.

Limitations

The main limitation of our study was the lack of measuring serum potassium and calcium concentrations before and after HD. The ECG changes might be due to the cumulative effects of electrolytes and hemodynamic changes provoked by dialysis.

Ethical Considerations

Compliance with ethical guidelines

The Ethics Committee of Mashhad University of Medical Sciences approved the study (Code: IR.MUMS.REC.1388.200), and it conforms to the provisions of the Declaration of Helsinki.

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Authors' contributions

Conceptualization, investigation, data validation, data curation, writing, project administration, and resources: Mitra Naseri and Samanah Kouzegaran; Methodology, visualization, supervision, software, and formal analysis: Mitra Naseri.

Conflict of interest

The authors declared no conflict of interest.

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