Left Ventricular Mass Assessment by 1- and 2-Dimensional Echocardiographic Methods in Hemodialysis Patients: Changes in Left Ventricular Volume Using Echocardiography Before and After a Hemodialysis Session

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Rationale & Objective: Left ventricular (LV) mass (LVM) is a predictor of cardiovascular morbidity and mortality and commonly calculated using 1-dimensional (1D) echocardiographic methods. These methods are vulnerable to small measurement errors and LVM may wrongly change according to changes in LV volume (LVV). Less commonly used 2-dimensional (2D) methods can accommodate to the changes in LVV and may be a better alternative among patients receiving hemodialysis (HD) with large fluid fluctuations.

Study Design: Observational study.

Setting & Participants: Patients with end-stage kidney disease receiving HD.

Exposure: One HD session.

Analytical Approach: Transthoracic echocardiography was performed right before and after HD. LVM was calculated using 1D (Devereux, Penn, and Teichholz) and 2D methods (truncated ellipsoid and area-length).

Outcomes: Significant differences in LVM after HD.

Results: We compared dimensions, LVV and LVM, in 53 patients (mean age, 63 ± 15 years; 66%

men). For each 1-L increase in ultrafiltration volume (UFV), LV internal diameter decreased 1.1 mm (95% CI, 0.5-1.7 mm; $P = 0.001$). Patients were divided into 2 groups by the median UFV of 1.6 L. Patients with UFV > 1.6 L had significant smaller LVV and LV internal diameter after HD. LVM calculated using 1D methods decreased according to changes in LVV. Conversely, LVM calculated using 2D methods was not significantly different after HD. No significant change in differences between diastolic − systolic myocardial thickness or LVM as assessed using 1D and 2D methods was observed before and after HD, indicating that LVM remained constant despite HD.

Limitations: We did not use contrast enhancement, 3-dimensional methods, or cardiac magnetic resonance.

Conclusions: LVM calculated using 2D methods, truncated ellipsoid and area-length, is less affected by fluctuations in fluid and LVV, in contrast to 1D methods. Complementary LVM calculation using 2D methods is encouraged, especially in patients with large fluid fluctuations in which increased LVM using a 1D method has been detected.

Left ventricular (LV) mass (LVM) calculated using transthoracic echocardiography may be used as an indicator of target-organ damage or a sign of clinical deterioration and is important for the clinical follow-up of patients receiving hemodialysis (HD). As a predictor

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of cardiovascular morbidity and mortality,[1-3] increased LVM is associated with adverse consequences such as myocardial ischemia, myocardial fibrosis, systolic and diastolic dysfunction, and arrhythmias.[4,5] Moreover, progressive increase in LVM is the strongest predictor of sudden cardiac death among patients with end-stage kidney disease (ESKD) treated with HD.[6] Regression of LVM by factors such as intensified control of blood pressure and anemia results in independent favorable effects on cardiovascular survival among those patients.[7]

Patients receiving HD are at increased risk for incorrect assessment of LVM.[8] The echocardiographic methods rely on volumetric measurement of myocardial tissue and conversion from volume to mass by multiplying with the myocardial gravity of 1.05 g/mL.[9] The most commonly used methods are the 1-dimensional (1D) methods based on cubing of LV dimensions.[10] Large fluid fluctuations in HD patients affect LV volume (LVV), LV dimensions, and consequently the calculated value of LVM. Small linear measurement errors are raised to the magnitude of 3 and have a large impact on the calculated value. Furthermore, correct interpretation requires normal LV geometry.[9,11-13]

Two-dimensional (2D) methods, such as the truncated ellipsoid (TE) and area-length (A-L), would theoretically be less affected by fluctuations in fluid status and may complement or even be a better alternative compared with 1D methods. They can accommodate for some of the changes in LVV and are less dependent on normal LV geometry.[14,15]

PLAIN-LANGUAGE SUMMARY

Patients with end-stage kidney disease receiving hemodialysis are at increased risk for incorrect calculation of left ventricular mass using ultrasonography of the heart. This is problematic because left ventricular mass may be used as an indicator of clinical deterioration and is important for clinical follow-up. We examined patients' heart ultrasounds before and after hemodialysis and compared different methods for calculation of left ventricular mass. We found that the less commonly used method based on 2-dimensional calculations was less affected by the fluctuation in fluid. We therefore encourage complementary calculation of left ventricular mass using 2-dimensional methods among patients with large fluid fluctuations in which the conventional 1-dimensional methods have detected increased left ventricular mass.

The aim of this study was to test the hypothesis that LVM based on 1D, in contrast to 2D, methods would incorrectly change according to changes in LVV.

METHODS

Study Population

We included 53 patients 18 years or older with ESKD receiving HD at Zealand University Hospital, Holbaek, Denmark. Demographic data were acquired from the patient file and by medical history at the day of inclusion. Cardiac disease was defined as previous myocardial infarction, moderate or severe valvular heart disease, heart failure, or arrhythmia. Patients were not excluded due to poor acoustic window or obesity.

All patients provided informed consent. The study was approved by the local ethical committee; approval number SJ-218.

Study Protocol

To achieve considerable change in preload, patients were examined right before and after a single HD session. Weight, heart rate, and blood pressure were measured before and after HD. Ultrafiltration volume (UFV) was registered and side effects such as hypotension, nausea, headache, and leg cramp were reported. Patients were divided into 2 equal-sized groups divided by the median UFV. The amount of fluid or food administered orally during HD was not registered.

Echocardiographic Examination and Analysis

Image acquisition before and after HD was performed by 2 sonographers using an iE33 Echocardiography System scanner (Philips Healthcare) equipped with a Philips X5-1-xMATRIX array transducer. All examinations were stored externally and transferred to the vendor-specific workstation IntelliSpace Cardiovascular Version 1.2 (Philips Medical Systems Netherland BV) for off-line analysis by 1 reader with several years of echocardiographic experience. Intra- and interobserver analyses were performed in 25 random patients. End-diastole was defined as the first frame after mitral valve closure at the beginning of the QRS complex with the largest cavity volume. End-systole was defined as the first frame after aortic valve closure with the smallest cavity volume.

LVVs and Ejection Fraction

LVV and LV ejection fraction (LVEF) were calculated using Simpson's biplane method by delineating the endocardial border in the apical 4- and 2-chamber views with the papillary muscle included in the LV cavity.

1D Measurements and Mass Calculation

Interventricular septum (IVS), LV internal diameter (LVID), and LV posterior wall (LVPW) were measured in the 2D parasternal long-axis view at the level of the mitral valve leaflet tips, or as close to the mitral valve leaflet tip as possible but still perpendicular to the long axis of the left ventricle. The measuring positions were placed in the interface between myocardial wall and cavity and the interface between wall and pericardium.[9] LVM was calculated using the Teichholz, Devereux, and Penn formulas (Fig 1).

The cube formula-Teichholz correction[16]:

$$1.05 \times \left\{ \left[\frac{7}{2.4 + IVS + LVID + LVPW} \right] \right.$$
$$\times (IVS + LVID + LVPW)^3 - \left[\frac{7}{(2.4 + LVID)} \right]$$
$$\left. \times LVID^3 \right\}$$

The cube formula-Devereux correction[17]:

$$0.8 \times 1.04 \times \left((IVSd + LVIDd + LVPWd)^3 \right.$$
$$\left. - LVIDd^3 \right) + 0.6$$

where IVSd is IVS diastole, LVIDd is LVID diastole, and LVPWd is LVPW diastole.

The cube formula-Penn correction[10]:

$$1.04 \times \left((IVSd + LVIDd + LVPWd)^3 - LVIDd^3 \right) - 13.6$$

2D Measurements and Mass Calculation

Tracing of the LV total area and LV cavity area was performed in the parasternal short-axis view at the level of the papillary muscle or just below the papillary muscle, with the papillary muscle considered part of the LV cavity. The tracer was positioned at the blood-tissue interface. LV length (LVL) was calculated from apex to the mitral plane
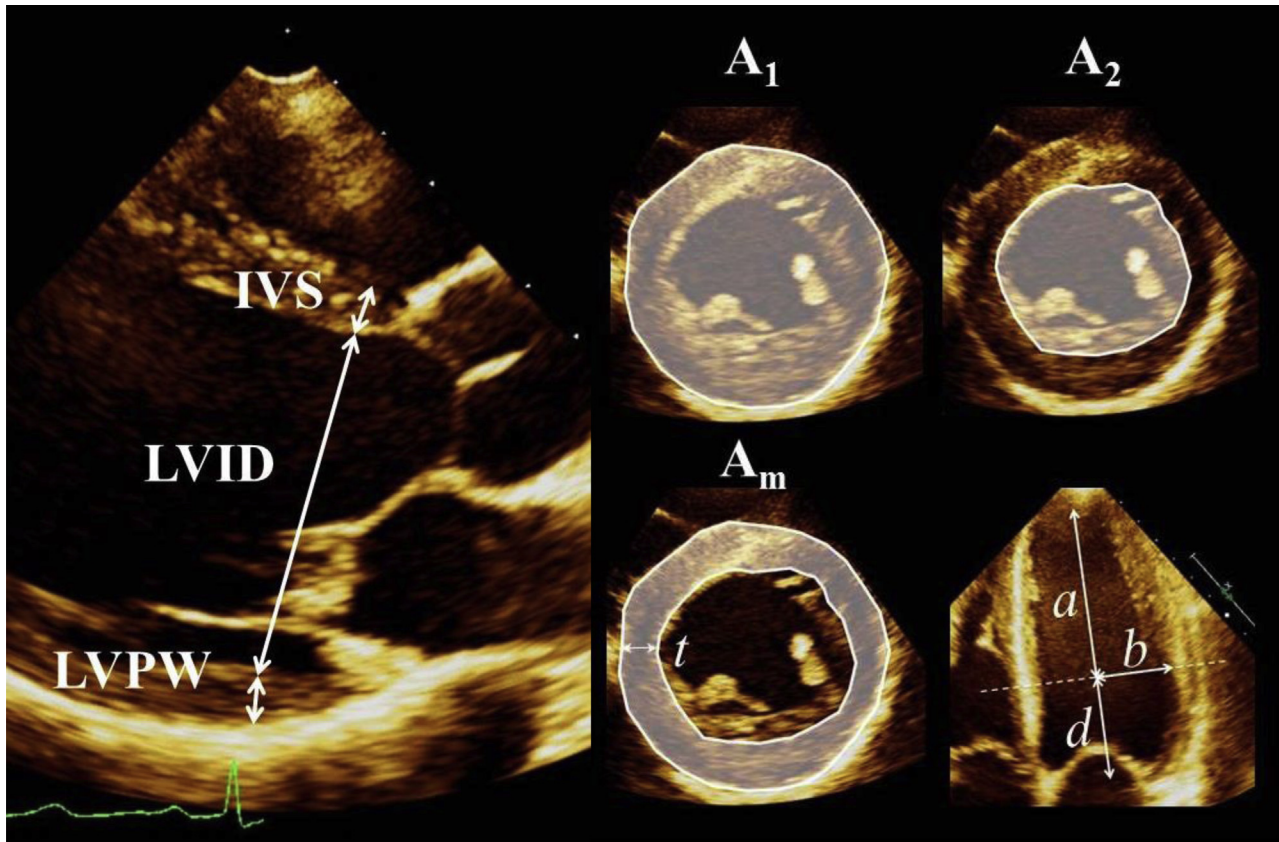
Figure 1. Measurements of (left image) 1-dimensional methods and (right image) 2-dimensional methods. Abbreviations: A_1, total area; A_2, cavity area; a, semi-major axis; A_m, myocardial area b, short-axis radius; d, truncated semi-major axis; IVS, interventricular septum, LVID, left ventricular internal diameter; LVPW, left ventricular posterior wall; t, mean wall thickness.

by adding semi-major axis and truncated semi-major axis measured in the apical 4-chamber view.[9] LVM was calculated using the A-L and the TE method (Fig 1).

A-L formula[14]: $1.05 \left\{ \left[\frac{5}{6} A_1 (a + d + t) \right] - \left[\frac{5}{6} A_2 (a + d) \right] \right\}$

where A_1 is total LV area diastole, A_2 is LV cavity area diastole, a is semi-major axis, d is truncated semi-major axis, and t is mean wall thickness.

TE formula[15]:

$$1.05\pi \left\{ (b + t)^2 \left[\frac{2}{3}(a + t) + d - \frac{d^3}{3(a + t)^2} \right] - b^2 \left[\frac{2}{3}a + d - \frac{d^3}{3a^2} \right] \right\}$$

Index Values

LVM was indexed according to the 2.7 power of height and body surface area (BSA) using the DuBois formula.[18,19] Measurements before HD were indexed to BSA calculated from the weight before HD and measurements after HD were indexed to BSA calculated from the weight after HD.

Statistical Analysis

Continuous variables are presented as mean ± standard deviation or median and interquartile range (IQR) if not normally distributed. Categorical data are presented as frequency and percentage. Agreement of the different methods before and after HD was expressed using Bland-Altman plots.[20] The blue line represents the bias (mean value) and the red line represents the 95% limits of agreement. Paired t test was used to compare differences before and after HD. Linear regression was used to test the association between UFV and LVID. Pearson correlation was used to evaluate the relationship between UFV and changes in differences between systole and diastole before and after HD. Intra- and interobserver data were compared using paired t test and expressed according to the bias, that is, mean difference ± 95% confidence interval (CI). Variations between measurements were further assessed using coefficient of variation.

All data were analyzed using SPSS, version 24.0 (IBM Corp; released 2016; IBM SPSS Statistics for Windows).

RESULTS

Fifty-three patients with ESKD were examined before and after HD. Clinical characteristics and medications for the

Table 1. Baseline Clinical Characteristics and Medications

| | | Divided in Groups According to UFV | | |
	All Patients (n = 53)	≤1.6L (n = 27)	>1.6L (n = 26)	*P*
Age, y	63 ± 15	67 ± 15	59 ± 14	0.07
Men	35 (66%)	16 (59%)	19 (73%)	0.29
Time since diagnosis, y	4.9 [2.7-9.4]	3.4 [1.8-7.8]	5.7 [3.2-10.5]	0.09
Time since initiation of HD, y	1.8 [0.5-4.5]	1.2 [0.3-2.8]	2.5 [0.8-5.8]	<0.05
Medical History				
Hypertension	44 (85%)	20 (77%)	24 (92%)	0.12
Diabetes	18 (35%)	6 (23%)	12 (46%)	0.08
Hyperlipidemia	13 (27%)	5 (19%)	8 (35%)	0.33
Claudication	7 (14%)	3 (12%)	4 (16%)	1.00
Stroke or TIA	7 (14%)	3 (12%)	4 (17%)	0.70
Cardiac disease	24 (45%)	15 (56%)	9 (35%)	0.13
Cause				
Diabetic nephropathy	16 (33%)	6 (22%)	10 (38%)	0.24
Hypertensive kidney disease	7 (14%)	3 (11%)	4 (15%)	0.70
Polycystic kidney diasese	5 (10%)	3 (11%)	2 (8%)	1.00
Congenital	4 (8%)	3 (11%)	1 (4%)	0.61
ATIN	3 (6%)	1 (4%)	2 (8%)	0.61
Unknown	2 (4%)	1 (4%)	1 (4%)	1.00
Other	12 (24%)	6 (22%)	6 (23%)	1.00
Medications				
Aspirin	12 (23%)	5 (19%)	7 (27%)	0.74
Statins	12 (23%)	5 (19%)	7 (27%)	0.74
β-blockers	27 (52%)	17 (65%)	10 (38%)	0.052
RAAS inhibitors	14 (27%)	7 (27%)	7 (27%)	1.00
Calcium antagonists	27 (52%)	14 (54%)	13 (50%)	0.78
Loop diuretics	28 (54%)	19 (73%)	9 (35%)	0.005
Moxonidine	1 (2%)	1 (4%)	0 (0%)	1.00
Other antihypertensives	7 (13%)	3 (12%)	4 (15%)	0.68

Note: Data for categorical variables expressed as number (percent); data for continuous variables expressed as mean ± standard deviation or median [interquartile range].

Abbreviations: ATIN, acute tubulointerstitial nephritis; HD, hemodialysis; RAAS, renin-angiotensin-aldosterone system; TIA, transient ischemic attack; UFV, ultrafiltration volume.

entire population and stratified in groups according to the median UFV of 1.6 (IQR, 0.6-3.1) L are presented in Table 1. Median duration of the HD session at the examination day was 3 hours 50 minutes. During HD, 7 (13%) patients experienced side effects such as hypotension, nausea, headache, or leg cramp. However, no patients were excluded during the examination day.

Clinical data related to the HD session are presented in Table 2. Significant differences in weight, heart rate, and systolic and diastolic blood pressures were observed in the group with UFV > 1.6 L, whereas the group with UFV ≤ 1.6 L had a significant difference only in weight.

Changes in Linear and Volumetric Measurements During HD

Table 3 summarizes echocardiographic measurements before and after HD. When evaluating the entire population as one group, we observed significant changes in the linear measurement of LVID. For each 1-L increase in UFV, LVID decreased 1.1 mm (95% CI, 0.5-1.7 mm; P = 0.001). We also observed changes in the 2D tracings of the LV total

area and cavity area and LVL, but no significant differences in LVM calculated using 1D or 2D methods. After dividing the population into 2 groups according to median UFV, echocardiography did not detect linear or volumetric differences in the group with UFV ≤ 1.6 L. In the group with UFV > 1.6 L, we observed significant decreases in both end-diastolic volume (EDV) and LVID. Accordingly, LVM calculated using 1D methods decreased significantly during HD, whereas LVM calculated using 2D methods was significantly unchanged. LVM indexed according to BSA and to the 2.7 power of height indicated a similar pattern, except for LVM calculated using Teichholtz and indexed by BSA, for which there was no significant difference.

Data from the entire population as one group are also presented in the Bland-Altman plots represented by Figure 2. These plots display differences before and after HD against mean values, indicating that the 2D methods have narrower limits of agreement compared with Devereux and Penn. The Teichholz method displays narrower limits of agreement but has inhomogeneous distribution along the x-axis. There were no significant changes in differences between systolic-

Table 2. Clinical Data Related to the HD Session

| | All patients | | | | | | UFV≤1.6L | | | | | | UFV>1.6L | | | | | |
| | n=53 | | | | | | n=27 | | | | | | n=26 | | | | | |
	Before	After	Δ%	Δ	(95% CI)	P	Before	After	Δ%	Δ	(95% CI)	P	Before	After	Δ%	Δ	95% CI	P
UFV mL	1600 (550-3050)						280 (390-1000)						3050 (2338 – 3800)					<0.001
Duration HD session min	230 (185-240)						230 (185-237)						233 (200-240)					0.25
Weight kg	77.3 ± 20.4	75.9 ± 20.0	−1.8	−1.4	(−1.8 to −1.1)	<0.001	71.4 ± 16.5	71.1 ± 16.4	−0.5	−0.3	(−0.5 to −0.1)	0.002	83.2 ± 22.5	80.7 ± 22.3	−3.2	−2.5	(−2.9 to −2.2)	<0.001
SBP mm Hg	153 ± 22	142 ± 24	−6.4	−11	(−17 to −5)	0.001	147 ± 19	143 ± 24	−1.9	−3	(−12 to 5)	0.41	160 ± 23	141 ± 24	−11.1	−19	(−27 to −10)	<0.001
DBP mm Hg	81 ± 14	75 ± 14	−5.4	−6	(−10 to −2)	0.008	78 ± 14	75 ± 15	−1.6	−3	(−9 to 3)	0.37	83 ± 14	74 ± 14	−9.2	−9	(−15 to −3)	0.005
Heart rate, beats/min	69 ± 12	72 ± 11	+4.6	+3	(−1 to 6)	0.12	71 ± 14	73 ± 13	+4.0	+2	(−4 to 8)	0.51	67 ± 9	70 ± 10	+5.2	+3	(0 to 6)	0.03

Note: Continuous variables expressed as median [interquartile range] or mean ± standard deviation.
Abbreviations: CI, confidence interval; DBP, diastolic blood pressure; HD, hemodialysis; SBP, systolic blood pressure; UFV, ultrafiltration volume.

diastolic dimensions, volumes, or mass as assessed using 1D and 2D methods before and after HD, indicating that LVM remained relatively constant despite HD (Table 4).

Feasibility and Intra- and Interobserver Variability

Feasibility for the 1D methods was 96%, whereas feasibility for the 2D methods was 78%. Intra- and interobserver analysis is presented in Table 5. The 2D methods had similar variation but slightly higher bias than the 1D methods. We also observed slightly lower variations in the intraobserver analysis compared with the interobserver analysis.

DISCUSSION

In the present study, we demonstrate the consequences of fluid fluctuations on echocardiographic measurements and calculations of LVM. We found that LVM calculated using 2D methods, in contrast to 1D methods, was significantly unchanged despite significant decreases in LVV and LV dimensions during HD. These results indicate that 2D methods for calculation of LVM are more resistant to fluid fluctuations compared with 1D methods.

Progressive increase in LVM index is the strongest predictor of sudden cardiac death among patients receiving HD.[6] The composite long-term burden of a cardiac condition is reflected in the degree of hypertrophy. Increased LVM may be a sign of poorly regulated blood pressure or progressive worsening in valvular disease. Regression of LVM index by factors such as increased control of blood pressure and anemia have independent favorable effects on cardiovascular survival in HD patients.[7] LVM may therefore be used as an indicator of target-organ damage or a sign of clinical deterioration and is valuable for clinical follow-up. Calculations of LVM in HD patients unfortunately are associated with inaccuracies because of large fluid fluctuations affecting the LVV and LV dimensions. There is no general consensus regarding the best timing of the echocardiographic examination, but logically it seems most correct on a nondialysis day and when at dry weight.[8]

In the present study we tested the influence of fluid fluctuations and found that the 2D methods were less affected compared with the conventional 1D methods. This is interesting because we found significant decreases in both LVV by Simpson's biplane and LV dimensions measured as LVID for the 1D calculations and measured as A_2, the LV cavity area for the 2D calculations after HD (Table 3). The same results were found after indexing for height to the power of 2.7, which is recommended for patients receiving HD.[18,21]

In this study, we did not test accuracy, precision, and correlation to the reference LVM by cardiac magnetic resonance. In general, LVM calculated using the 1D methods systematically seems to overestimate LVM,[22-25]

Table 3. Echocardiographic Measurements and Calculations Before and After HD

	All Patients (n = 53)						UFV ≤ 1.6 L (n = 27)						UFV < 1.6 L (n = 26)					
	Before	After	Δ%	Δ	95% CI	P	Before	After	Δ%	Δ	95% CI	P	Before	After	Δ%	Δ	95% CI	P
EDV,[a] mL	137 ± 51	129 ± 48	−2.8	−8	(−18 to 1)	0.09	130 ± 53	133 ± 56	+4.2	+2	(−12 to 17)	0.72	144 ± 49	124 ± 38	−10.1	−20	(−32 to −8)	0.003
ESV,[a] mL	67 ± 41	63 ± 42	−3.0	−4	(−10 to 1)	0.12	68 ± 50	69 ± 56	+3.7	+1	(−8 to 11)	0.75	67 ± 30	57 ± 21	−10.1	−11	(−17 to −5)	0.002
LVEF,[a] %	53 ± 12	54 ± 14	+0.8	+1	(−2 to 3)	0.81	52 ± 15	52 ± 18	−0.4	0	(−4 to 5)	0.81	55 ± 9	55 ± 7	+2.0	0	(−4 to 4)	0.92
SV,[a] mL	69 ± 23	65 ± 22	−1.8	−4	(−11 to 3)	0.24	62 ± 20	63 ± 24	+3.4	+1	(−7 to 10)	0.80	77 ± 25	68 ± 20	−7.4	−9	(−20 to 1)	0.09
IVSd, cm	0.99 ± 0.17	1.00 ± 0.13	+2.8	+0.01	(−0.03 to 0.05)	0.56	0.91 ± 0.15	0.96 ± 0.12	+6.7	+0.05	(0 to 0.10)	0.07	1.07 ± 0.16	1.05 ± 0.14	−1.2	−0.02	(−0.08 to 0.03)	0.34
LVIDd, cm	5.2 ± 0.7	5.0 ± 0.7	−3.6	−0.2	(−0.3 to −0.1)	<0.001	5.2 ± 0.7	5.1 ± 0.7	−1.3	−0.1	(−0.2 to 0)	0.16	5.1 ± 0.7	4.8 ± 0.7	−5.9	−0.3	(−0.5 to −0.2)	<0.001
LVPW$_d$, cm	0.91 ± 0.16	0.92 ± 0.17	+2.1	+0.01	(−0.02 to 0.05)	0.52	0.84 ± 0.16	0.84 ± 0.15	+1.0	0	(−0.05 to 0.05)	0.99	0.98 ± 0.13	1.00 ± 0.14	+3.2	+0.02	(−0.03 to 0.08)	0.39
LVM-Devereux, g	182 ± 51	174 ± 51	−3.1	−8	(−18 to 1)	0.09	165 ± 47	168 ± 56	+2.3	+3	(−9 to 15)	0.57	200 ± 49	180 ± 46	−8.4	−20	(−34 to −6)	0.008
LVM-Penn, g	214 ± 63	203 ± 64	−3.2	−10	(−22 to 2)	0.09	192 ± 59	196 ± 70	+2.5	+4	(−11 to 19)	0.57	235 ± 62	210 ± 57	−8.8	−25	(−43 to −7)	0.008
LVM-Teichholz, g	139 ± 29	136 ± 28	−1.4	−3	(−9 to 2)	0.21	127 ± 27	129 ± 30	+2.5	+2	(−5 to 10)	0.48	151 ± 26	141 ± 25	−5.3	−9	(−18 to −1)	0.03
LVMI-Devereux, g/m^2	98 ± 27	94 ± 28	−2.2	−3	(−8 to 2)	0.19	91 ± 24	94 ± 30	+3.5	+3	(−4 to 10)	0.38	104 ± 28	95 ± 27	−7.2	−9	(−15 to −2)	0.01
LVMI-Penn, g/m^2	114 ± 33	110 ± 35	−2.2	−4	(−10 to 2)	0.19	106 ± 30	110 ± 38	+3.6	+4	(−5 to 12)	0.38	122 ± 34	111 ± 33	−7.6	−11	(−19 to −3)	0.01
LVMI-Teichholz, g/m^2	75 ± 16	74 ± 16	−0.4	−1	(−4 to 2)	0.50	70 ± 15	72 ± 17	+3.4	+2	(−2 to 6)	0.31	79 ± 16	75 ± 16	−4.0	−4	(−8 to 0)	0.06
LVMI-Devereux, g/h$^{2.7}$	44 ± 19	43 ± 19	−2.9	−2	(−4 to 0)	0.10	40 ± 11	41 ± 13	+2.9	+1	(−2: 4)	0.45	49 ± 24	44 ± 23	−8.4	−5	(−8 to −1)	0.006
LVMI-Penn, g/h$^{2.7}$	52 ± 23	50 ± 23	−3.0	−2	(−5 to 0)	0.10	46 ± 14	47 ± 16	+3.2	+1	(−2 to 5)	0.45	58 ± 29	52 ± 28	−8.8	−6	(−10 to −2)	0.006
LVMI-Teichholz, g/h$^{2.7}$	34 ± 12	33 ± 12	−1.2	−1	(−2 to 1)	0.25	31 ± 7	31 ± 7	+3.1	+1	(−1 to 2)	0.37	37 ± 15	35 ± 15	−5.3	−2	(−4 to 0)	0.02
A$_1$-diastole, cm^2	48.2 ± 10.3	46.2 ± 10.5	−3.8	−2.0	(−3.7 to −0.2)	0.03	45.8 ± 10.8	45.5 ± 11.6	−0.5	−0.3	(−2.4 to 1.9)	0.80	51.1 ± 9.1	47.0 ± 9.3	−7.9	−4.1	(−6.9 to −1.4)	0.006
A$_2$-diastole, cm^2	26.6 ± 7.4	24.9 ± 7.4	−5.6	−1.7	(−3.1 to −0.3)	0.02	26.1 ± 8.2	25.7 ± 7.8	−0.5	−0.4	(−2.0 to 1.3)	0.65	27.3 ± 6.5	24.0 ± 6.9	−11.9	−3.3	(−5.8 to −0.9)	0.01
A$_m$-diastole, cm^2	21.6 ± 4.6	21.3 ± 4.7	−0.8	−0.3	(−1.2 to 0.7)	0.54	19.7 ± 3.4	19.8 ± 4.6	+0.5	+0.1	(−1.3 to 1.5)	0.88	23.8 ± 4.9	23.1 ± 4.2	−2.4	−0.8	(−2.2 to 0.6)	0.26
t-diastole, cm	1.00 ± 0.17	1.02 ± 0.17	+1.9	+0.01	(−0.03 to 0.06)	0.52	0.94 ± 0.10	0.95 ± 0.14	+0.8	0.01	(−0.05 to 0.06)	0.88	1.09 ± 0.19	1.12 ± 0.17	+3.2	+0.03	(−0.04 to 0.09)	0.43
LVL-diastole, cm	8.2 ± 0.9	8.0 ± 0.8	−1.7	−0.2	(−0.3 to 0)	0.04	8.0 ± 0.9	8.0 ± 0.9	−0.3	0	(−0.3 to 0.2)	0.90	8.6 ± 0.6	8.3 ± 0.7	−3.3	−0.3	(−0.5 to −0.1)	0.02
LVM-TE, g	177 ± 48	172 ± 48	−2.5	−6	(−15 to 4)	0.23	157 ± 38	158 ± 47	+0.4	+1	(−11 to 13)	0.86	202 ± 47	188 ± 44	−6.2	−14	(−29 to 1)	0.07
LVM-A-L, g	200 ± 54	194 ± 55	−2.3	−6	(−16 to 5)	0.26	176 ± 43	178 ± 54	+0.5	+1	(−12 to 15)	0.83	229 ± 53	214 ± 51	−5.9	−15	(−32 to 2)	0.08
LVMI-TE, g/m^2	95 ± 23	92 ± 28	−2.6	−2	(−7 to 2)	0.31	86 ± 19	86 ± 26	−0.7	0	(−7 to 6)	0.93	105 ± 24	100 ± 28	−4.9	−5	(−12 to 3)	0.18
LVMI-A-L, g/m^2	107 ± 27	104 ± 32	−2.4	−2	(−8 to 3)	0.36	97 ± 23	97 ± 30	−0.6	0	(−7 to 7)	0.97	118 ± 27	113 ± 33	−4.6	−5	(−14 to 3)	0.22
LVMI-TE, g/h$^{2.7}$	43 ± 17	42 ± 20	−3.3	−1	(−3 to 1)	0.28	38 ± 9	37 ± 11	−0.8	0	(−3 to 3)	0.89	49 ± 22	47 ± 26	−6.2	−2	(−6 to 1)	0.20
LVMI-AL, g/h$^{2.7}$	48 ± 20	47 ± 23	−3.1	−1	(−4 to 1)	0.34	42 ± 10	42 ± 13	−0.7	0	(−3 to 3)	0.93	56 ± 26	53 ± 30	−5.9	−2	(−6 to 2)	0.25

Note: Data expressed as mean ± standard deviation.
Abbreviations: A$_1$, total left ventricular area diastole; A$_2$, left ventricular cavity area diastole; A-L, area length; A$_m$, myocardial area diastole; CI, confidence interval; EDV, end-diastolic volume; ESV, end-systolic volume; HD, hemodialysis; IVSd, interventricular septum diastole; LVEF, left ventricular ejection fraction; LVIDd, left ventricular internal diameter diastole; LVL, left ventricular length; LVM, left ventricular mass; LVMI, left ventricular mass index; LVPWd, left ventricular posterior wall diastole; SV, stroke volume; t, mean wall thickness; TE, truncated ellipsoid; UFV, ultrafiltration volume.
[a]Volumes and LVEF estimated using Simpson's biplane method.
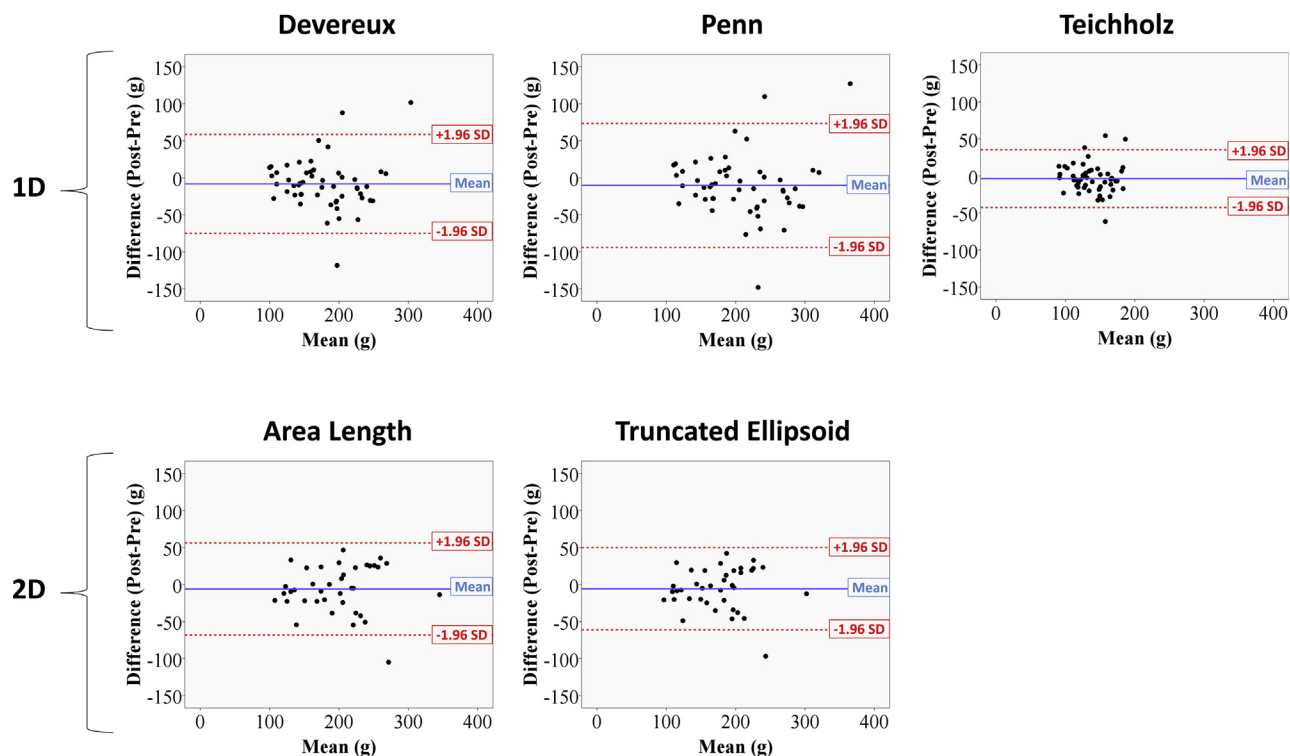
Figure 2. Bland-Altman plots; differences between calculations of left ventricular mass before and after hemodialysis plotted against mean. Abbreviations: 1D, 1-dimensional; 2D, 2-dimensional; SD, standard deviation.

increasing their suitability for screening of increased LVM. The 2D methods are more accurate and precise compared with 1D methods[14,22,24,25] and are suitable for verification of LVM. We therefore encourage complimentary calculation of LVM using 2D methods among HD patients with increased LVM using the 1D methods. The 2D methods seem to be less dependent on the timing of the echocardiographic examination. However, this may not be the case for many other echocardiographic parameters not reported in this report, and the common routines regarding echocardiographic timing on a nondialysis day and when at dry weight should therefore not be changed.

The 1D methods are based on the mathematical assumption of a prolate ellipsoid with relationship 2:1 between long axis to short axis. The simplified "cube formula" is based on cubing of the linear dimensions of the left ventricle. Consequently, small linear measurement errors are raised to the magnitude of 3.[9,11-13] The most common correction factors are the Devereux and Penn, which are constant and not dependent on the dimensions.[10] The Teichholz correction factor allows the left ventricle to adopt a more rounded shape as LVV increases. As LV diameter expands, the correction factor decreases. Consequently, a larger LV diameter has less impact on the calculated LVV and LVM, resulting in less variation and distinguishable lower values of LVM (Fig 2). EDV, LVID, and LVM calculated using 1D methods by Devereux and Penn decreased significantly in the UFV > 1.6 L group

(Table 3). Similar results have been reported before.[26-32] We also noticed a significant decrease in LVL in the UFV > 1.6 L group, which is in agreement with the correction factor by Devereux and Penn. Similar LVL shortening during preload reduction has been reported in dogs.[33]

The A-L method divides the left ventricle into 2 parts; cylinder and prolate ellipsoid, which gives the left ventricle the shape of a bullet.[14] The TE method is also based on a prolate ellipsoid and truncated at the level corresponding to the aortic and mitral valve annulus, with a proportional representation of the septum and LV free wall, where the septum corresponds to one-third of LVM and free wall to two-thirds of LVM.[15] The 2D methods, as well as 1D methods, are based on geometrical assumptions. However, several factors contribute to the favorable effect of the 2D methods: (1) they are partially based on tracing of an area, which minimizes the impact of minor tracings errors; and (2) LVL is measured, not estimated. Unchanged LVM despite significant changes in LV dimensions has been reported before.[34] Furthermore, the 2D methods seem superior compared with 1D methods in regard to abnormalities in LV shape and geometry.[35]

Feasibility was slightly lower for the 2D methods compared with the 1D methods; 78% versus 96%. These results are not surprising; 1D methods require only 1 image with sufficient image quality, whereas 2D methods require 2 images. Furthermore, our feasibility reflects the

Table 4. Differences Between Systolic and Diastolic Echocardiographic Parameters Before and After HD and Correlation to UFV

| | Before HD | | | After HD | | | | | Correlation to UFV[a] | |
| | Systole − Diastole | | | Systole − Diastole | | | | Diff | | |
	Mean	± SD	Δ%	Mean	± SD	Δ%	P	(95% CI)[b]	r	P
IVS, cm	0.35	±0.20	29.6	0.34	±0.18	28.9	0.76	0.01 (−0.05 to 0.07)	−0.04	0.79
LVID, cm	−1.58	±0.51	−36.9	−1.46	±0.49	−36.6	0.09	−0.11 (−0.25 to 0.02)	0.20	0.15
LVPW, cm	0.54	±0.22	45.2	0.50	±0.24	42.0	0.31	0.04 (−0.03 to 0.11)	0.07	0.62
LVM-Devereux, g	−1.6	±26.2	−0.83	−0.5	±30.6	−1.9	0.84	−1.1 (−12.2 to 10.0)	0.13	0.35
LVM-Penn, g	−2.0	±32.8	−0.90	−0.7	±38.2	−2.3	0.84	−1.4 (−15.2 to 12.5)	0.13	0.35
LVM-Teichholz, g	19.9	±18.0	13.3	17.6	±21.0	11.6	0.54	2.3 (−5.2 to 9.8)	0.08	0.58
LVM-TE, g	−5.0	±17.9	−3.6	−1.3	±14.5	−0.9	0.33	−3.7 (−11.3 to 3.9)	−0.25	0.16
LVM-A-L, g	−5.8	±20.0	−3.7	−1.9	±16.3	−1.2	0.35	−3.9 (−12.4 to 4.6)	−0.25	0.16
LVMI-Devereux, g/m^2	−1.5	±13.5	−1.0	−0.7	±17.6	−2.1	0.81	−0.7 (−6.9 to 5.4)	0.11	0.47
LVMI-Penn, g/m^2	−1.9	±16.9	−1.1	−0.9	±22.0	−2.5	0.81	−0.9 (−8.6 to 6.7)	0.11	0.47
LVMI-Teichholz, g/m^2	10.2	±9.3	13.3	9.3	±12.0	11.6	0.64	1.0 (−3.2 to 5.2)	0.07	0.64
LVMI-TE, g/m^2	−2.7	±9.6	−3.8	−0.3	±8.1	−0.9	0.26	−2.3 (−6.4 to 1.8)	−0.25	0.15
LVMI-A-L, g/m^2	−3.1	±10.7	−3.9	−0.6	±9.1	−1.2	0.27	−2.5 (−7.1 to 2.1)	−0.26	0.15

Abbreviations: A-L, area length; CI, confidence interval; Diff, difference; HD, hemodialysis; IVS, interventricular septum; LVID, left ventricular internal diameter; LVM, left ventricular mass; LVMI, left ventricular mass index; LVPW, left ventricular posterior wall; SD, standard deviation; TE, truncated ellipsoid; UFV, ultrafiltration volume.
[a]Correlation between UFV and difference between systole − diastole before and after HD.
[b]Difference between systole − diastole before and after HD.

Table 5. Intra- and Interobserver Variation

| | Intraobserver | | Interobserver | |
	Bias (95% CI)	CV, %	Bias (95% CI)	CV, %
Interventricular septum, cm	0.06 (0.01 to 0.11)	13.3	−0.02 (−0.08 to 0.04)	14.2
Left ventricular internal diameter, cm	−0.09 (−0.16 to −0.02)	0.01	−0.01 (−0.13 to 0.11)	5.6
Left ventricular posterior wall, cm	0.01 (−0.05 to 0.06)	13.4	0.02 (−0.04 to 0.09)	16.3
LVM-Devereux, g	3 (−7 to 12)	12.1	1 (−10 to 12)	13.6
LVM-Penn, g	4 (−8 to 15)	12.9	2 (−12 to 15)	14.5
LVM-Teichholz, g	3 (−3 to 10)	11.1	0 (−6 to 7)	11.3
Total area, cm^2	−1.3 (−2.8 to 0.3)	7.0	1.1 (−1.1 to 3.2)	10.0
Cavity area, cm^2	−1.3 (−2.1 to −0.4)	6.8	1.9 (0.4 to 3.3)	12.5
Myocardial area, cm^2	0 (−1.2 to 1.1)	11.9	−0.8 (−2.1 to 0.4)	13.1
Left ventricular length, cm	−0.3 (−0.4 to −0.2)	2.7	−0.2 (−0.3 to −0.1)	2.9
Semi-major axis, cm	−0.1 (−0.3 to 0)	5.0	0.1 (0 to 0.3)	7.3
Truncated semi-major axis, cm	−0.1 (−0.3 to 0)	16.7	−0.4 (−0.6 to −0.2)	19.2
LVM-truncated ellipsoid, g	−7 (−17 to 4)	12.7	−13 (−26 to 0)	13.7
LVM-area-length, g	−7 (−19 to 4)	12.5	−13 (−25 to −2)	13.7

Abbreviations: CI, confidence interval; CV, coefficient of variation; LVM, left ventricular mass.

real clinical feasibility because we did not exclude any patient because of poor acoustic window. Endo- and epicardial definition and tracing of the 2D images is altered by reduced lateral resolution in the parts in which the ultrasound beam is longitudinal to the LV wall, usually the inferior septum and on the other side, the lateral/anterolateral wall. Furthermore, the anatomy and angle of the left ventricle for some patients make it impossible to achieve a proper short-axis view perpendicular to the LV long axis. The increased difficulty performing LVM calculation using the 2D methods is also reflected in the intra- and interobserver analyses. There were similar variations but lower biases for the 1D methods. The 2D methods had slightly higher bias and variation in the interobserver analysis compared with the intraobserver analysis.

The results reflect the wide use of the 1D methods and also indicate that the 2D methods may require some training to standardize the measurements. For example, it is important not to include pericardial thickening of the inferior/posterior wall or parts of the moderator band or right ventricular trabeculae in the traced area, which is not emphasized in the guidelines and may be forgotten. It is also very important to mention that we only performed intra- and interanalysis on the offline analysis of the recordings. The analyses would be more representative of real daily practice if the intra- and interobserver variability also included separate bedside image acquisitions by the same examiner/reader for intra-analysis and another examiner/reader for the interanalysis. The parasternal long-axis view for 1D measurement is very dependent on correct angulation of the left ventricle during image acquisition. Small subtle changes in rotating or angulating the probe may cause larger differences in the linear dimensions and hypothetically induce larger intra- and interexaminer variability for the 1D methods than we observed in this study.

Previous studies have reported both unchanged and increased LVEF after HD.[26,36-40] Some differences may be related to methodology. One study based on linear measurements of LV dimensions by Teichholz reported 26% increase in LVEF after HD, which is more likely methodological and not physiologic.[41] The LVEF is a ratio of 2 volumes and any change related to one of the volumes will have an effect on LVEF. In the group with UFV ≤ 1.6 L, the EDV and end-systolic volume were unchanged, and in the group with UFV > 1.6 L, the EDV and end-systolic volume decreased proportionally, resulting in unchanged LVEF in both groups. According to the Frank-Starling law, decreased length-tension relationship after HD would result in decreased stroke volume. We observed a small insignificant decrease in stroke volume in the UFV < 1.6 L group. The contractility of the left ventricle after HD is complex and influenced by several factors, such as reduced afterload, reduced myocardial stress, changes in biochemical factors, possible induced ischemia or stunning, and perhaps

reduction in myocardial edema. One must also keep in mind that LV function can be evaluated in other ways not examined in this study.

Our study has several limitations. *First*, we included only 53 patients. Repeated measurements of the same patients on different dialysis sessions would have increased the impact of this study. *Second*, we did not use echocardiographic contrast enhancement, which would probably have improved both feasibility and inter- and intraobserver variability. *Third*, we did not test accuracy and precision with comparison to 3-dimensional echocardiographic methods or cardiac magnetic resonance. *Fourth*, we assumed that myocardial gravity and LVM remained constant during HD and that alterations in LVM during HD primarily were related to geometrical miscalculations related to the different methods. However, increased LVM related to myocardial edema during cardiopulmonary bypass and hemodilution/ischemic injury has been observed in dogs.[42] However, our measurements indicated that LVM remained constant despite HD (Table 4); thus, there was no significant indication of myocardial edema pre-HD. Furthermore, a potential effect of hemodilution would probably affect the entire body equally. Therefore, besides indexing the values to the 2.7 power of height, we also indexed to BSA using weight from both before and after HD. *Fifth*, we did not register the amount of fluid or food administered orally during HD. Most patients had a recommended allowance and did not consume considerable amounts of fluids; thus, we believe that the relatively small amount of fluid administered orally during HD did not have a significant impact on results. *Sixth*, we exclusively examined patients with ESKD treated by HD, in which myocardial fibrosis is more common.[43] Hypothetically we would notice a larger LVV change and larger measurement differences in a population with less myocardial fibrosis.

In summary, LVM calculated using the 2D methods, TE and A-L, is less affected by fluctuations in fluid and LVV, in contrast to 1D methods. Complementary calculation of LVM using the 2D methods is encouraged, especially in patients with large fluid fluctuations for whom increased LVM using the 1D methods has been detected.

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1-dimensional vs 2-dimensional echo methods: do left ventricular (LV) mass measurements differ with LV volume changes?

Kidney Medicine

Methods and Cohort

Cross-sectional
Single center
N = 53

Echocardiogram
before and after a
hemodialysis session

Calculations based on:

1-dimensional
methods

Vs

2-dimensional
methods

Median duration of
dialysis: **3 h 50m**

Median fluid removal
during dialysis: **1.6 L**

Findings

For each 1-liter increase in
fluid removal during HD ➝ LV internal diameter
decreases by 1.1mm

1-Dimensional ⚠ When the fluid removal was > 1.6 liters, LV
mass calculated by 1-dimensional methods
decreased according to changes in LV volume

2-Dimensional LV mass calculated by 2-dimensional
methods was not significantly different after
hemodialysis

Conclusion: LV mass calculated by 2-dimensional methods are less affected by changes in fluid and LV volume, in contrast to 1-dimensional methods. Calculation of LV mass by the 2-dimensional methods is encouraged, especially in patients with large fluid changes.