Myocardial Performance Index Suggests Optimal Fluid Loss During Hemodialysis

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ABSTRACT

Background: Patients on long-term maintenance hemodialysis (HD) are at high risk of developing cardiovascular disease and suffering various cardiovascular complications during HD.

Hypothesis: The purpose of this study was to evaluate the influence of changing loading conditions on the myocardial performance index (MPI) in patients on long-term HD and to specify an optimal level of fluid loss during HD that would maintain stable global cardiac function.

Methods: The study consisted of 52 patients with end-stage renal failure (ESRF), mean age 56 ± 11.7 y, range: 25–80 y, on regular HD. For each patient a complete echocardiographic-Doppler examination was performed before and after HD. Systolic and diastolic parameters of left ventricular function were measured, and the myocardial performance index (MPI) was calculated.

Results: The MPI was significantly prolonged after HD (0.47 ± 0.15 before HD versus 0.59 ± 0.16 after HD, $p < 0.001$). Mean change in body weight during HD was 2.1 ± 0.86 kg. The MPI did not change significantly in patients with intradialytic weight loss up to 1.75 kg.

Conclusions: The MPI value seems to be independent of acute preload changes only when fluid loss is less than 1.75 kg. A 1.75-kg fluid loss during HD seems to be the optimal goal. In ESRF patients on HD, the MPI seems to be a good indicator of global left ventricular function and potentially a valuable aid in the effort to maintain optimal fluid balance.

Introduction

Patients on long-term maintenance hemodialysis (HD) are at high risk of developing cardiovascular disease, a risk estimated to be up to 20 times higher than that of the general population.¹ The prevalence of ischemic heart disease and heart failure in these patients is estimated at 50% and 55%, respectively. The annual incidence of ischemic heart disease is 4%, whereas the annual incidence of heart failure is approximately 8%. The annual cardiovascular mortality exceeds 9%.² On the other hand, it is well known that even mild renal disease is a major risk factor for subsequent events or even death after myocardial infarction. The 2-y mortality rate following myocardial infarction among patients with end-stage renal failure (ESRF) is approximately 50%.^{2,3} Furthermore, patients on long-term HD may suffer various cardiovascular complications during dialysis, namely, intradialytic hypotension (which is the most common), hypoxemia, cardiac arrhythmias, and depression of myocardial contractility due to electrolyte abnormalities, metabolic acidosis, and other metabolic abnormalities.⁴ Frequent episodes of intradialytic hypotension have been implicated in the acceleration of the decline of residual renal

function and associated with life-threatening conditions such as mesenteric ischemia—damage to the brain and reduced coronary flow. It has also been postulated that frequent intradialytic hypotension can lead to increased morbidity and mortality.^{5,6}

Echocardiography is routinely used to study systolic and diastolic left ventricular (LV) function and measure the degree of LV hypertrophy. Systolic function is traditionally reflected by the ejection fraction (EF) and fractional shortening, whereas diastolic function is described by Doppler indexes such as isovolumic relaxation time (IRT), peak E-wave velocity, deceleration time (DT), and the deceleration slope (DS) of E-wave, peak late atrial filling A-wave velocity and the ratio of E/A peak velocities. All these indexes are influenced by changes in preload, thus rendering echocardiographic study of HD patients problematic. Moreover, the m-mode measurements of LV dimensions used in calculating LV mass and volume fluctuate with changes in intravascular volume.⁷

The MPI is a relatively new index⁸ that reflects the global function of the LV and has already been used in a variety of cardiovascular diseases such as heart failure,⁹ myocardial infarction,^{10,11} dilated cardiomyopathy,¹² amyloidosis,¹³ and heart transplantation.^{14,15} It has been shown that MPI not only reflects the severity of the disease but also adds significant prognostic value.^{13,14,17} Furthermore, MPI seems

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to be independent of changes in heart rate, afterload, and, possibly, preload.¹² Thus, MPI seems to be promising as an adjunct in the evaluation of patients on HD.¹⁶

The purpose of this study was to evaluate the influence of changing loading conditions on MPI, especially in the setting of patients with end-stage renal failure on long-term hemodialysis. Moreover, it was to specify an optimal level of fluid loss during hemodialysis that would maintain stable global cardiac function in a patient in this acute setting.

Methods

Population

Participating in the study were all 52 patients with ESRF on regular hemodialysis at our hospital. Patients were treated with hemodialysis 3 times per week for more than 3 mo. Mean duration of hemodialysis was 38.44 ± 20.15 mo (range: 6–85 mo). Mean age of the patients was 56 ± 11.7 y (range: 25–80 y). Thirty-one patients were male (59.6%). All patients underwent echocardiographic-Doppler examination 30 min before and 30 min after hemodialysis. Clinical data including systolic and diastolic arterial blood pressure, heart rate, and weight before and after HD were also obtained. All patients were in sinus rhythm. Patients with a rhythm other than sinus, a pacing rhythm, bundle-branch block, or high-grade atrioventricular block were excluded from the study. None of the patients had hemodynamically significant aortic valve disease, dilated cardiomyopathy, or right ventricular myocardial infarction. The Scientific Committee of our hospital approved the study protocol, and all patients gave informed consent.

Echocardiographic Study

For each patient, a complete m-mode, 2-dimensional, and color-flow Doppler echocardiographic examination was performed. Studies were performed using a commercially available Hewlett-Packard machine (Sonos 1000; Andover, MA, USA) and 2.5-MHz phased-array transducer. Echocardiographic-pulsed Doppler data were recorded at a sweep speed of 50 or 100 mm/sec by a Panasonic videocassette recorder (AG-MD830E, Osaka, Japan) and stored on high-quality super-VHS videotape for later playback and blinded analysis. Echocardiographic examination and measurements were done using standard views and techniques according to the guidelines of the American Society of Echocardiography.^{18,19} Ejection fraction was calculated from the apical 4-chamber view using a single-plane Simpson's rule algorithm. Doppler measurements included peak early (E) and late (A) transmitral filling velocities, E/A ratio, and DT and DS of E waves measured from the mitral inflow tracings (apical 4-chamber view). These parameters along with isovolumic relaxation time (IRT) were used in order to diagnose and classify diastolic dysfunction. In normal diastolic filling the E/A ratio is >1 , DT = 160–240 msec, and IRT = 70–90 msec. In grade I

diastolic dysfunction (impaired relaxation), the E/A ratio is <1 , DT >240 msec, and IRT >90 msec. In grade II diastolic dysfunction (pseudonormal pattern), the E/A ratio is >1 but reverses with the Valsalva maneuver to E/A <1 , deceleration time is shortened (160–200 msec), and IRT <90 msec. In restrictive filling, the E/A ratio is >1.5 , DT <60 msec, and IRT <70 msec.²⁰ Five consecutive beats were measured and averaged for each parameter.

The MPI⁸ is defined as the summation of isovolumic contraction time (ICT) and relaxation time (IRT) divided by ejection time (ET). In the present study, MPI was calculated as follows (Figure 1): From the mitral inflow Doppler tracings, time interval a , from the cessation to onset of mitral inflow, and time interval c , between the R

Figure 1. Measurement of myocardial performance index (MPI), defined as the sum of isovolumic contraction time (ICT) plus isovolumic relaxation time (IRT), divided by ejection time (b). The MPI is calculated as the ratio of $a - b/b$, where a is the time interval between the cessation and onset of mitral inflow; c is the time interval between the R wave of the ECG and the onset of the following mitral inflow; and d is the time interval between the R wave of the ECG and the cessation of left ventricular outflow (ECG, electrocardiogram).

wave of the electrocardiogram and the onset of mitral inflow, were measured. From LV outflow tracings, time interval *b*, which equals the ET, and time interval *d*, between the R wave of the electrocardiogram and cessation of LV outflow, were measured. Thus, $MPI = a - b/b$. The IRT was calculated by subtracting time interval *d* from time interval *c*, and the ICT was calculated by subtracting the IRT and ET from *a*.

Statistical Analysis

Continuous data are expressed as means±SDs and categorical variables as percentages. Echocardiographic-Doppler indices of cardiac function as well as clinical indices for each patient were compared before and after HD using the paired *t* test. The independent-samples *t* test was used to compare the indices between different patient groups. The chi-square test was used to assess sex differences between the 2 groups. A *p*<0.05 was considered statistically significant.

Results

Patient Characteristics

A significant mean body weight reduction during HD was noticed (72.34±11.28 kg before HD versus 70.23±11.07 kg after HD, *p*<0.001). The mean reduction and mean percentage reduction in body weight during HD were 2.1±0.86 kg (range 0.30–4.10 kg) and 3% ±1%, respectively. Accordingly, a significant reduction in systolic blood pressure (132.88±19.61 mm Hg before HD versus 120.76±22.95 mm Hg after HD, *p*<0.001) and diastolic blood pressure (78.75±9.54 mm Hg before HD versus 71.73±10.37 mm Hg after HD, *p*<0.001) and an increase in heart rate (77.09±11 beats/min before HD versus 85.27±11.55 beats/min after HD, *p*<0.001) were noticed (Table 1).

Echocardiographic-Doppler Measurements

The LV dimensions were significantly reduced, but the EF (Simpson's rule) did not change significantly (Table 1). The EF was normal at baseline in 42 patients, and only 9 patients had an EF <50%. Analysis of Doppler recordings revealed that E-wave velocity, A-wave velocity, the E/A ratio, the deceleration slope of the E-wave of transmitral flow, the ICT (44.43±26.41 msec before HD versus 36.96±21.29 msec after HD, *p*<0.046), and the ET (285.56±32.21 msec before HD versus 245.78±31.78 msec after HD, *p*<0.001) were significantly reduced. In contrast, the DT of the E-wave of transmitral flow and the IRT (89.62±28.45 msec before HD versus 107.45±31.28 msec after HD, *p*<0.001) were significantly prolonged. The MPI was significantly prolonged (0.47±0.15 before HD versus 0.59±0.16 after HD, *p*<0.001; Table 2).

Patient Groups

The MPI did not change significantly in patients with intradialytic weight loss up to 1.75 kg (17 men, 5 women;

Table 1. Clinical characteristics and echocardiographic indices before and after hemodialysis

(<i>n</i> = 52)	Before HD (mean±SD)	After HD (mean±SD)	<i>p</i> <
Heart rate (beats/min)	77.09±11.09	85.27±11.55	0.001
Systolic BP (mm Hg)	132.88±19.61	120.76±22.95	0.001
Diastolic BP (mm Hg)	78.75±9.54	71.73±10.37	0.001
Body weight (kg)	72.34±11.28	70.23±11.07	0.001
LVID (mm)	51.03±6.40	46.80±6.46	0.001
LVIS (mm)	31.95±6.59	29.10±6.43	0.001
IVST (mm)	11.8±3.7	12.06±3.2	ns
PWT (mm)	9.64±1.40	9.8±1.44	0.049
EF (Simpson) %	52.7±6.10	52.5±6.30	ns

Abbreviations: BP, blood pressure; LVID, left ventricular internal dimension in diastole; LVIS, left ventricular internal dimension in systole; IVST, interventricular septal thickness in diastole; PWT, posterior wall thickness in diastole; EF, ejection fraction.

mean age 62.6±8.6 y), whereas mean body weight, heart rate, and systolic and diastolic blood pressure were significantly changed (Table 3). The mean percentage change in MPI was 14%. The ICT and ET were reduced, and the IRT was prolonged. In contrast, in patients with a weight reduction >1.75 kg, there was a significant increase in the MPI after hemodialysis (0.44±0.15 versus 0.61±0.18, *p*<0.001; Table 4). Baseline characteristics were similar between the 2 patient groups. However, significantly fewer female patients were included in the second group (weight loss <1.75 kg during hemodialysis; Table 5).

Discussion

This study demonstrates that MPI was not influenced by preload reduction when weight loss was <1.75 kg in ESRF patients undergoing hemodialysis. In this case, the mean change of MPI was 14%. Similar results were found in a previous study performed on ESRF patients on HD where weight loss >1.5 kg during HD induced significant MPI changes.²¹ The ET as well as ICT were significantly shortened because of the earlier crossover of LV and reduced left atrial pressure. The IRT was prolonged because of the shortening of the ET and delayed opening of the mitral valve following reduced preload and left atrial pressure. The ICT/ET ratio was reduced nonsignificantly, and the IRT/ET ratio was prolonged significantly. The net result was a nonsignificant change in the MPI (Table 3). The ICT/ET and IRT/ET ratios were previously shown to correlate with +dp/dt and -dp/dt of left ventricular pressure, respectively, thus reflecting systolic and diastolic

Table 2. Doppler indices before and after hemodialysis

(n = 52)	Before HD (mean±SD)	After HD (mean±SD)	p <
E-point velocity (cm/sec)	77.84±18.81	58.24±15.20	0.001
A-point velocity (cm/sec)	88.43±22.94	81.91±22.78	0.002
E/A ratio	0.92±0.32	0.73±0.22	0.001
Deceleration slope (cm/sec ²)	367.02±113.62	252.22±66.57	0.001
Deceleration time (msec)	227.85±43.35	243.30±32.29	0.016
Ejection time (msec)	285.56±32.21	245.78±31.78	0.001
IRT (msec)	89.62±28.45	107.45±31.28	0.001
ICT (msec)	44.43±26.41	36.96±21.29	0.046
IRT/ET	0.32±0.11	0.44±0.15	0.001
ICT/ET	0.16±0.09	0.15±0.09	ns
MPI	0.47±0.15	0.59±0.16	0.001
Abbreviations: ICT, isovolumic contraction time, IRT, isovolumic relaxation time, MPI, myocardial performance index, ET, ejection time, HD, hemodialysis, n, number of patients.			

performance.²² Therefore, it seems that systolic LV function remained stable, whereas diastolic LV function worsened.

Overall, our patients lost during HD 2.11±0.86 kg and demonstrated a significant increase in MPI (Tables 1 and 2). This increase in the MPI was mainly a result of the increase in the IRT/ET index. In contrast, the ICT/ET was only minimally decreased and could not account for any changes in the MPI. The other traditional indices used to describe systolic function, (i.e., EF) were also found unchanged before and after HD. On the other hand, the diastolic indices worsened and indicated a pattern of worsened LV relaxation post-HD. Early peak E and late peak A transmitral flow velocities were reduced, whereas DT and IRT were increased significantly. These results of the Doppler study are in keeping with previous observations on the influence of HD on diastolic Doppler indices.^{23–25} Preload reduction with HD unmasked the LV relaxation abnormality in most ESRF

Table 3. Clinical and echocardiographic-Doppler indices of patients with weight reduction ≤1.75 kg before and after hemodialysis

(n = 22)	Before HD (mean±SD)	After HD (mean±SD)	p <
Heart rate (beats/min)	76.63±11.36	82.03±12.80	0.013
Systolic BP (mm Hg)	135.90±14.44	126.59±17.07	0.001
Diastolic BP (mm Hg)	78.64±6.57	73.63±7.89	0.003
Body weight (kg)	70.90±8.20	69.55±8.33	0.001
LVID (mm)	51.80±7.73	49.37±7.95	0.001
LVIS (mm)	32.93±8.90	31.36±8.43	0.006
EF (%)	50.66±7.61	50.30±7.73	0.59
E/A ratio	0.89±0.4	0.76±0.31	0.001
Deceleration time (msec)	230.26±34.44	234.93±25.37	0.14
Deceleration slope (cm/sec ²)	350.95±82.43	270.95±65.12	0.001
Ejection time (msec)	277.09±38.34	253.0±29.48	0.001
IRT (msec)	96.00±31.98	109.82±30.54	0.05
ICT (msec)	46.72±26.87	34.77±17.57	0.01
IRT/ET	0.36±0.13	0.44±0.13	0.01
ICT/ET	0.17±0.10	0.14±0.08	0.07
MPI	0.52±0.14	0.57±0.13	0.08
Abbreviations: BP, blood pressure; LVID, left ventricular internal dimension in diastole; LVIS, left ventricular internal dimension in systole; IVST, interventricular septal thickness in diastole; PWT, posterior wall thickness in diastole; EF, ejection fraction.			

patients, which was pseudonormalized before HD because of the increased left atrial pressure. Previous studies have shown that a 3-h ultrafiltration, which results in loss of 3 L, causes a 17% reduction in plasma volume and a reduction in pulmonary capillary wedge pressure from an average of 12.5 to 3.1 mm Hg,^{26,27} suggesting a considerable decrease in preload. Mitral inflow profiles are dependent not only

Table 4. Clinical and echocardiographic-Doppler indices of patients with weight reduction >1.75 kg before and after hemodialysis

(n = 30)	Before HD (mean±SD)	After HD (mean±SD)	p <
Heart rate (beats/min)	77.45±11.08	87.82±9.97	0.001
Systolic BP (mm Hg)	130.67±22.66	116.50±25.90	0.001
Diastolic BP (mm Hg)	78.33±11.35	70.33±11.81	0.001
Body weight (kg)	73.40±13.13	70.72±12.83	0.001
LVID (mm)	50.39±5.25	44.84±4.23	0.001
LVIS (mm)	31.21±4.09	27.38±3.66	0.001
EF (%)	54.21±4.31	54.17±4.62	0.97
E/A ratio	0.95±0.26	0.71±0.13	0.001
Deceleration slope (cm/sec ²)	379.07±132.55	238.18±65.27	0.001
Deceleration time (msec)	232.43±46.98	248.54±27.42	0.06
Ejection time (msec)	292.00±25.53	240.31±32.87	0.001
IRT (msec)	84.79±24.95	105.65±32.26	0.005
ICT (msec)	42.69±26.39	38.62±23.91	0.46
IRT/ET	0.29±0.10	0.46±0.17	0.001
ICT/ET	0.15±0.10	0.16±0.10	0.54
MPI	0.44±0.15	0.61±0.18	0.001

Abbreviations: BP, blood pressure; LVID, left ventricular internal dimension in diastole; LVIS, left ventricular internal dimension in systole; IVST, interventricular septal thickness in diastole; PWT, posterior wall thickness in diastole; EF, ejection fraction.

on the LV diastolic properties but also on hemodynamic parameters such as preload.^{28–31} Therefore, it has been suggested that the estimation of diastolic properties in

Table 5. Baseline characteristics of patients with weight loss after hemodialysis >1.75 kg (group 1) versus patients with weight loss ≤1.75 kg

	Group 1 (WL >1.75 kg)	Group 2 (WL ≤1.75 kg)	p <
Age (y)	54.26±10.22	62.6 ± 8.6y	ns
Male/female	14/16	17/5	0.02
Duration of HD (mo)	40.03±17.57	36.24±23.49	0.51
SBP (mm Hg)	130.6±22.65	135.90±14.44	0.31
DBP (mm Hg)	78.83±11.34	78.63±6.57	0.94
Weight (kg)	73.40±13.13	70.90±8.2	0.43
HR (beats/min)	77.44±11.08	76.63±11.36	0.81
LVDD (mm)	50.51±5.2	51.88±1.64	0.47
IVS (mm)	11.86±4.80	51.88±7.73	0.99
LVPW (mm)	9.5±1.5	9.98±1.37	0.25
EF %	54.20±4.31	50.27±7.6	0.06
E/A	0.94±0.26	0.89±0.40	0.61
DT (msec)	231.93±46.21	222±37.35	0.41
IRT (msec)	84.79±24.94	96±31.98	0.16
ICT (msec)	42.68±26.39	46.72±26.87	0.59
MPI	0.44±0.14	0.52±0.14	0.06

Abbreviations: BP, blood pressure; LVID, left ventricular internal dimension in diastole; LVIS, left ventricular internal dimension in systole; IVST, interventricular septal thickness in diastole; PWT, posterior wall thickness in diastole; EF, ejection fraction; WL, weight loss.

these patients should be done at identical intervals post-HD, preferably when patients are close to their dry weight.²⁴ However, the independence of MPI from preload when weight reduction is <1.75 kg suggests that the index may provide a quick and reliable estimate of diastolic function regardless of the patient's volume status. A change >15% from previous Doppler studies would suggest worsening of LV function in this setting. Moreover, it seems that 1.75 kg is the optimal fluid volume removal from the cardiac point of view because global LV function is unaffected by hemodynamic and metabolic changes induced by HD, as reflected by the unchanged MPI during HD.

In most ESRF patients, systolic and diastolic dysfunction coexist at later stages of the disease.^{4,32} In this setting, strict management of fluids is mandatory. Worsening compliance is added to poor relaxation so that even a mild increase in preload can induce pulmonary edema, whereas a small decrease in filling pressures can reduce cardiac output and cause intradialytic hypotension. The MPI seems promising

in guiding the effort to maintain optimal fluid balance in this particular group of patients. It has already been shown in a cohort of ESRF patients on HD that MPI was significantly higher in patients with low versus normal intradialytic blood pressure, suggesting that the index could be a more sensitive predictor of intradialytic hypotension compared with standard echocardiographic indices.³³ It seems that in this particular patient group, an intradialytic weight loss <1.75 kg in order to avoid hemodynamic instability may be of great benefit. Further studies with larger numbers of patients are needed for definite conclusions.

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