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Intradialytic exercise increases cardiac power index

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Original Article

ABSTRACT

Introduction: Mortality rates are high in end-stage renal disease due to cardiovascular complications. Perfusion of the myocardium declines during and after hemodialysis sessions with the potential for aerobic exercise to mitigate these during hemodialysis.
Objectives: The purpose of this study was to investigate acute changes in hemodynamics in subjects with end-stage renal disease (ESRD) during exercise.
Patients and Methods: Subjects (n = 10) were monitored for 1.5 hours during hemodialysis treatment during a control (CON) and an exercise (EX) session. Subjects cycled using an ergometer strapped to the reclining dialysis chair at an RPE of 11-13 for 30 minutes during the EX session beginning at 30 min into dialysis and ending at 60 minutes. Data for systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean arterial pressure (MAP) were collected using an automated blood pressure cuff attached to the hemodialysis machine. Data for cardiac output ($\dot{Q}$), cardiac power index (CPI), stroke volume (SV), systemic vascular resistance (SVR), and heart rate (HR) were collected using the NICaS bioelectrical impedance device.
Results: During the EX session, CPI, $\dot{Q}$, SV, and HR were significantly greater ($P < 0.05$) than the CON session. Additionally, $\dot{Q}$ was significantly ($P < 0.05$) greater at 45 minutes and 60 minutes compared to 15 minutes. HR was significantly ($P < 0.05$) greater at 45 minutes compared to 90 minutes. No significant interactions were found for MAP, CPI, $\dot{Q}$, HR, SV, SBP, DBP, or SVR.
Conclusion: In conclusion, exercise during dialysis may decrease the likelihood of experiencing ischemic or hypotensive events by enhancing myocardial perfusion through increasing CPI and $\dot{Q}$.

Implication for health policy/practice/research/medical education:
ESRD patients undergo hypotension and perfusion issues during hemodialysis. Acute aerobic exercise during a hemodialysis session was investigated to determine if CPI would increase compared to a control session. CPI was enhanced through increases in cardiac output and may improve perfusion during hemodialysis.
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Introduction

End-stage renal disease (ESRD) is present in 15 per 10 000 people in first world countries and these individuals are more prone to developing cardiovascular disease (CVD) (1). Risk of CVD in ESRD patients is enhanced by albuminuria, anemia, hyperparathyroidism, metabolic bone disease, hyperhomocysteinemia, malnutrition, apolipoprotein isoforms, inflammation, endothelial dysfunction, and oxidative stress (2). Research pertaining to rehabilitation for ESRD patients and mitigating risk factors for CVD is lacking on a nation-wide level (3). Furthermore, low exercise capacities in ESRD patients

contributes to abnormally high mortality rates (4).

Patients with impaired renal function display lower glomerular filtration rates (GFR) and present with elevated serum creatinine and blood urea nitrogen levels from damage to nephrons (1). ESRD patients must undergo renal replacement therapy through hemodialysis, peritoneal dialysis, or kidney transplantation (1). Byproducts not removed through the renal system affect every organ system (5). Causes of chronic kidney disease (CKD) arise due to injury to nephrons from inflammation, hypoperfusion, ischemia, or toxic damage (5). Cardiovascular complications occur from CKD such

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as, left-ventricular hypertrophy (LVH), hypertension, reduced vascular compliance, atherosclerosis, cardiomyopathy, cardiac fibrosis, and anemia (3).

Exercise during hemodialysis has been of interest as it may negate effects produced by hemodialysis treatment and may enhance the overall efficacy of dialysis (3). ESRD patients undergoing intradialytic exercise experience enhancement of heart rate variability, ejection fraction, and lower risk of sudden cardiac death (6). Intradialytic exercise enhances solute removal from blood serum by increasing perfusion of capillary beds (3,7). Exercise during hemodialysis improves aerobic capacity, resting diastolic and systolic blood pressure values, and hemoglobin levels (6,7). Furthermore, markers of inflammation and oxidative stress are reduced from intradialytic exercise, possibly reducing overall mortality rate (8,9).

Hemodynamic instability with transient myocardial ischemia is prevalent in ESRD patients undergoing traditional three-day per week hemodialysis treatment (3,10). Rapid fluid removal from intravascular spaces during hemodialysis requires fluid shifts from intracellular and interstitial spaces (3). Inadequate fluid shifting results in hemodynamic instability and a reduction in blood pressure. Reductions in cardiac output ($\dot{Q}$) and mean arterial pressure (MAP) provokes systemic and myocardial hypoperfusion, leading to greater chances of experiencing myocardial stunning during and after hemodialysis (3).

Intradialytic hypotension (IDH) is induced through reduced ventricular filling, ventricular dysfunction, impaired reaction to catecholamines, reduced blood volume, and autonomic dysfunction (11). Abnormal regulation of arterial pressure from desensitized baroreceptors may also provoke IDH (11). Episodes of IDH correlate highly with adverse cardiovascular events during hemodialysis treatment (12).

Myocardial stunning is seen as transient ischemic episodes during hemodialysis inducing abnormalities in left-ventricular function (10,13). Stunning of the myocardium is defined as post-ischemic myocardial dysfunction even with restored blood flow (10). A stunned myocardium presents as a sluggish contraction during systole. Repeated events of stunning leads to fibrosis, diastolic dysfunction, and higher myocardial workloads. Prolonged stunning of the myocardium leads to eventual hibernation and irreversible death of myocardial tissues with possible sudden death (10). Changes in circulatory patterns from myocyte-capillary mismatching reduces coronary flow and is typically present in patients demonstrating LVH (14). Increases in vascular stiffness and LVH work together to reduce coronary perfusion and endothelial function, increasing the likelihood of myocardial stunning (13,14).

Exercise induces increases in $\dot{Q}$ and MAP, which could theoretically increase perfusion of myocardial tissue, reducing hemodynamic instability in ESRD patients(3). Reasonable interventions should increase $\dot{Q}$ and MAP to reduce adverse ischemic events. Little research has been done to investigate the effect of intradialytic exercise to enhance myocardial perfusion and reduce episodes of IDH. The potential for intradialytic exercise to reduce hemodynamic instability, myocardial stunning, and negative outcomes of hemodialysis has not been well studied (3). CPI may be a potential indicator of myocardial perfusion and is measured in watts per meter squared by multiplying MAP by $\dot{Q}$ (15).

Objectives
The purpose of this study was to investigate differences in hemodynamic variables in subjects undergoing intradialytic exercise compared to no exercise. We hypothesized that intradialytic exercise would increase CPI, MAP, and $\dot{Q}$ compared to a control session.

Patients and Methods
A repeated measures study design was used to determine the effect of an acute bout of intradialytic exercise on hemodynamics in ESRD subjects using the NICaS bioelectrical impedance device (NICaS, NI Medical, Peta Tikva, Israel) and an automated blood pressure device attached to the dialysis machine (2008T Hemodialysis Machine, Fresenius, USA). The independent variables were intradialytic exercise condition (no exercise, exercise) and time (seven time points at 15 min intervals). The primary dependent variables were MAP, CPI, and $\dot{Q}$. Secondary dependent variables were systolic blood pressure (SBP), diastolic blood pressure (DBP), heart rate (HR), stroke volume (SV), and systemic vascular resistance (SVR).

Subjects
Subjects (n = 10) in this study were ESRD patients sourced from the American Renal Associates Dialysis clinic in Western, MA. Average age of subjects was 54.30 years (SD = 9.93), eight were men and two were women. Average time since hemodialysis begun was 2.99 years (SD = 2.49). Subject weight averaged 93.17 kg (SD = 25.45) during the control session and 93.04 kg (SD = 25.24) during the exercise session. Descriptive statistics can be found in Table 1. Inclusion criteria were: (1) conventional hemodialysis three times per week; (2) 20 to 70 years of age; (3) undergoing hemodialysis for >3 months; (4) physically able to exercise with no contraindications; (5) capable of independently giving informed consent; (6) medical clearance from a nephrologist. Full exclusion and inclusion criteria were reviewed by the subject's nephrologist. Participation was voluntary. The researcher obtained Institutional Review Board approval and subjects

Table 1. Subject characteristics

Characteristics (n = 10)	
Age (y), mean ± SD	54.30 ± 9.93
Height (cm), mean ± SD	172.90 ± 12.07
Dry weight Con (kg), mean ± SD	93.17 ± 25.45
Dry weight EX (kg), mean ± SD	93.04 ± 11.24
Hemoglobin (mg/dL), mean ± SD	11.24 ± 1.33
Years on dialysis	2.99 ± 2.49
Sex (m/f)	(8/2)
Race (CN/LT/AFR)	(5/3/2)
Reason for dialysis (HT/T2D/TN/GN)	(5/2/2/1)
Medications	
Alpha receptor agonists	5
Angiotensin 2 receptor blockers	4
Angiotensin converting enzyme inhibitor	2
Beta 2 agonist	3
Beta blocker	7
Calcium channel blocker	3
Diuretic	3
Gaba analogue	3
Insulin	4
Phosphate binder	8
Proton pump inhibitor	3
Statin	5

Abbreviations: CN, Caucasian; LT, Latin; AFR, African American; HT, hypertension; T2D, Type II diabetes; TN, toxic nephropathy; GN, glomerular nephritis.

completed informed consent prior to sessions with the researcher.

Measuring instruments

A standard automated blood pressure device attached to the hemodialysis machine was used to determine SBP and DBP at 15 minutes time intervals during the dialysis treatment. Using SBP and DBP, MAP was calculated to determine instances of IDH at or below 70 mm Hg.

The NICaS device was used to collect data on $\dot{Q}$, CPI. Secondarily, the NICaS was used to collect data on secondary variables SV, HR, and SVR. The NICaS whole-body bioelectrical impedance device has been validated to measure $\dot{Q}$ and SV (16–20). NICaS strongly correlates with pulmonary artery catherization thermodilution and echocardiograph techniques for $\dot{Q}$ and SV estimation (16–20). The NICaS device measures CPI (W/m²) (15). CPI may decrease in subjects undergoing hemodialysis treatment due to less contractile force production from impaired coronary blood flow (15).

Procedures

Following approval from the Institutional Review Board, a

letter was sent to the ARA hemodialysis center in Western Massachusetts for permission to identify subjects and conduct research in the center. Once approval had been granted by the hemodialysis center, recruitment flyers were posted. If subjects were interested in participating, the researcher and the subject's nephrologist completed the medical history and medical release form to vet subjects through exclusion and inclusion criteria. The researcher obtained signed medical history and medical release forms prior to the start of the sessions. The researcher assigned subjects a number for anonymous and confidential data collection and analysis. Subject number was assigned based upon the time of study entry.

Subjects underwent three sessions: (1) familiarization with equipment and paperwork completion; (2) control session (CON); (3) experimental session (EX). During the familiarization session, subjects approved by their nephrologist signed the consent form, with emphasis on subject confidentiality. Height was recorded during the familiarization session utilizing a stadiometer; dry weight was recorded at the beginning of each session with a weight scale. All subjects were informed that participation was voluntary, and subjects could withdraw at any time. Subjects were fitted to the cycle ergometer (881 E, Monark Exercise AB, Vansbro, Sweden) for later use in EX session.

After the familiarization session and all paperwork were completed, subjects underwent session 2 (CON) and session 3 (EX) in a randomized order. Both CON and EX sessions occurred during the mid-week hemodialysis session to standardize dry weight of the subject, with one to two weeks between sessions. Conventional hemodialysis entails hemodialysis treatment in a dialysis center for three days per week lasting approximately three hours per session. Medical staff were present for routine monitoring during the dialysis sessions for indications of adverse cardiac or hypotensive events as per the clinic guidelines. Medical staff acted according to routine clinical care as indicated by the clinic.

For CON and EX sessions, data were collected with the NICaS device and the automated blood pressure cuff. The NICaS device had two electrodes placed on the palm side of the distal portion of the inferior radioulnar joint on each arm. During the EX session, the cycle ergometer was attached to the foot of the chair in which the subject was reclining during hemodialysis to be stable and comfortable for the subject while pedaling.

Both CON and EX sessions underwent conventional hemodialysis with data being collected from start of hemodialysis to 1 hour and 30 minutes into hemodialysis at 15 minutes intervals (Figure 1). For the CON session, data were collected with no intradialytic exercise. For the EX session, subjects remained sedentary for the first 25 minutes. At the 25 minutes mark, subjects underwent a
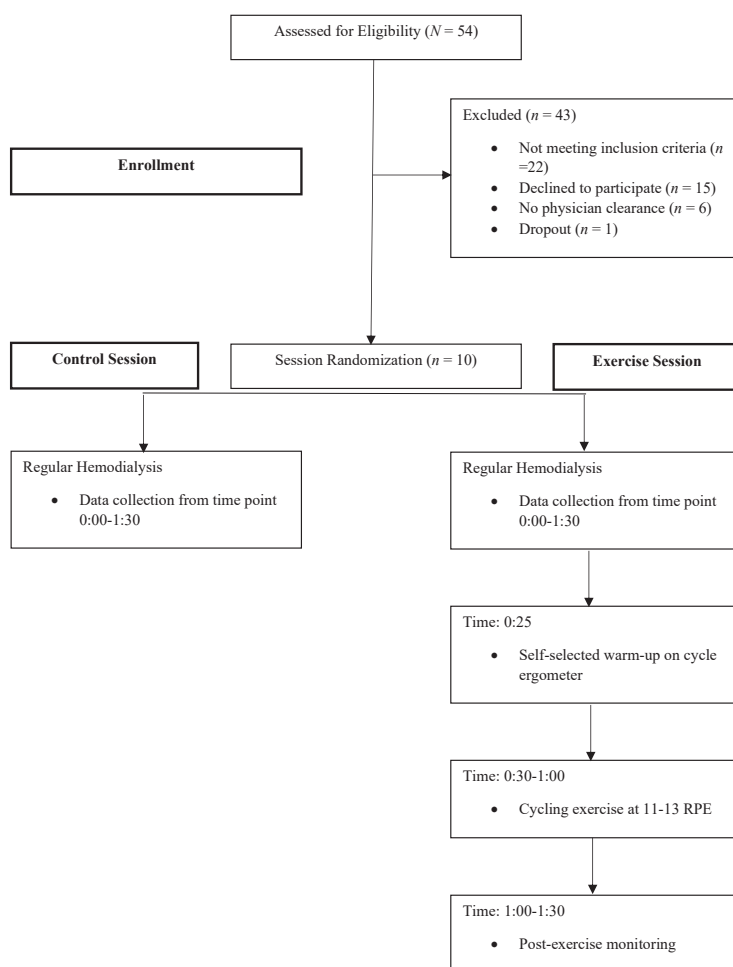
Figure 1. Enrollment and flow chart for exercise and control sessions.

self-selected intensity 5 minutes warm up utilizing a cycle ergometer. After the 5 minutes warm up was finished, 30 minutes of cycling exercise was completed at an 11-13 RPE aiming for 55% of age-predicted HR maximum. Exercise ceased at the 60 minutes mark.

Ethical issues
Subjects signed informed consent and the study was approved by the Springfield College Institutional Review Board prior to data being collected. All procedures performed in studies involving human participants are in accordance with the ethical standards of 1964 Helsinki Declaration and its later amendments. All participants provided written and informed consent. This study was conducted as a master's thesis by Brent Momb at Springfield College.

Statistical analysis
IBM statistical package for the social sciences (SPSS, v. 20) was used for analysis with an alpha level of $P = 0.05$. A total of three repeated measures factorial analysis

of variance 2 X 7 (ANOVA) were used to examine mean differences and interactions between two conditions across seven-time points (EX, CON) for MAP, CPI, and Q̇. Five repeated measures factorial Analysis of Variance 2 X 7 (ANOVA) were used to examine mean differences and interactions between two conditions across seven-time points (EX, CON) for secondary variables HR, SV, SBP, DBP, and SVR.

Results

All potential subjects (N = 54) were screened for eligibility. Forty-four were excluded due to not meeting the inclusion criteria (n = 22), declining to participate (n = 15), for not being cleared to participate by their physician (n = 6). Eleven of the subjects were approved, one dropped out prior to the study commencing. Ten subjects completed both the EX and CON sessions. Three completed the CON session first and seven completed the EX session first. The data were screened for missing data, normality, and outliers. No missing values or outliers were observed. All data were determined to be mesokurtic. CPI during

the EX session at 45 minutes and 75 minutes were positively skewed. CPI was positively skewed during the CON session at 90 minutes. All other data were normally skewed. The test of sphericity indicated no significant difference ($P > 0.05$) for MAP, CPI, Q̇, HR, SV, SBP, DBP, and SVR. Descriptive statistics for variables are summarized in Table 2. All means are reported ± SE.

No significant interactions were found for the primary or secondary variables. Significant ($P < 0.05$) mean differences for CPI $F = 12.796$ (1, 9), $P = 0.006$, $\eta_p^2 = 0.587$, Q̇ $F = 32.178$ (1, 9), $P = 0.000$, $\eta_p^2 = 0.781$, SV $F = 20.939$ (1, 9), $P = 0.001$, $\eta_p^2 = 0.699$, and HR $F = 13.013$ (1, 9), $P = 0.006$, $\eta_p^2 = 0.591$ were found between conditions. Additionally, significant ($P < 0.05$) time effects were found for Q̇ $F = 2.678$ (6, 54), $P = 0.024$, $\eta_p^2 = 0.229$ and HR $F = 2.815$ (6, 54), $P = 0.019$, $\eta_p^2 = 0.238$ (Figure 2).

CPI was significantly higher ($P < 0.05$) in EX (0.79 W/m^2 ± 0.03) compared to CON (0.67 W/m^2 ± 0.04), 95% CI = 0.045, 0.200 (Table 2). For Q̇, the EX condition (7.91 L/min ± 0.49) was significantly higher ($P < 0.05$) than the CON condition (6.90 L/min ± 0.048), 95% CI = 0.606, 1.409. For SV, the EX condition (96.99 mL ± 4.39) was significantly higher ($P < 0.05$) than the CON condition (88.73 mL ± 3.99), 95% CI = 4.175, 12.340. For HR, the EX condition (78.23 BPM ± 4.19) was significantly higher ($P < 0.05$) than the CON condition (73.21 BPM ± 4.26), 95% CI = 1.870, 8.159. The time effects for Q̇ and HR were analyzed using pairwise comparisons. At 45 minutes, Q̇ was significantly ($P < 0.05$) higher (7.83 L/min ± 0.42) compared to 15 minutes (6.78 L/min ± 0.53), 95% CI = 0.175, 1.919. Q̇ was also significantly higher ($P < 0.05$) at 60 minutes (7.97 L/min ± 0.56) compared to 15 minutes (6.78 L/min ± 0.53), 95% CI = 0.157, 2.206. HR was significantly ($P < 0.05$) higher at 45 minutes (78.30 BPM ± 0.42) compared to 90 minutes (75.00 BPM ± 4.89), 95% CI = 0.179, 6.421.

Discussion

The purpose of this study was to determine if exercise during a session of dialysis would increase MAP, CPI, and Q̇ compared to a control session with no exercise. The main findings are two-fold: CPI was higher during the EX session compared to CON session; and second, Q̇ was higher during the EX session compared to the CON session. No changes were observed regarding MAP when comparing the EX to the CON session.

Hemodialysis induces large decreases in plasma volume which could potentially induce hemodynamic instability and IDH (3). IDH may precipitate myocardial ischemia through hypoperfusion of cardiac tissues (13). Thus, it has been postulated that normal responses to exercise may negate the impact of IDH by preventing it during dialysis treatment (3).

No changes in MAP were observed between the CON or EX session or over the 1.5 hours monitoring period. No periods of hypotension were observed during the study. MAP in this study was similar between the control session (90.26 mm Hg ± 2.78) and exercise session (93.86 mm Hg ± 3.40). From this, SBP (Table 2) was similar in the control session (132.60 mm Hg ± 5.13) to the exercise session (136.76 mm Hg ± 6.44). Recent studies examining blood pressure in subjects receiving intradialytic exercise reported similar findings with no differences in either control or exercise sessions (21,22). Other researchers observed no changes in SBP between control (140.90 mm Hg ± 22.30) and exercise sessions (131.30 mm Hg ± 20.00) (21). However, other researchers have demonstrated significant increases in SBP with the introduction of intradialytic exercise (6,9,23).

The typical response to exercise is increases in peripheral vasodilation to meet metabolic needs of skeletal muscle (23). Baroreceptors, chemoreceptors, and skeletal muscle receptors increase sympathetic mediated outflow to the heart to maintain or increase blood pressure. However,

Table 2. Hemodynamics for control (CON) and exercise (EX) sessions

Characteristics (n = 10)	CON	EX	η_p^2
Primary variables			
Mean arterial pressure (mm Hg)	90.26 ± 2.78	93.86 ± 3.40	0.078
Cardiac power index (W/m^2)	0.67 ± 0.05	0.79 ± 0.03**	0.587
Cardiac output (L/min)	6.90 ± 0.48	7.91 ± 0.48**	0.781
Secondary variables			
Heart rate (beats/min)	73.21 ± 4.26	78.23 ± 4.18**	0.591
Stroke volume (mL/beat)	88.73 ± 3.99	96.99 ± 4.39**	0.699
Systolic blood pressure (mm Hg)	132.60 ± 5.13	136.76 ± 6.44	0.039
Diastolic blood pressure (mm Hg)	70.88 ± 2.57	72.87 ± 2.37	0.040
Systemic vascular resistance(dyn·s·cm^{-5})	2292 ± 176	2102 ± 200	0.144

Note. ** Indicates a significant difference ($P < 0.01$) between conditions.
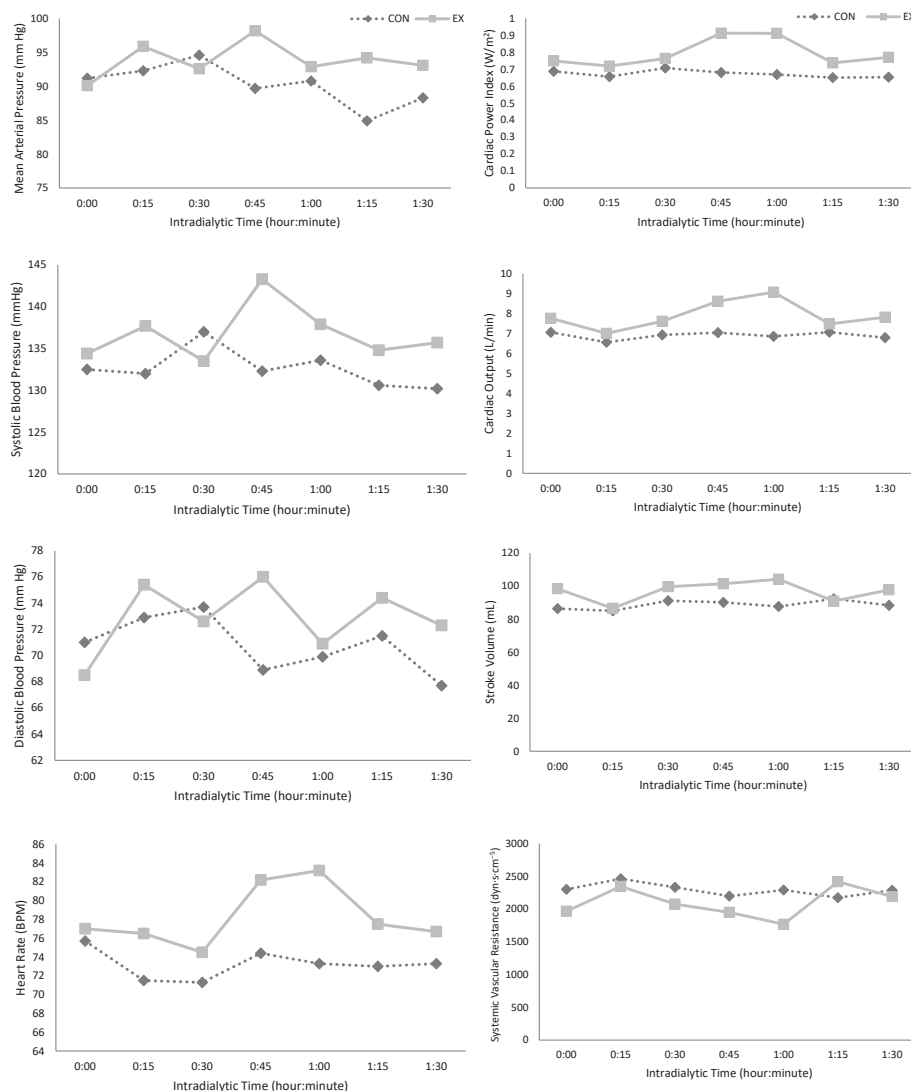
Figure 2. Changes in hemodynamic parameters between the control (CON) and exercise (EX) sessions in hemodialysis patients.

subjects undergoing hemodialysis treatment may present with enhanced sympathetic activity, and decreased baroreceptor sensitivity (23). Sympathetic dominance and rapid fluid removal during dialysis treatment may be a possible explanation of no changes in blood pressure in this current study. Subjects who have impaired renin-angiotensin-aldosterone systems along with inability to match Q̇ during dialysis may be sympathetically dominated. No statistical difference was found in SVR between EX (2101.78 dyn·s·cm^{-5} ± 199.944) and CON (2291.90 dyn·s·cm^{-5} ± 176.29). However, the small decrease in SVR observed in the EX session may suggest the small increase in MAP was due to increased Q̇ and decreased SVR. Second, self-selected intensity between an RPE of 11-13 may not have been enough to induce increases in MAP. Last, subjects heavily medicated with anti-hypertensive medication may not produce normal responses to exercise leading to no changes in MAP,

medication list can be found in Table 1.

Even though no differences were noted in MAP during either session EX or CON, it is possible that intradialytic exercise could potentially maintain MAP during hemodialysis treatment. Maintaining blood pressure during exercise could be of benefit to subjects who experience IDH. Furthermore, it is evident that exercise during dialysis treatment does not exacerbate hemodynamic instability and did not induce post-exercise hypotension in this study.

Subjects who are prone to IDH have reductions in overall cardiac contractility, leading to reductions in cardiac power output (11). Cardiac power may be reduced due to reductions in preload from high ultrafiltration rates (15). In the present study, CPI during the EX session was higher compared to the CON session. CPI is a product of Q̇ and MAP and is measured in Watts produced compared to the patient's total body surface area (24). The increase

in CPI from this study can likely be attributed to increases in $\dot{Q}$ from enhanced contractility and preload of the myocardium (15).

Myocardial stunning presents with a myocardium that fails to contract normally and thus may potentially have a reduced power output (10). This reduced power output may be attributed to decreased $\dot{Q}$ or MAP during the dialysis session. Decreased $\dot{Q}$ or MAP can lead to hypoperfusion of the myocardium. Potential ways to increase CPI would be to reduce ultrafiltration rate or increase the target weight of the patient (15). However, intradialytic exercise increased CPI compared to control and may be an alternative option. This is the first study known to the researcher to determine changes in CPI from intradialytic exercise. In ESRD subjects, average CPI during dialysis treatment appears to be 0.59 W/m² ± 0.04 (15). In comparison to baseline values seen in other studies, this study demonstrated a CPI of 0.67 W/m² ± 0.04 during the control session and increased to 0.79 W/m² ± 0.03 during the exercise session. The increase in CPI in this study indicates intradialytic exercise may mitigate IDH and hypoperfusion of tissues.

Ultrafiltration from hemodialysis reduces $\dot{Q}$ and SV but MAP is typically maintained by variations in SVR (11). Reductions in overall cardiac contractility may coincide with reductions in $\dot{Q}$ (11). The current study demonstrated a 13% increase in cardiac output from 6.90 L/min ± 0.48 during the control session to 7.91 L/min ± 0.49 in the exercise session. Similar results were noted by other researchers when patients exercised for two, 10-min periods during hemodialysis (25). Researchers recorded a 36% increase from 5.1 L/min ± 1.1 up to 7.9 L/min ± 2.4 (25). $\dot{Q}$ in this study was increased through enhanced SV and HR. SV increased from 88.73 mL ± 3.99 in the CON session to 96.99 mL ± 4.39 in the EX session. HR increased from 73.21 BPM ± 4.26 in the CON session to 78.23 BPM ± 4.18 in the EX session. This study demonstrated intradialytic exercise increases $\dot{Q}$ compared to a control session, similar to results described by other researchers (23).

$\dot{Q}$ is a product of HR and SV. Exercise in normal populations enhances $\dot{Q}$ through both HR and SV increases (3). SV during dialysis treatment may be impaired through reductions in circulating blood volume (11). Dialysis treatment also has a potential side effect of inducing LVH through pressure dependent mechanisms of hypertension and aortic stiffness (26). Reductions in SV from lower circulating blood volumes and concentric hypertrophy leads to enhancement of $\dot{Q}$ primarily from increases in HR (3). Increases in primarily from heart rate increases myocardial oxygen consumption and may potentiate ischemic conditions (27). Declining cardiac output correlates with decreased coronary perfusion, and this decreased coronary perfusion leads to myocardial stunning (3). Thus, increases in cardiac output may contribute to reductions in the negative impact of hemodialysis by keeping the myocardium adequately perfused (3). Increasing $\dot{Q}$ through intradialytic exercise in dialysis patients may help attenuate the negative impacts of reducing relative blood volume from ultrafiltration (11).

Myocardial stunning is described as a prolonged, post-ischemic left ventricular dysfunction (10). Myocardial stunning precipitates both hibernation of the myocardium and myocardial infarction and is a major contributor to mortality rate. The pathophysiology of myocardial stunning is multifactorial. Myocardial fibrosis interferes with the capability of the left ventricle to relax normally, decreasing cardiac output. Fibrotic tissues and excess workload placed on the myocardium induces LVH. Furthermore, rapid fluid removal from ultrafiltration can potentially impact the myocardial vascular bed leading to hypoperfusion. A stunned myocardium appears as sluggish during systole with a failure to contract normally (10).

By observing changes in MAP, CPI, and $\dot{Q}$ we can begin to draw conclusions on the issue of myocardial stunning in hemodialysis patients. Maintaining or increasing MAP and $\dot{Q}$ by enhancing CPI may potentially reduce incidences of hypoperfusion during hemodialysis sessions (3,10). While MAP did not increase or decrease in this study, exercise may contribute to the maintenance of perfusion during hemodialysis.

This study is limited primarily by the inability to monitor intensity beyond rate of perceived exertion. This could skew results dependent on the subject's differential thoughts on exerted effort during the EX session. Heart rate was taken, however 70% of the subjects were on beta-blockers. Age-predicted HR maxes for subjects ranged between 151-181 BPM. Based upon observed HR, subjects averaged between 40-48% HR maximum during the CON session and 43-52% HR maximum during the EX session.

The study was also limited by the assumption that the NICaS device used adequately monitored hemodynamic variables during the session. Due to fluid being removed from where the electrical signals were being sent, this could have influenced the results. To combat this, a repeated measures design was implemented. The power analysis conducted prior to the study commencing suggested 15 subjects would be adequate. We obtained only 10 subjects due to a limited number of subjects available at the clinic and being willing to participate in the study. Finally, the inability to prescreen for myocardial stunning in subjects may impact the conclusions. Future research should look to identify if myocardial stunning

can be linked to reductions in CPI by cross validation with echocardiography.

Conclusion

In conclusion, exercise during dialysis increased both CPI and $\dot{Q}$, potentially reducing IDH and hypoperfusion of the myocardium. As myocardial stunning represents a high risk for mortality in hemodialysis patients, more research should be done in this population on the effects of exercise during treatment. It may be prudent to include exercise during dialysis in patients who are receptive to the intervention.

Authors' contribution

BAM proposed the subject and methods, collected data, performed statistical analysis, and wrote the manuscript. SAEH provided insight into methods and edited the final manuscript. TDM provided insight into statistical procedures and editing the final manuscript. MJG provided original research question along with editing manuscript. All authors read and signed the final paper.

Conflicts of interest

The authors have no conflicts of interest to declare.

Ethical considerations

Ethical issues (including plagiarism, data fabrication, double publication) have been completely observed by the authors.

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