Research Article

Retrospective Observational Study of Hemodynamic Alterations During Hemodialysis

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ABSTRACT

Critically ill patients have unstable hemodynamics when presenting to the ICU. In such instances, procedures like hemodialysis and slow low-efficiency daily dialysis may subject the patient to high variability in hemodynamics which may cause increased morbidity and mortality in susceptible individuals.

No Indian study has studied the hemodynamic alteration during the initiation of hemodialysis by continuous cardiac output monitoring. Hemodynamic variables of 10 matched patients subjected to hemodynamic monitoring were studied retrospectively and conclusions were drawn. The results of this study help us to understand the hemodynamics at the initiation of dialysis and thus develop protocols for monitoring.

Keywords: Hemodialysis; Hemodynamic; ICU; Cardiac output

Introduction

In critical care hemodynamic monitoring is used to detect cardiovascular insufficiency, to differentiate contributing factors, to guide therapy. Ultimately the goal is to optimize the delivery of oxygen and nutrients to the tissues. Critically ill patients are often hemodynamically unstable (or at risk of becoming unstable) owing to hypovolemia, cardiac dysfunction, or alterations of vasomotor function, leading to organ dysfunction, deterioration into multi-organ failure, and eventually death. Over the last few decades, hemodynamic monitoring has evolved from basic monitoring of Cardiac Output (CO) to sophisticated devices providing a plethora of variables. CO is the most fundamental hemodynamic parameter. It is measured by various invasive and non-invasive methods based on imaging (Echocardiography/Magnetic Resonance [MR]), oxygen consumption (Fick principle), or indicator dilution techniques. The latter is most widely used in clinical practice and relies on the Stewart-Hamilton equation [volume of injected indicator divided by the Area Under The Dilution Curve (AUC)].

Haemodialysis (HD) patients suffer from high cardiovascular morbidity and mortality. CO monitoring during HD is thought to detect deterioration of systemic hemodynamics before clinical events such as hypotension or syncope occur. Even in the absence of an event, CO monitoring could identify those HD patients with critically low CO-be it at the beginning or at the end of HD that might be a risk factor for sudden death and increased mortality.

This article is set about to understand the various changes in hemodynamics during the initiation of hemodialysis in critical patients with respect to CO, CI, SV, SVV, SVR, SVRI, BP, CVP. We monitored the above values with the help of inserting EV 1000 continuous cardiac output monitoring system in 10 patients in the critical care unit.

Materials and Methods

This is retrospective observational data (collected between January 2019 and December 2019) of 10 patients with chronic renal failure requiring hemodialysis due to volume overload

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and hyperkalemia. The demographics of the patient were as mentioned in **Table 1**. These 10 patients were subjected to hemodialysis in the Intensive Care Unit (ICU). As a protocol in our intensive care unit such patients are subjected to hemodynamic monitoring and consent was sought for insertion of the central line and the femoral line for the EV1000 set up (Edwards Lifesciences, Irvine, USA). A baseline transpulmonary thermodilution was done using 20 ml cold saline followed by which continuous monitoring was done. Hemodynamic parameters like Cardiac Output (CO), Stroke Volume Variation (SVV), Systematic Vascular Resistance (SVR), and Stroke Volume Index (SVI), Systematic Vascular Resistance Index (SVRI), Pulse Rate (PR), Mean Arterial Pressure (MAP), Central Venous Pressure (CVP) were monitored with the help of inserting EV1000 continuous cardiac output monitoring system. The data were collected before initiation of dialysis and after the start of hemodialysis at the interval of every 5 min till 30 minutes.

Table 1: Pt demographics.

N=10	
Age (Yrs ± S.D)	60 ± 12
Sex	60% males: 40% females 6 males and 4 females
Comorbidities (%)	
Diabetes mellitus	100%
Hypertension	100%
Ischemic heart disease	40%
Chronic asthma	10%
Chronic kidney disease	100%
Apache score	12 ± 4
Height (cm)	168 ± 10
weight	60 kg ± 8

Inclusion criteria

Patients admitted to the ICU require conventional hemodialysis due to volume overload and hyperkalemia due to chronic renal failure.

Exclusion criteria

- Patient having concomitant or newly developed systolic dysfunction (with EF<40%)
- Patient in bacterial Sepsis and septic shock defined as (two out of hypotension (BP<100), altered mental status, or tachycardia (Hr>90)
- Patient with neurological insult
- Patient on previous antihypertensive agents
- Patients who have been diagnosed with autonomic neuropathy or manifest signs or symptoms suggesting autonomic neuropathy
- Patient with hypotension or tachycardia (Hr>120)
- Moribund patient
- Patient on any form of vasopressor support
- Patients who have not been adequately resuscitated demonstrated delayed capillary refill and no correction of lactates
- Patient on pacemakers
- Patient not having a functioning AV fistula
- Patient who has been intubated and mechanically ventilated

Statistics

Two-way repeated-measures ANOVA (**Tables 2-10**) using the SPSS software version 26 was used to analyze the data. Mean, standard deviation, median, interquartile range, F value, and P value were obtained. As per convention p-value, less than 0.05 was taken for the F value to be significant (**Figures 1-8**).

It is found that the mean SVRI is different as compared to the baseline. P value <0/001 and the difference is found to be significant.

Results

Readings of hemodynamic monitoring were documented immediately after the initiation of the dialysis and after the start of hemodialysis at the interval of every 5 mins till 30 mins. The results were analyzed and then compared. 10 patients who were admitted to the ICU for dialysis were taken into consideration. For each result obtained mean, standard deviation, median, interquartile range, F value, and P value were obtained.

Discussion

Managing fluid overload and hyperkalemia is part of the daily routine in intensive care units. Generally, chronic kidney disease patients are

Table 2: Two way repeat measure analysis of the cardiac output.

CO	N	Mean	Standard deviation	Median	IQR	Two way repeat measure analysis	
BL	10	4.35	1.07	4.40	2.08	**F Value**	**P Value**
5 min	10	4.75	1.18	4.90	2.33	1.372	0.242
10 min	10	4.80	1.29	4.85	2.58	Difference is not significant	
15 min	10	4.87	1.34	5.10	2.65		
20 min	10	4.94	1.28	5.15	2.38		
25 min	10	4.99	1.32	5.35	2.63		
30 min	10	4.56	2.09	5.40	3.20		

Table 3: Two-way repeat measure analysis for the systemic vascular resistance.

SVR	N	Mean	Standard deviation	Median	IQR	Two way repeat measure analysis	
BL	10	1,313.00	177.23	1,355.00	203.00	**F Value**	**P Value**
5 min	10	1,133.80	143.13	1,148.50	241.25	14.185	<0.001
10 min	10	1,096.00	118.32	1.102.50	210.75	Difference is significant	
15min	10	1,122.70	170.95	1,166.50	336.25		
20 min	10	1,087.00	157.80	106.50	308.00		
25 min	10	1,090.00	134.27	1,102.50	250.25		
30 min	10	1,091.30	132.75	1,091.00	154.50		

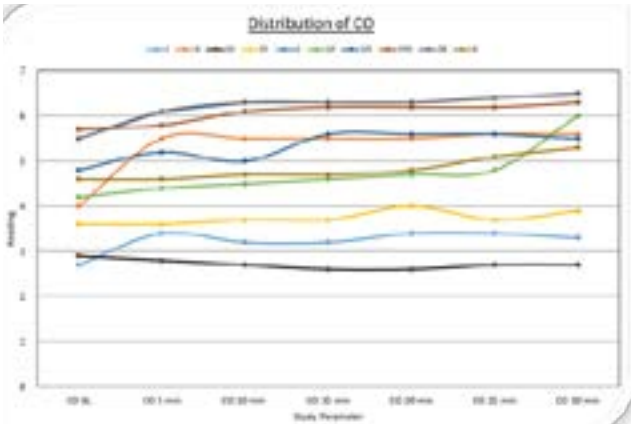

Figure 1: Graph demonstrating the distribution of cardiac output, reading on Y-axis, and cardiac output range for every 5 minutes until 30 minutes on X-axis. Four patterns are observed CO remains stable from the baseline till 30 mins of start of HD. No significant difference was found. P-value remained insignificant.

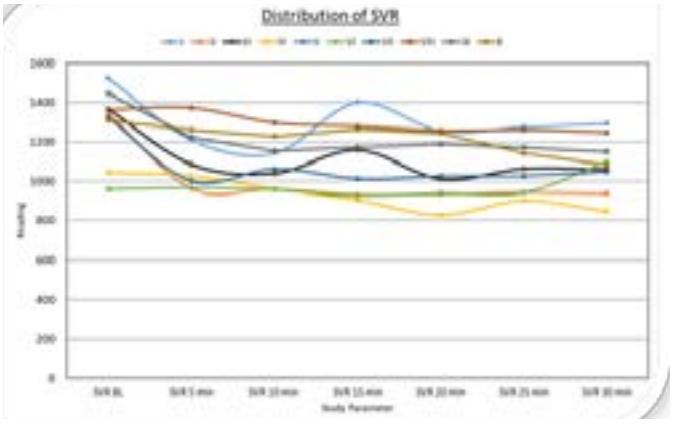

Figure 2: Graph demonstrating the distribution of Systematic Vascular Resistance (SVR), reading on Y axis and (systematic vascular resistance) range for every 5 minutes until 30 minutes on X-axis. Four patterns are observed and there is a significant decrease in SVR at the start of HD from the baseline. P value was found to be <0.001 and the difference was significant.

Table 4: Two-way repeat measure analysis for the stroke volume index.

SVI	N	Mean	Standard deviation	Median	IQR	Two way repeat measure analysis	
BL	10	24.90	8.56	44.00	17.00	**F Value**	**P Value**
5 min	10	27.20	8.78	46.50	14.75	1.305	0.271
10 min	10	27.50	9.12	49.00	16.25	Difference is not significant	
15min	10	27.60	9.14	50.00	17.00		
20 min	10	28.10	8.77	51.00	16.75		
25 min	10	28.20	8.93	52.00	14.75		
30 min	10	25.80	12.75	55.00	21.50		

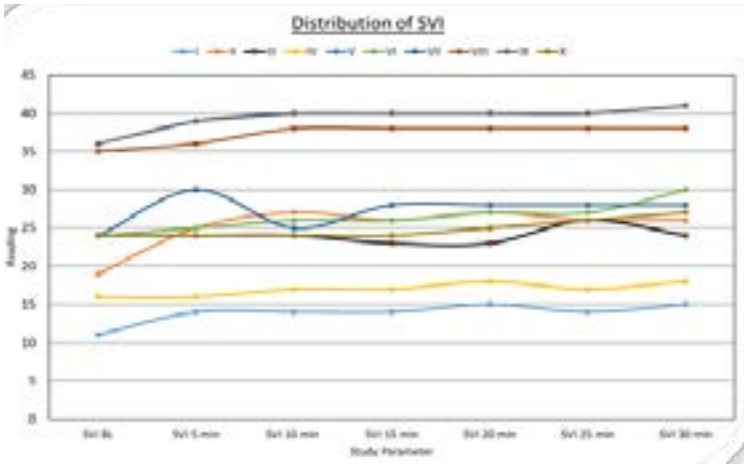

Figure 3: Graph demonstrating the distribution of stroke volume index, reading on Y axis and stroke volume index range for every 5 min until 30 min on X-axis. Three patterns are observed. No significant difference was found.

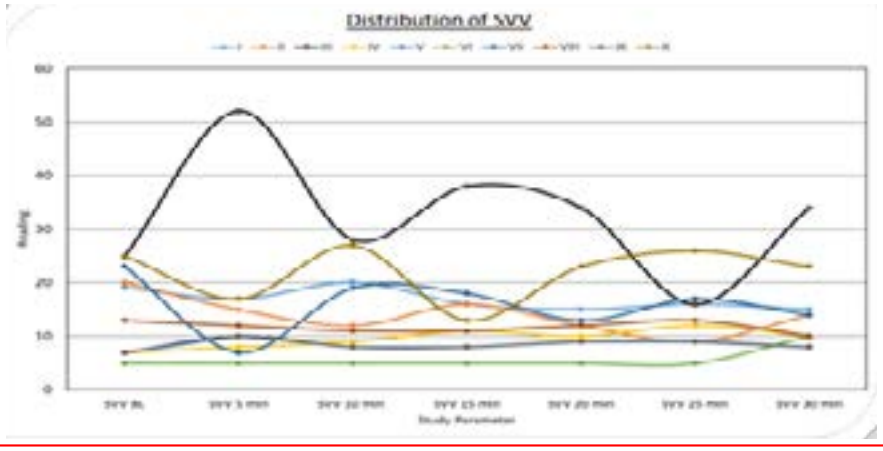

Figure 4: Graph demonstrating the distribution of stroke volume index, reading on Y axis and stroke volume index range for every 5 min until 30 min on X-axis. Three patterns are observed. No significant difference was found.

Table 5: Two-way repeat measure analysis for the stroke volume variation.

SVV	N	Mean	Standard deviation	Median	IQR	Two-way repeat measure analysis	
BL	10	15.10	8.17	16.00	16.50	**F Value**	**P Value**
5 min	10	15.30	13.53	11.00	9.25	0.212	0.971
10 min	10	14.70	8.25	11.50	13.75	Difference is not significant	
15min	10	14.40	9.25	12.00	8.50		
20 min	10	14.20	8.42	12.00	8.00		
25 min	10	14.20	5.92	12.50	7.25		
30 min	10	14.60	8.15	12.00	7.50		

Table 6: Two-way repeat measure analysis for the stroke volume.

SV	N	Mean	Standard deviation	Median	IQR	Two-way repeat measure analysis	
BL	10	43.80	11.61	44.00	20.50	**F Value**	**P Value**
5 min	10	46.80	11.55	46.50	19.50	9.625	<0.001
10 min	10	48.30	12.67	49.00	22.25	Difference is significant	
15min	10	48.80	12.89	50.00	24.25		
20 min	10	49.70	12.17	51.00	23.50		
25 min	10	50.20	12.65	52.00	20.75		
30 min	10	51.70	12.86	55.00	22.50		

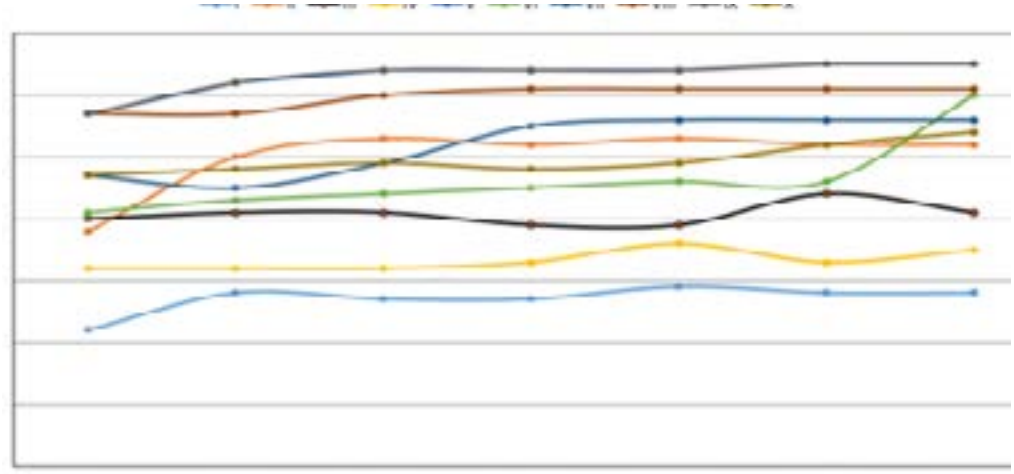

Figure 5: Graph demonstrating the distribution of stroke volume, reading on Y axis, and stroke volume range for every 5 minutes until 30 minutes on X-axis. four patterns are seen in which there is an increase in the stroke volume from the baseline. P value was found to be <0.001 and there is significant difference found.

Table 7: Two-way repeat measure analysis for the systematic vascular resistance index.

SVRI	N	Mean	Standard deviation	Median	IQR	Two-way repeat measure analysis	
BL	10	2,364.10	366.28	2,313.00	487.75	**F Value**	**P Value**
5 min	10	2,009.40	264.77	1,958.00	248.75	13.006	<0.001
10 min	10	1,970.60	233.39	1,884.50	308.50	Difference is significant	
15min	10	2,019.20	339.80	1,919.00	336.25		
20 min	10	1,953.00	299.16	1,901.00	442.75		
25 min	10	1,958.10	250.59	1,875.00	306.75		
30 min	10	1,941.30	251.84	1,848.50	316.25		

Table 8: Two-way repeat measure analysis for the pulse rate.

PR	N	Mean	Standard deviation	Median	IQR	Two-way repeat measure analysis	
BL	10	100.60	12.98	101.00	11.75	**F Value**	**P Value**
5 min	10	100.70	13.65	100.50	12.50	0.415	0.866
10 min	10	99.90	14.26	101.50	7.75	Difference is not significant	
15 min	10	100.60	14.43	102.00	8.25		
20 min	10	100.30	13.96	101.00	7.50		
25 min	10	99.90	15.45	101.50	10.50		
30 min	10	100.00	13.04	100.00	9.25		

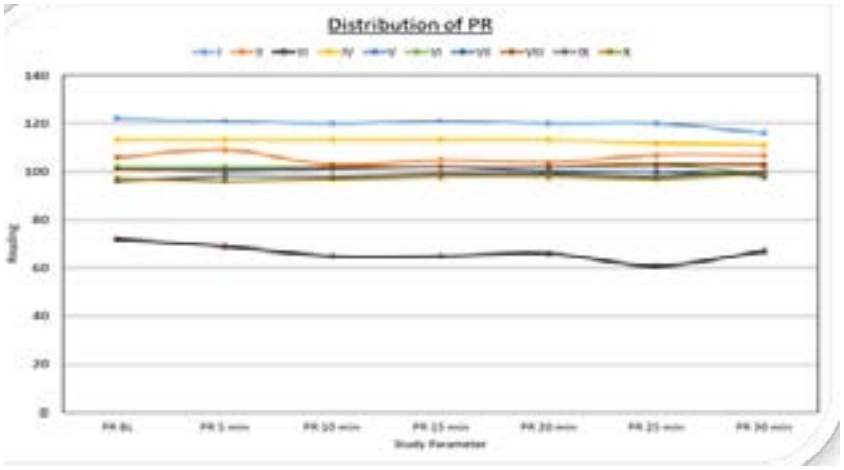

Figure 6: Graph demonstrating the distribution of pulse rate, reading on Y axis and pulse rate range for every 5 minutes until 30 minutes on X-axis. Two patterns are seen but heart rate remains stable in both the patterns and there is no significant difference found.

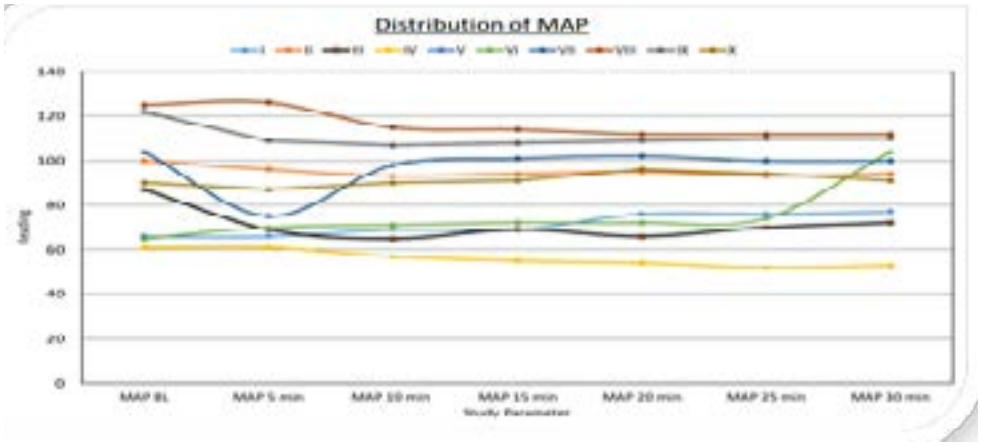

Figure 7: Graph demonstrating the distribution of mean arterial pressure, reading on Y axis and mean arterial pressure range for every 5 minutes until 30 minutes on X-axis. MAP decreased in some patients at the start of HD but remained constant throughout. There is no significant difference found.

Table 9: Two-way repeat measure analysis for the mean arterial pressure.

MAP BP	N	Mean	Standard deviation	Median	IQR	Two-way repeat measure analysis	
BL	10	94.20	24.59	95.00	56.25	F Value	P Value
5 min	10	86.80	22.22	81.00	40.75	1.733	0.131
10 min	10	87.20	20.31	91.50	39.00	Difference is not significant	
15 min	10	88.10	20.43	92.50	39.00		
20 min	10	89.10	20.53	95.50	38.50		
25 min	10	89.10	20.27	93.50	37.00		
30 min	10	92.30	19.45	97.00	34.25		

Table 10: Two-way repeat measure analysis for the central venous pressure.

CVP	N	Mean	Standard deviation	Median	IQR	Two-way repeat measure analysis	
BL	10	18.60	6.36	18.00	8.75	F Value	P Value
5 min	10	14.10	5.6 9	13.50	7.50	2.213	0.056
10 min	10	14.80	8.20	14.00	16.00	Difference is not significant	
15 min	10	13.90	7.94	14.50	16.00		
20 min	10	15.10	8.74	14.50	15.75		
25 min	10	14.70	8.56	13.50	15.25		
30 min	10	14.50	9.56	14.50	15.75		

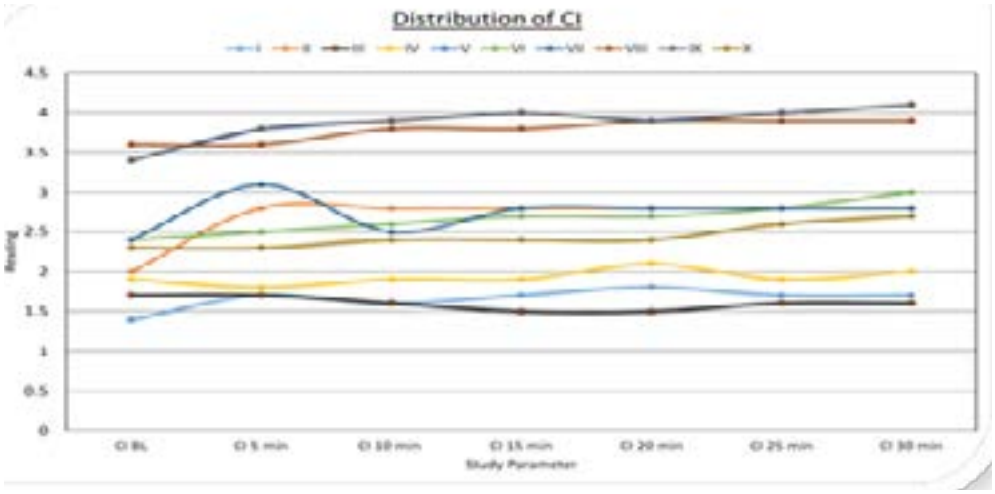

Figure 8: graph demonstrating the distribution of cardiac index, reading on Y axis, and cardiac index range for every 5 minutes until 30 minutes on X-axis. Three patterns are observed, in which cardiac index remained stable and there is no significant difference found.

managed in the kidney dialysis unit and do not require intensive care unit support. Few patients on maintenance hemodialysis come in an emergency into the intensive care unit for problems like fluid overload, hyperkalemia, and absence of appointment slot in the kidney dialysis unit. 2% of chronic dialysis patients require the intensive care unit. What is also known is that ESRD patients have a higher all cause mortality and experience higher rates of cardiovascular events as compared to a patient with normal renal function [1]. Also chronic dialysis patients have more intensive care unit admission as compared to those not on chronic dialysis [2]. Many of these patients do have adverse cardiac events which include myocardial ischemia, pulmonary edema, cardiogenic shock, arrhythmias, and sudden cardiac death [3]. The mode of renal replacement therapy usually in these kinds of hemodynamically stable patients are Intermittent Hemodialysis (IHD) and Slow Low-Efficiency Daily Dialysis (SLEDD). Most of the intermittent hemodialysis is performed using single-pass systems with blood flows of 200 ml/min-250 ml/min and counter-current dialysis flow of 500 ml/min. SLEDD is formed using flows of about 200 ml/min with dialysate flows of 100 ml/min-300 ml/min. Needless to say, these therapies (both IHD and SLEDD) lead to large fluid and solute shifts. Hence these therapies may have adverse cardiac and hemodynamic consequences in 15%-30% of patients [4]. These hemodynamic events may be dangerous in the susceptible patient (a patient with ischemic heart disease) and in the long run, if such incidences are repeated this leads to end-organ damage [5]. The cardiovascular response to intermittent hemodialysis is known to be unpredictable and largely depends on the individual's reflex compensatory ability [6].

Specific hemodynamic effects of intermittent hemodialysis

Cardiac output and cardiac index: Few studies have demonstrated an increase of more than 10% in cardiac output and index in stable ESRD patients with volume overload and heart failure [7,8]. Many others have demonstrated a drop in cardiac output by more than 10% especially those who are critically ill with or without Ultrafiltrate removal. This drop seems to be gradual and is exaggerated when there is a major drop in blood pressure [9-15]. Hence the anticipation of intradialytic hypotension may be suboptimal if only blood pressure is monitored.

Stroke volume, Stroke volume index, and Stroke volume variation: Studies have demonstrated a drop of stroke volume up to 20% during hemodialysis [16,17]. Again just as cardiac output blood pressure does not correlate to the stroke volume changes during hemodialysis [18]. Higher stroke volume variation is closely related to the occurrence of intradialytic hypotension [19]. There are no studies that have chronicled the SVV in patients on continuous dialysis. However, there is good biological plausibility

that large increases in Stroke volume variations might indicate fluid responsiveness and a higher chance of hypotension.

Pulse rate and mean arterial pressure: During hemodialysis, the removal of fluid will lead to a drop in plasma volume which is then taken care of by refilling from the interstitium. This translocation of fluid varies from person to person. However, the more hypervolemic the patient is, the faster the refilling would take place with good maintenance of blood pressure. However, if the patient reaches a euvolemic or a so-called "dry state" at this stage the fluid removal may cause a drop in the mean arterial blood pressure if there is no compensation from the sympathetic system and cardiac output. Moreover, those patients who have left ventricular hypertrophy or left ventricular diastolic dysfunction will develop hypotension earlier due to the dependence on the preload for cardiac output. Hence each patient would respond differently to dialysis [20]. There is also up to 15% incidence of intradialytic hypertension, which is associated with adverse outcomes [21]. The pathogenesis of this intradialytic hypertension is not very clear and may be related to volume overload, increases renin-angiotensin-aldosterone activity, sympathetic overactivity, etc.

We decided to study the first 30 minutes after starting hemodialysis on our patients to understand the time course of variations in these parameters by continuous monitoring. The results of our study show that statistical difference is significant in the SVR of the patients as shown in Table 2 and its corresponding graph. There is a drop in SVR at 5 min and towards 15 min of the hemodialysis according to the tabular and graphical depiction. Similarly, the statistical difference is significant in SV And SVRI during the 30 min interval after starting HD as shown in **Table 5** and **Table 6** respectively.

The results of this study seem to indicate a possibility of significant systemic vasodilatation that may result in a drop in blood pressure. At this point of time, it is important to reiterate that this study was performed in a population of reasonable healthy individuals. In addition to the systemic vasodilation the sharp decline of stroke volume seen in the first 15 minutes may also add to the incidence of ischemia related issues, especially in those patients that are pressure dependant (for example flow restricted and pressure dependant coronary ischemia patients). In some cases, this may also lead to the termination of haemodialysis. Hence watchful expectancy during the start of haemodialysis with close monitoring of hemodynamics in individuals (with ischemic heart disease, established flow or pressure dependant cerebrovascular disease like carotid stenosis etc.) would help in mitigating untoward effects. At this time the judicious use of inotropic agents and vasopressors to counteract the reduced systemic vascular resistance and low stroke volume for a short duration till the hemodynamic settle would help. The above-mentioned changes do not seem to cause a significant change in the mean arterial pressure though when measured at 5 minute intervals. Perhaps these alterations would have been picked up if we would have monitored this at shorter intervals. These observations need to be replicated in a larger study to make the results of this study more robust.

Conclusion

When the SV, SVR, and SVRI is compared amongst the study group at various intervals it is found that the mean is statistically different as compared to the baseline ($p<0.001$) after applying the multiple paired comparison the difference is found to be significant at a various interval of starting the HD.

As per our results, we found that HD leads significant drop in the SVR, SV, and SVRI Possibly due to the vasodilatory effect of HD thus reducing the sympathetic activity. Although it was not compensated with an increase in the HR/MAP/CVP which Suggests the chronotropic incompetence effect of the HD.

This hypothesis-generating study thus lays the impetus for a larger study to validate these findings and thus generate more data in the management of patients who would be susceptible to changes in stroke volume and systemic vascular resistance. However, this study seems to suggest that the first 15 minutes of hemodialysis does lead to a hemodynamic consequence which may demand a higher level of monitoring in susceptible individuals.

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