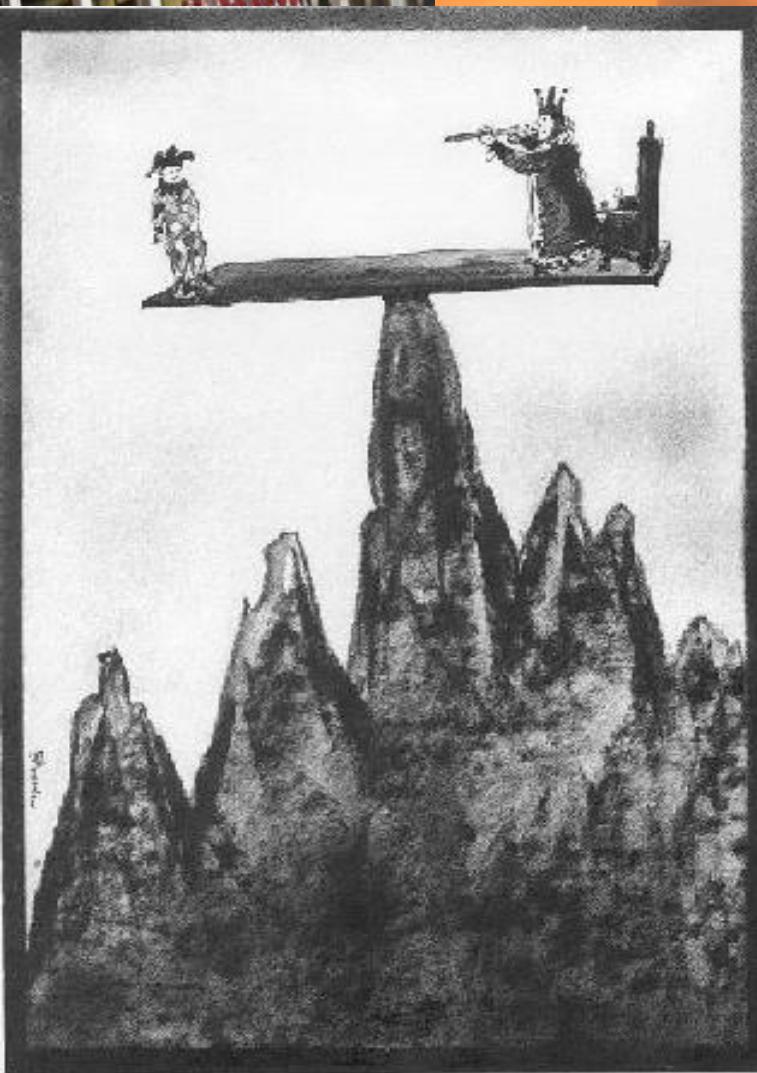


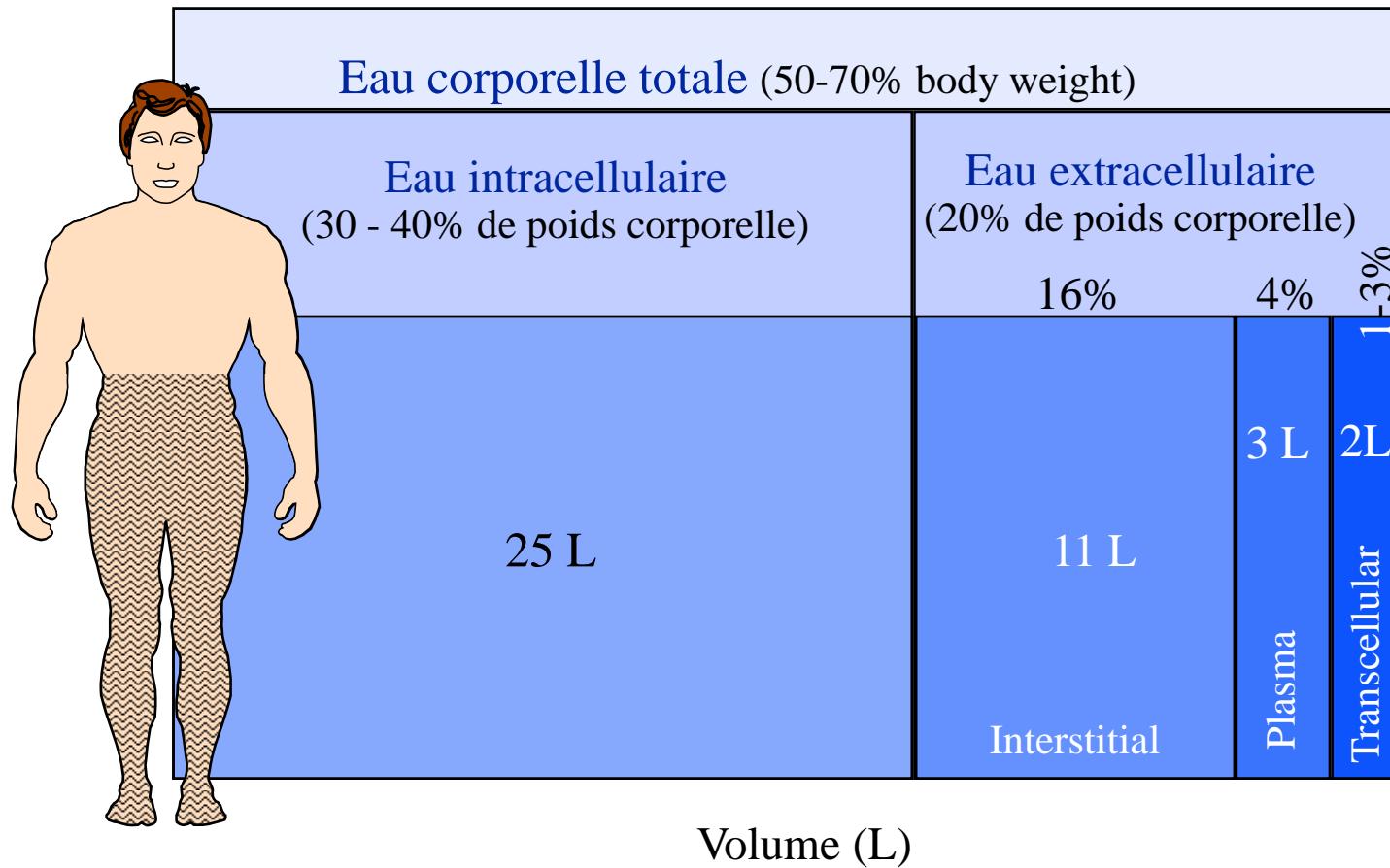
Volume and bodycomposition



W. Van Biesen, Renal Division, Hopital Universitaire de Ghent, Belgique







Bio-impedance before and after HD

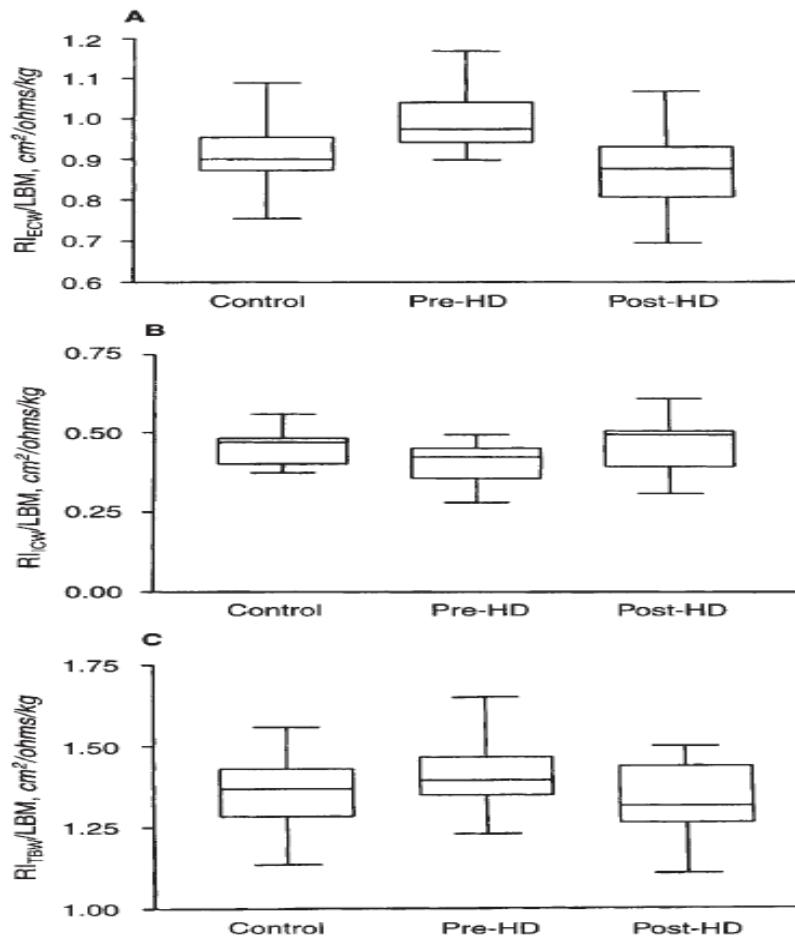


Fig. 1. ECW, ICW, and TBW resistive indices corrected for lean body mass. Shown as 25th percentile through 75th percentile (box) with mean shown as horizontal line and overall range (whiskers). A. RI_{ECW}/LBM. B. RI_{ICW}/LBM. C. RI_{TBW}/LBM.

$$\text{ECW Resistive Index} = H^2/R_{\text{ECW}}$$

$$\text{ICW Resistive Index} = H^2/R_{\text{ICW}}$$

$$\text{TBW Resistive Index} = H^2/R_{\text{TBW}}$$

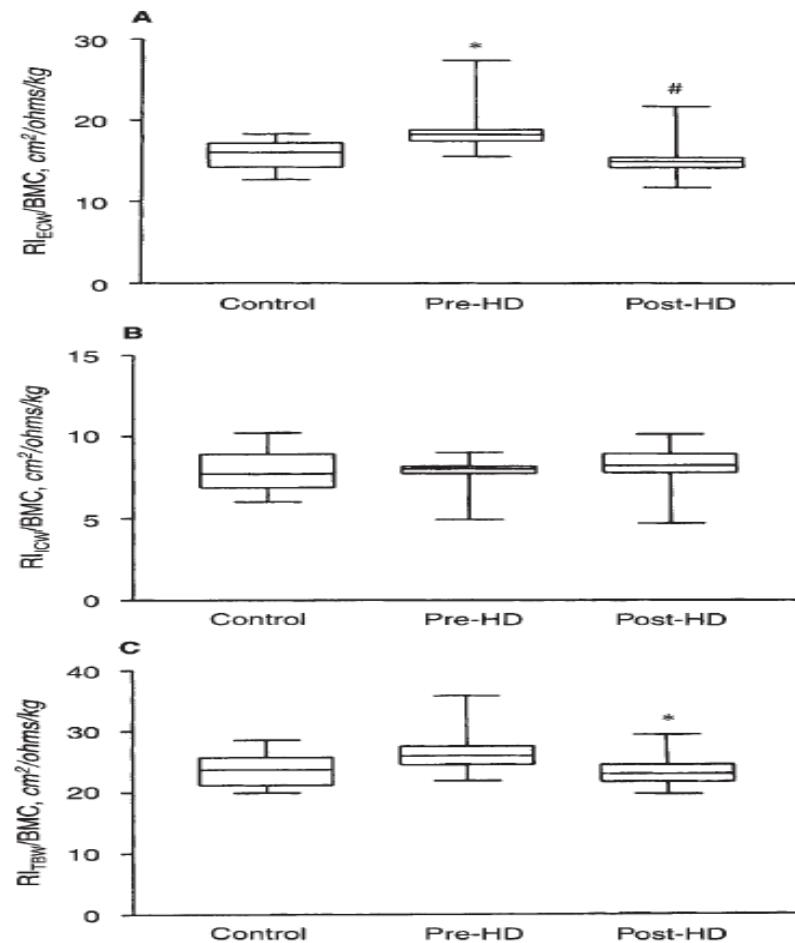
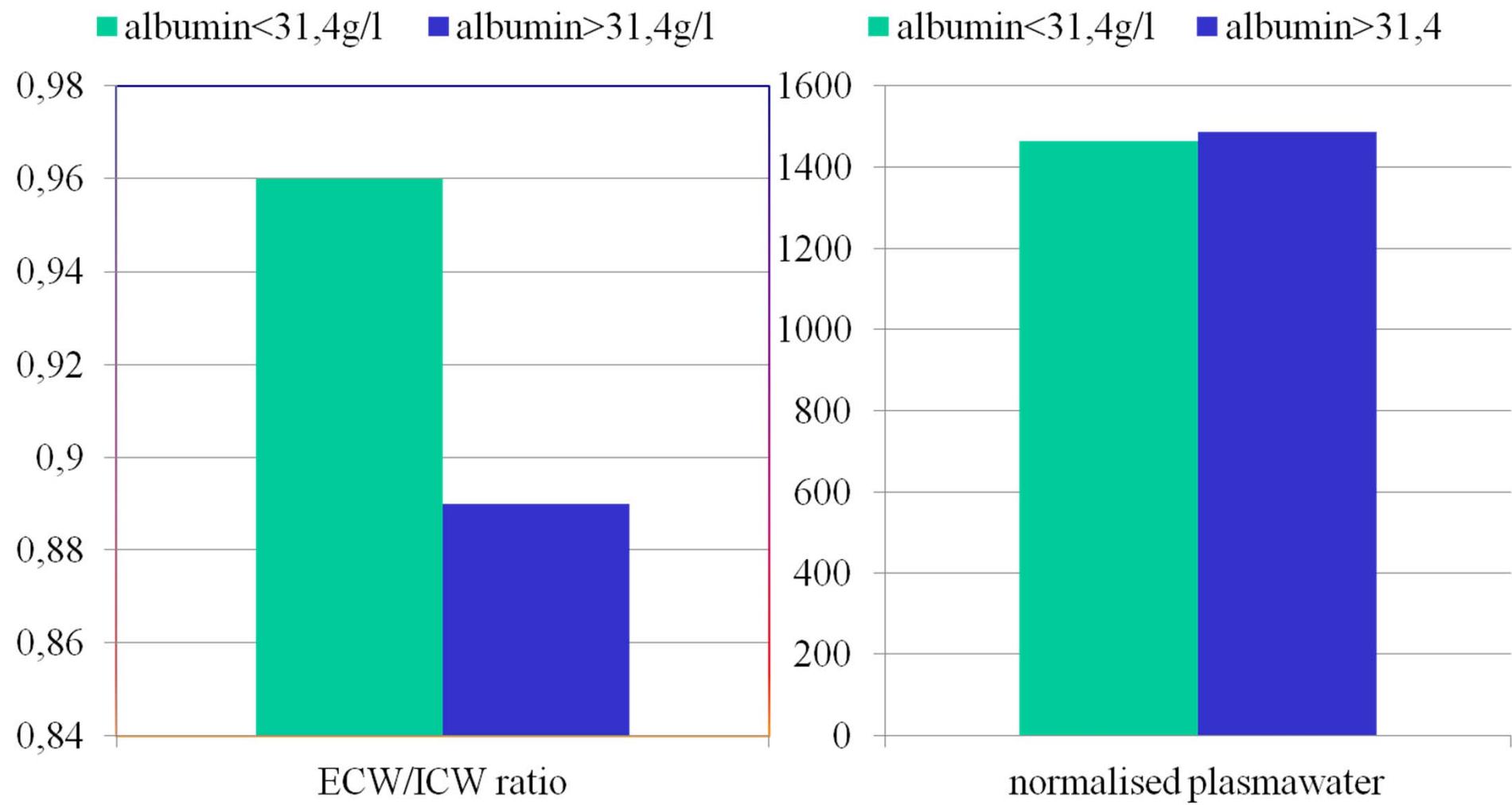
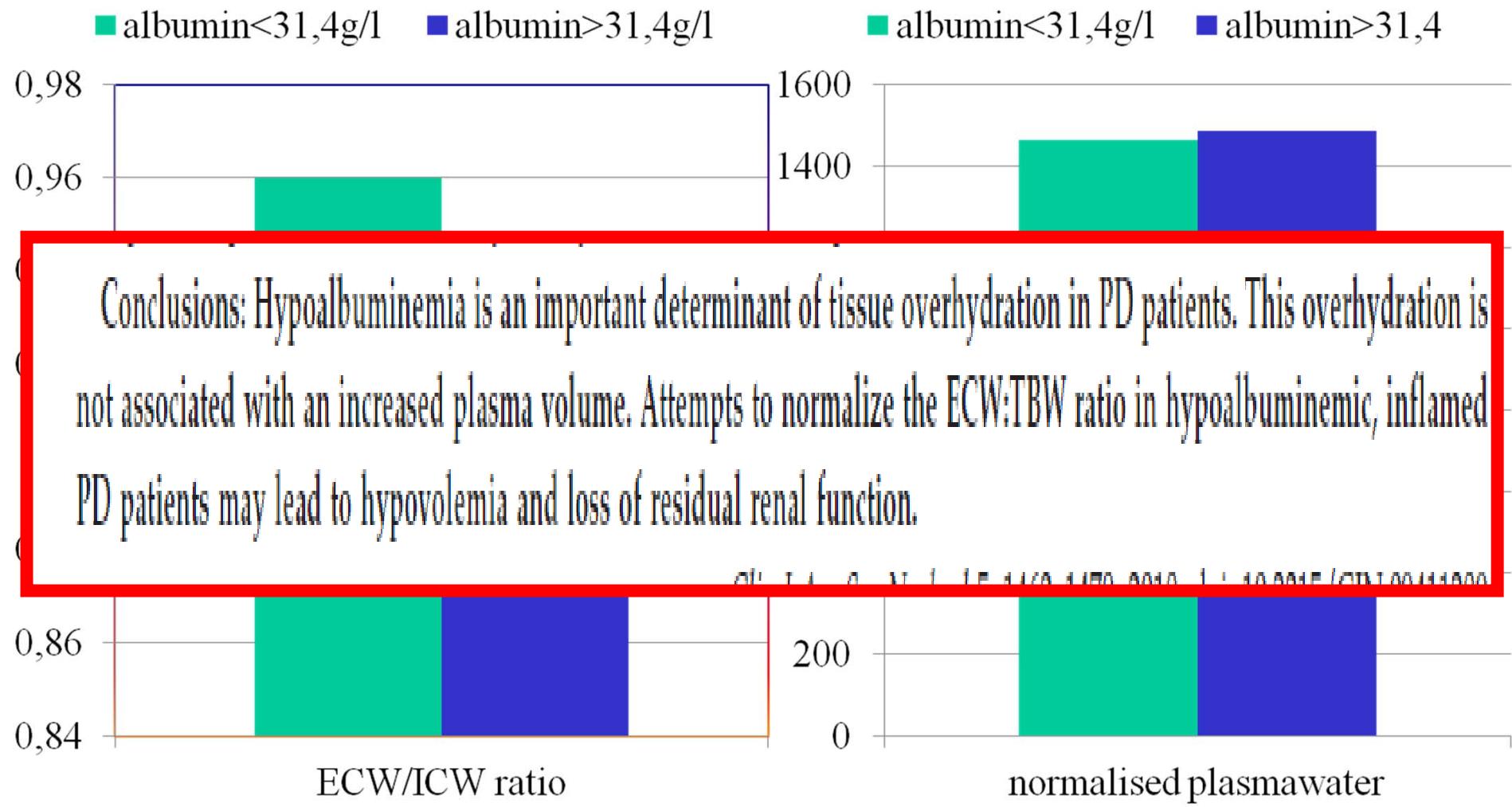


Fig. 2. ECW, ICW, and TBW resistive indices corrected for bone mineral content. Shown as 25th percentile through 75th percentile with mean shown as horizontal line (box) and overall range (whiskers). A. RI_{ECW}/BMC. *P < 0.01 versus controls. B. RI_{ICW}/BMC. #P < 0.01 versus pre-HD. C. RI_{TBW}/BMC. *P < 0.05 versus pre-HD.

Volume overload in PD patients

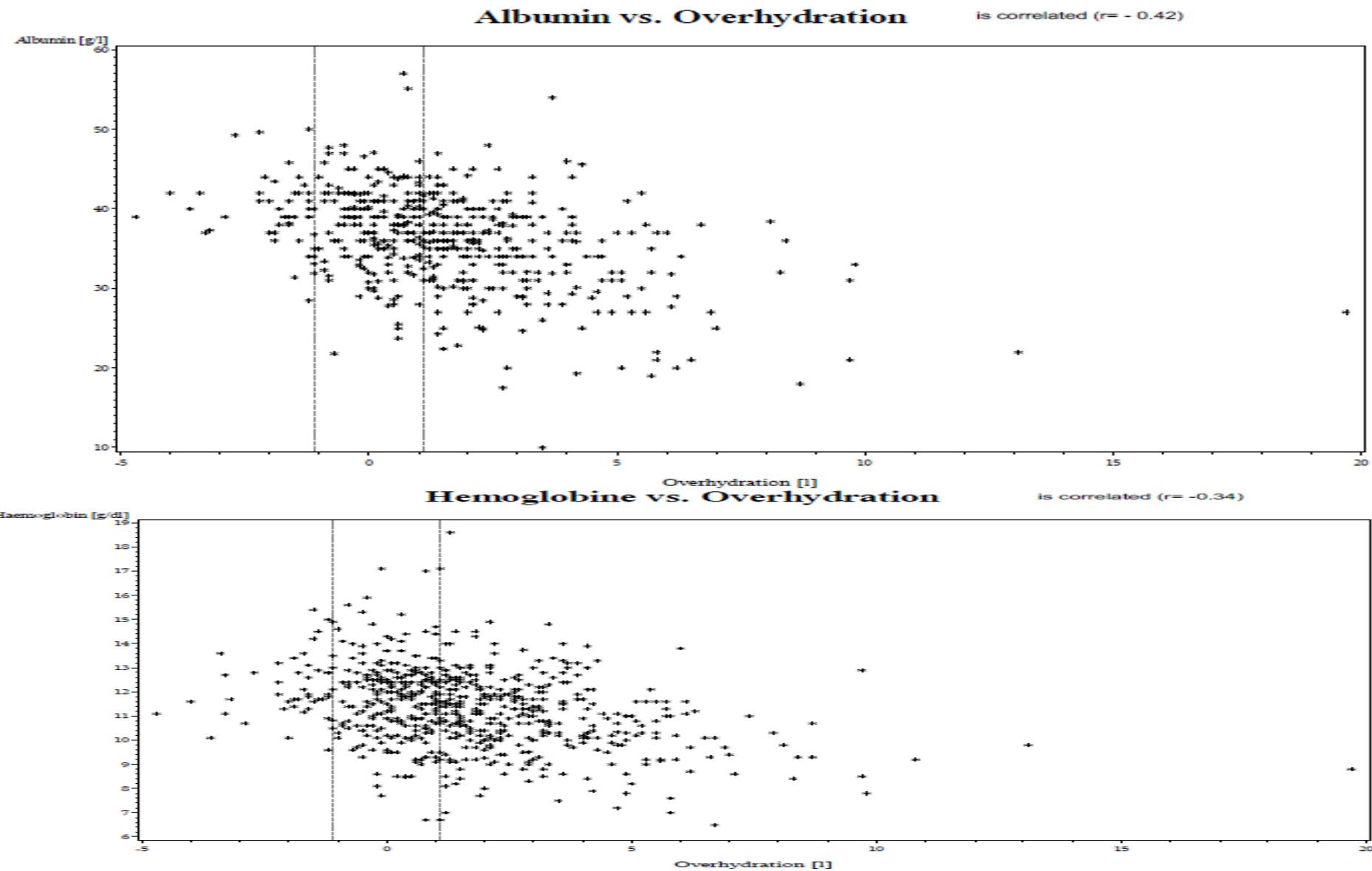


Volume overload in PD patients

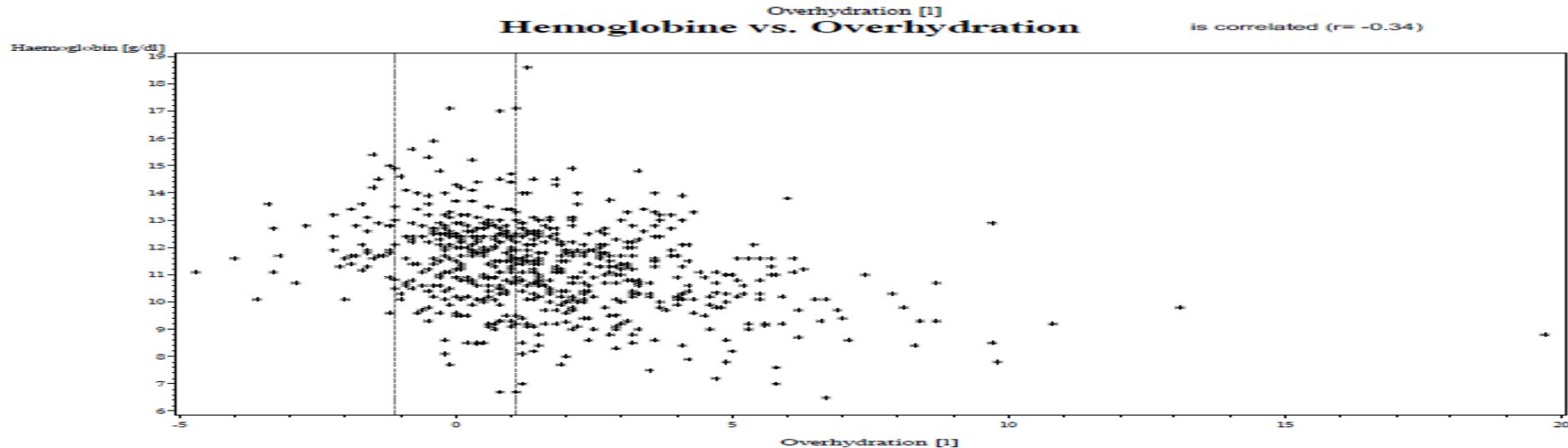
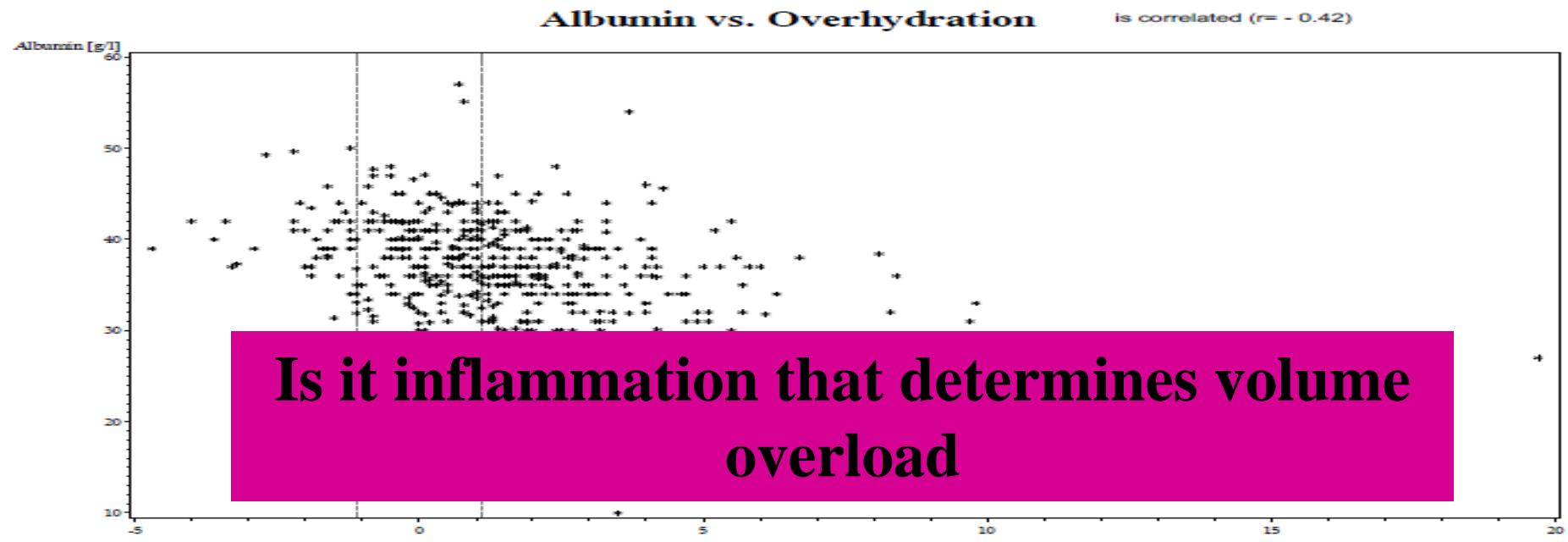


Biju J., cJASN, 2010

EuroBCM: Relation between albumine and volume overload



EuroBCM: Relation between albumine and volume overload



Critline measurement (Blood Volume Measurement)

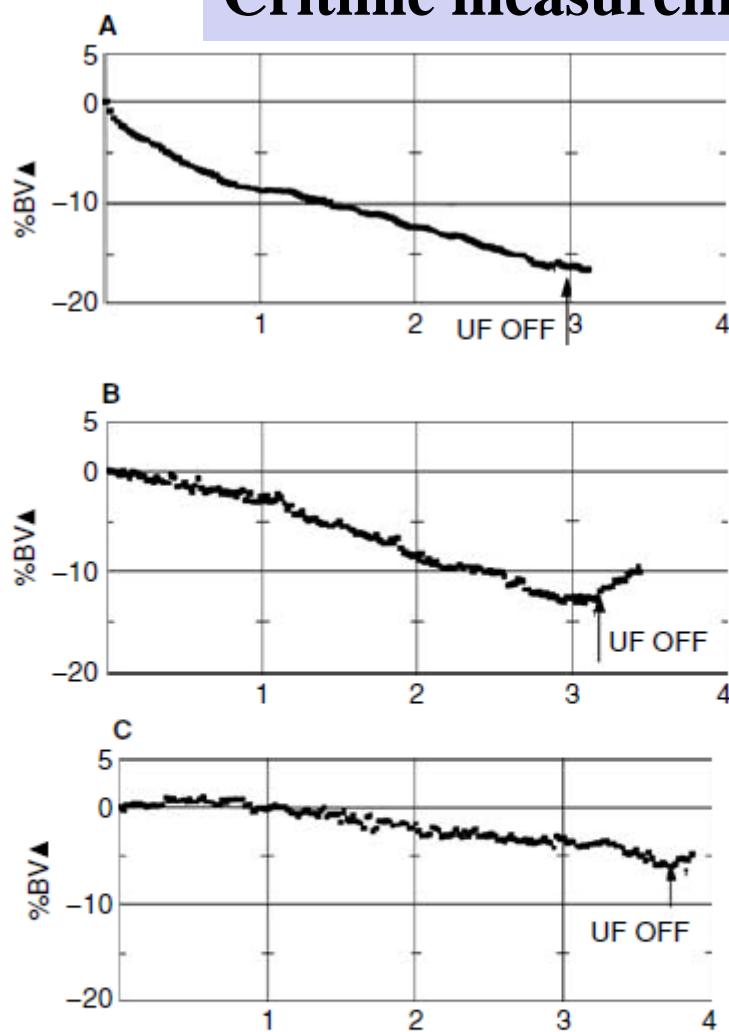


Fig. 2. Actual Crit-Line print out sheets showing typical percent blood volume (BV) reduction and absence or presence of postdialytic vascular refilling in graphic form. (A) Blood volume reduced by 16%; no post dialytic vascular refilling. (B) Blood volume reduced by 12%; clear-cut postdialytic vascular refilling. (C) Blood volume reduced by 6%; no postdialytic vascular refilling. The vertical axis in Figures 1 and 2 to C represents a % change in blood volume while the horizontal axis represents dialysis time in hours.

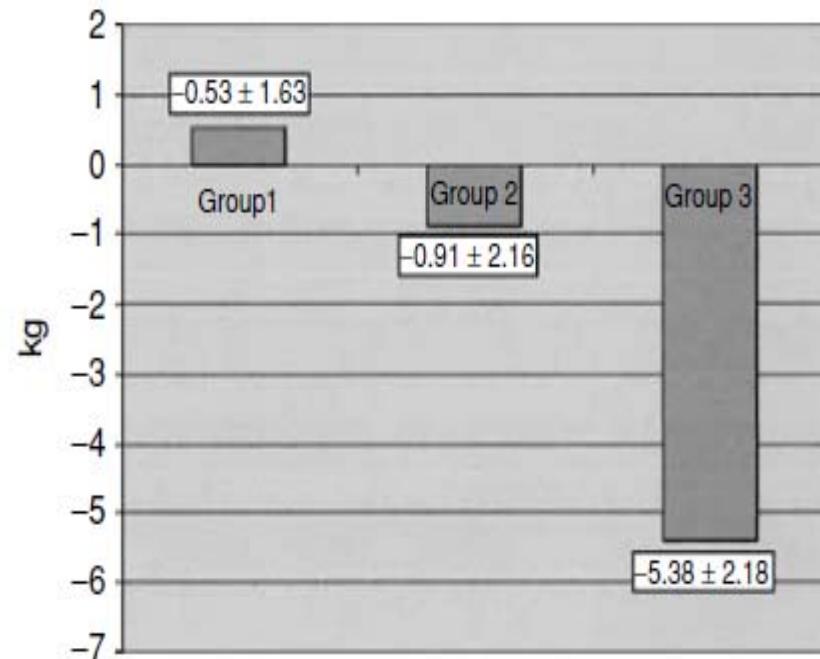


Fig. 3. A bar chart indicating the dry weight changes among the three groups. The change in dry weight is based on the difference between estimated dry weight (prestudy) and the actual dry weight at the conclusion of the study. Group 1 patients exhibited significant intradialytic reductions in blood volume but no postdialytic vascular compartment refill. Group 2 patients exhibited significant intradialytic reductions in blood volume and significant postdialytic vascular compartment refill. Group 3 patients did not exhibit significant intradialytic reductions in blood volume.

Rodriguez et al, KI, 2005

Evaluation of volume status

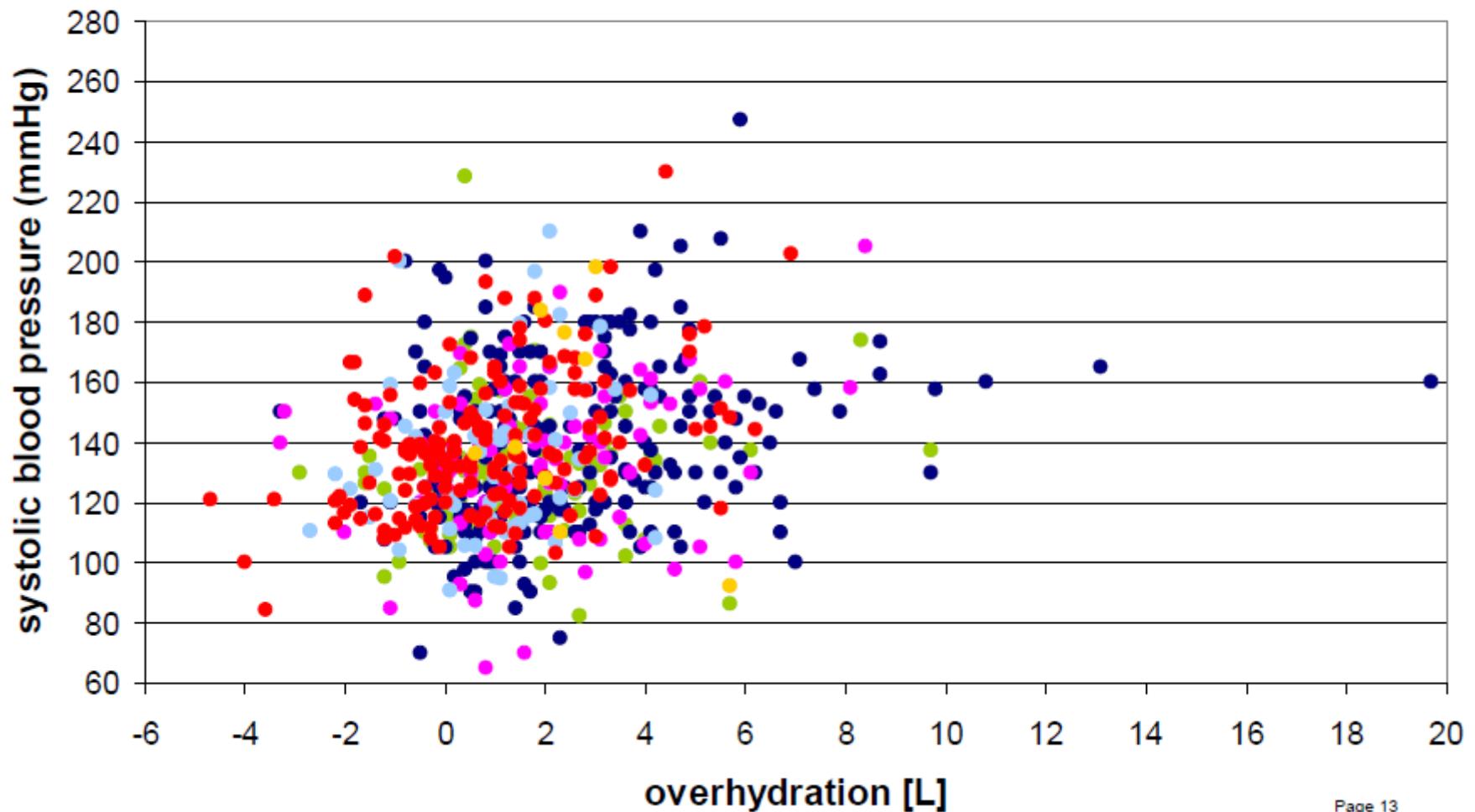


Clinical Evaluation

Your tests reveal that
you are retaining fluids!

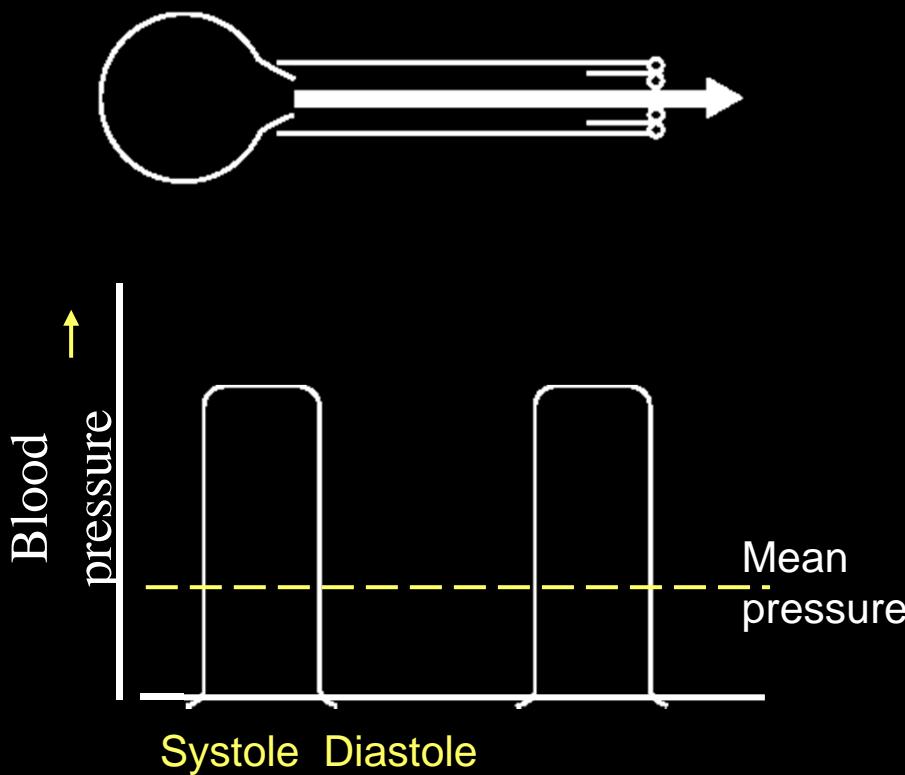
Overhydration in peritoneal dialysis patients

Overhydration scatter plot

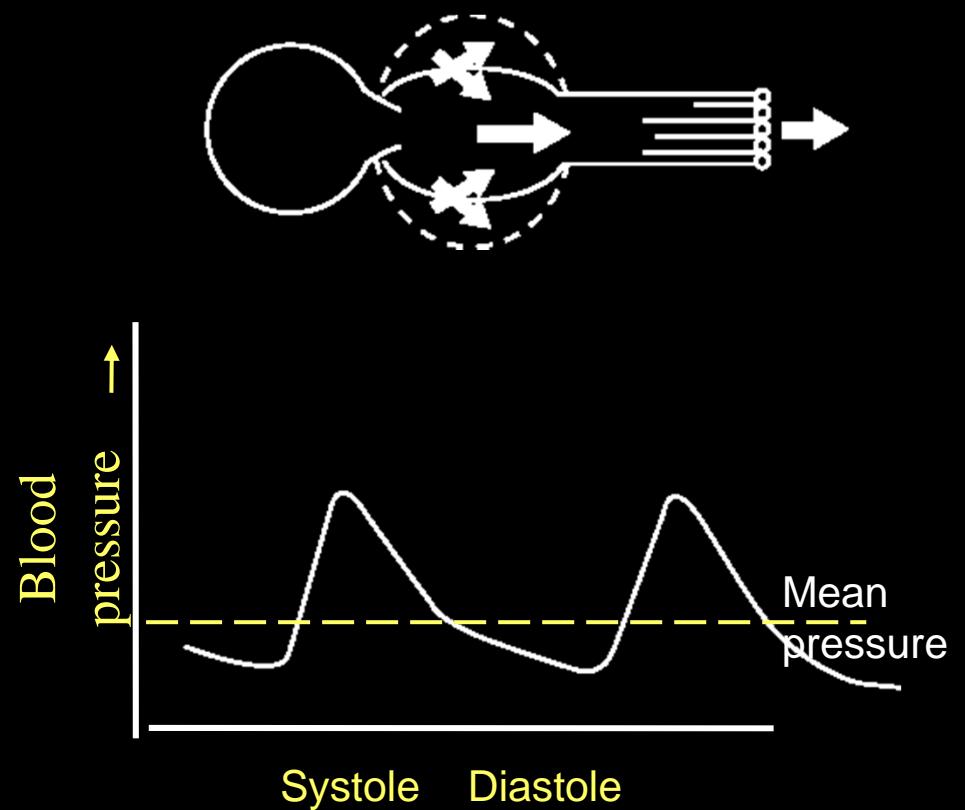


Arterial function and blood pressure

Pure Conduit Function



Conduit and Cushioning Function



Pulse pressure and mortality in PD patients

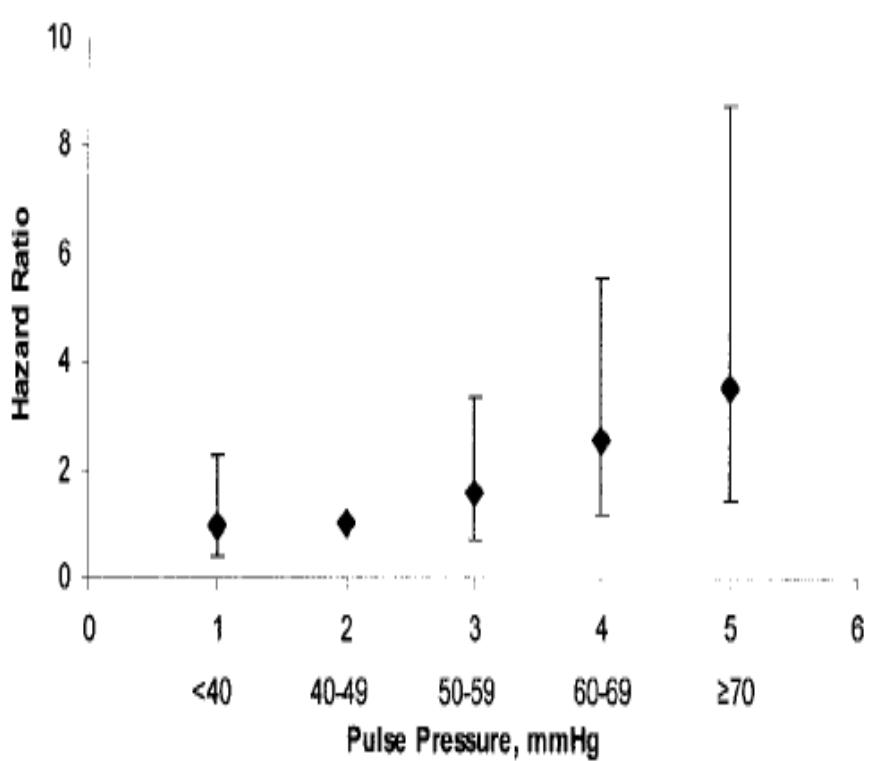


Figure 1 – Hazard ratios for mortality associated with pulse pressure after adjustment for systolic pressure. The category with pulse pressure 40 – 49 mmHg served as reference.

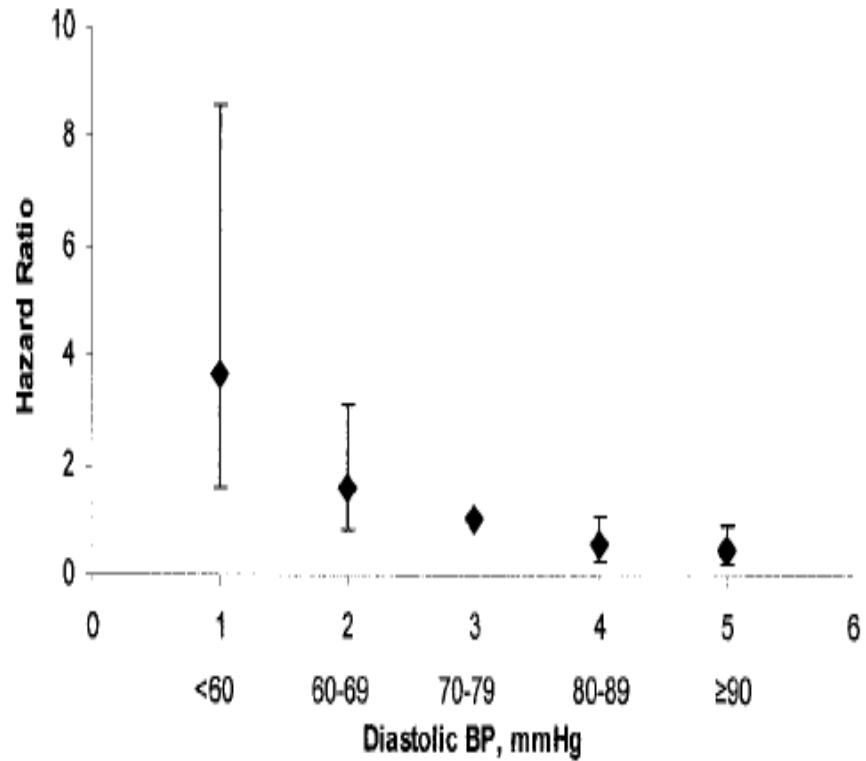
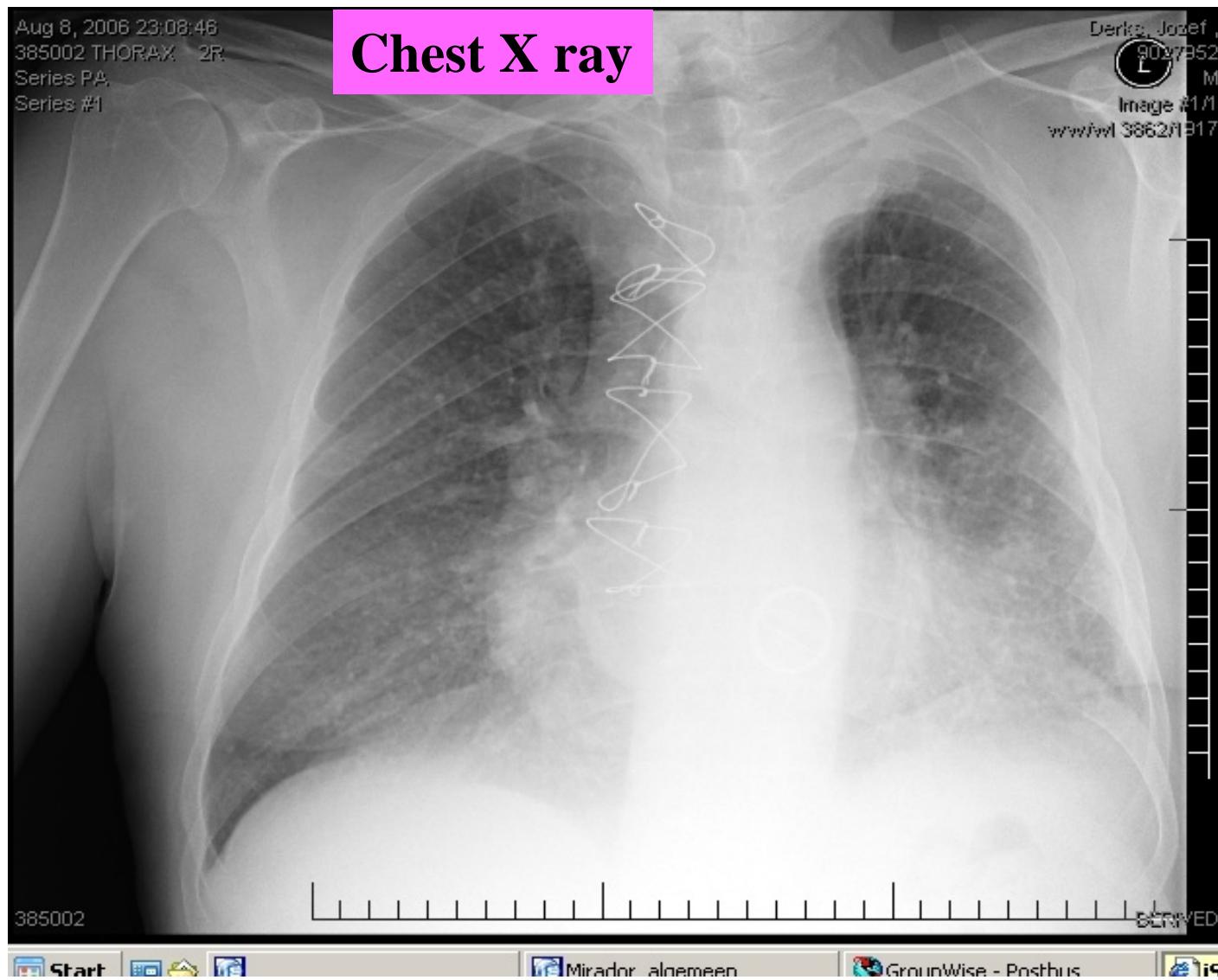
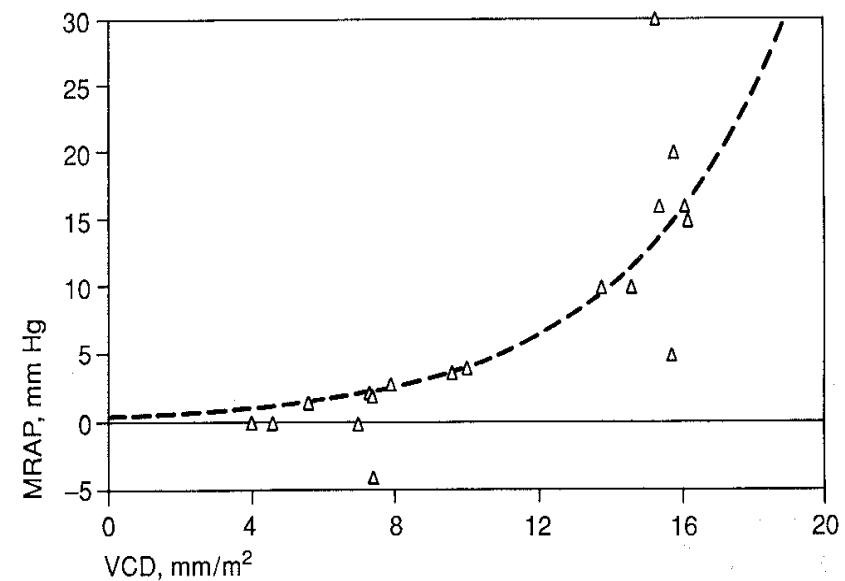
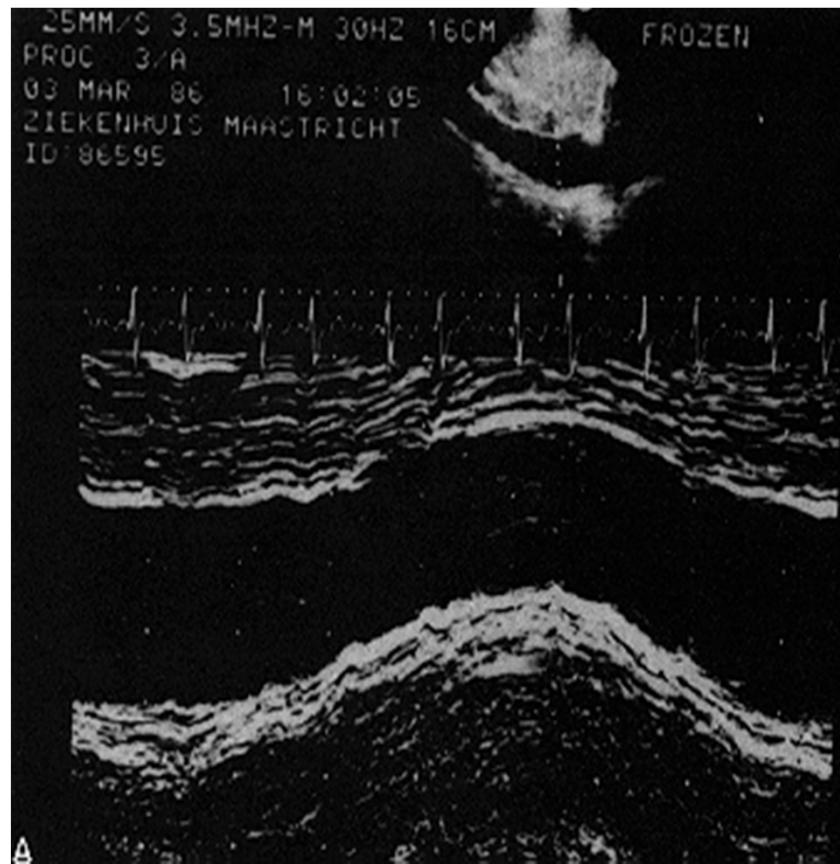


Figure 2 – Hazard ratios for mortality associated with diastolic blood pressure after adjustment for systolic pressure. The category with diastolic pressure 70 – 79 mmHg served as reference.

Evaluation of volume status



Evaluation of volume status vena cava ultrasound



Right atrial pressure

Leunissen et al, KI 1993

Ultrasound evaluation of lung water

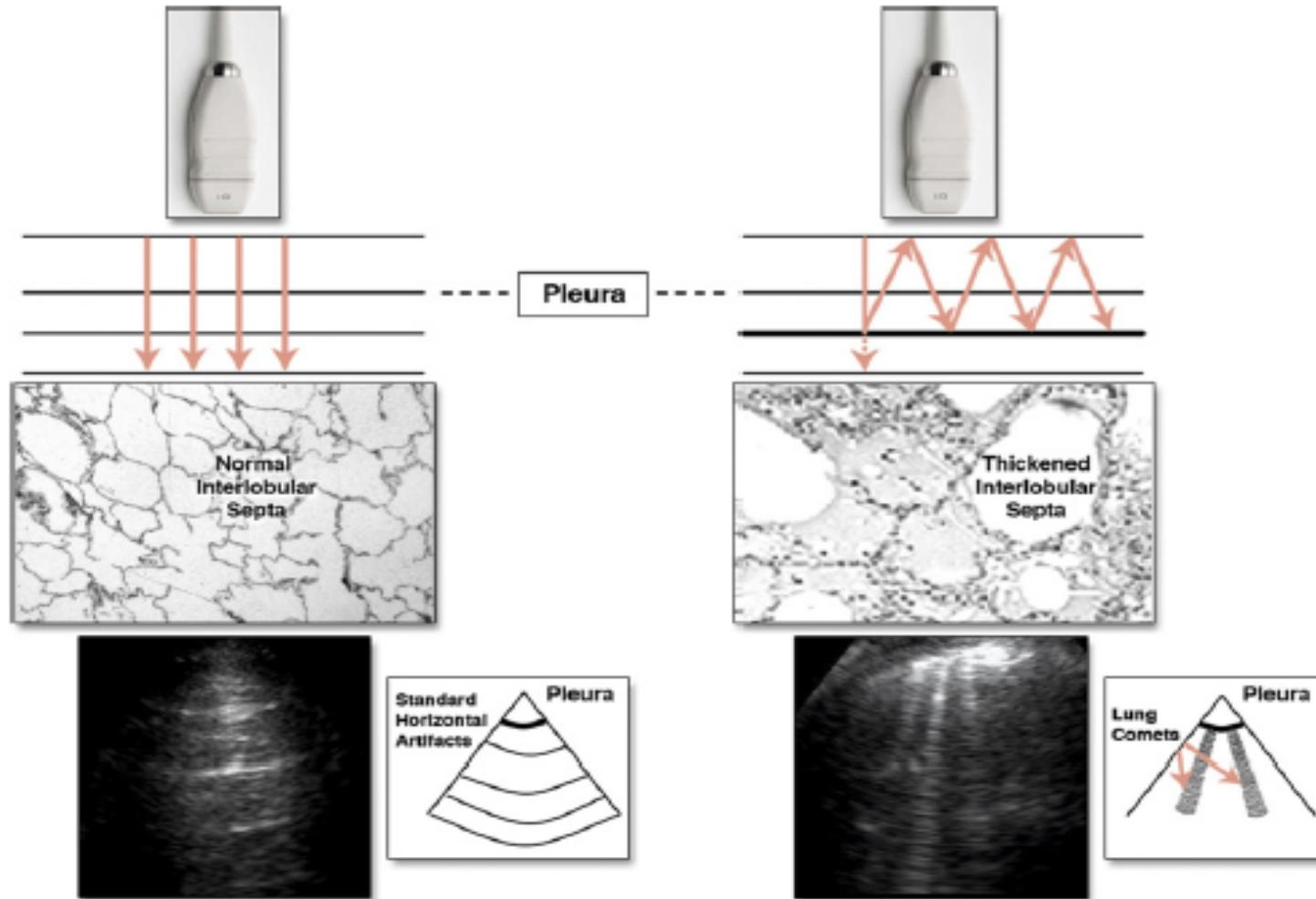
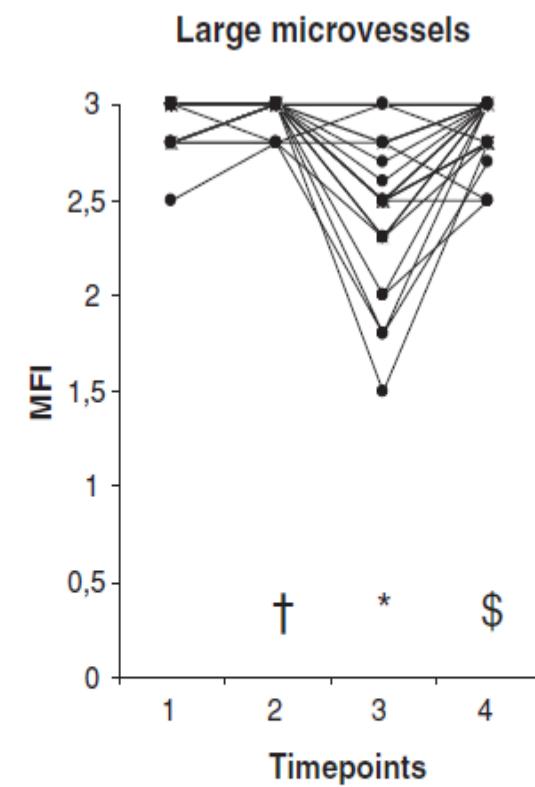
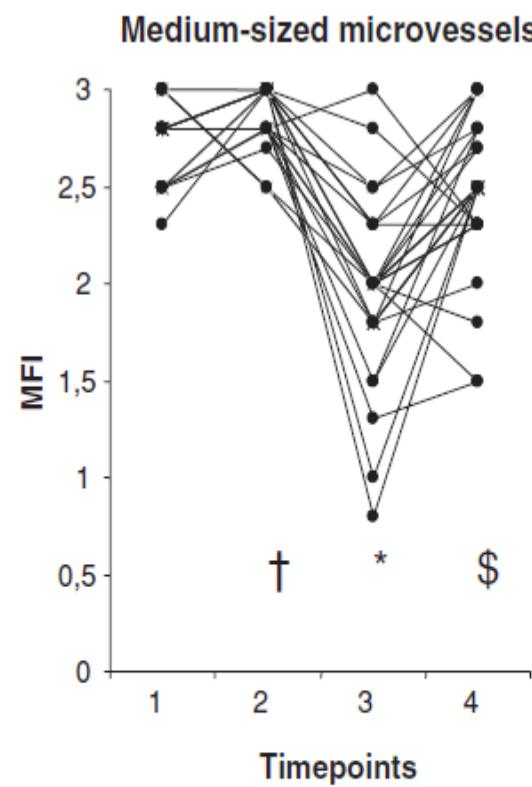
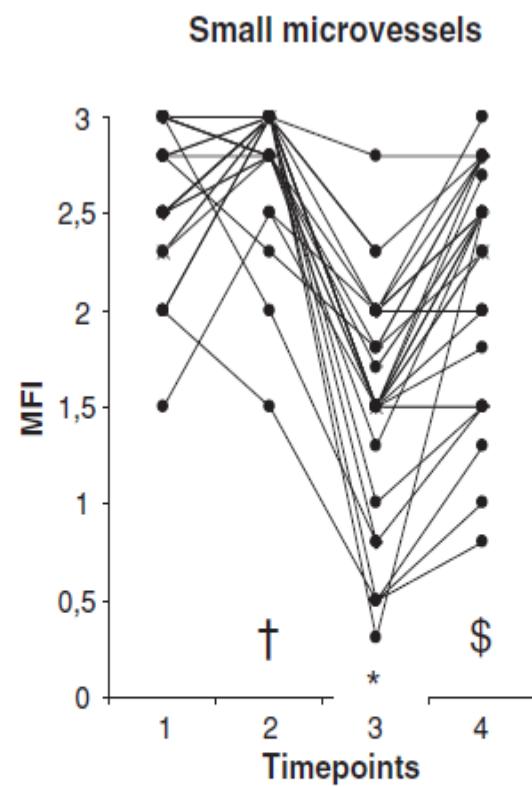


Figure 1. US of Normal Lung and Pulmonary Congestion

(Left) Normal lung ultrasound (US): the regular, parallel, horizontal hyperechogenic lines are due to the lung-wall interface. (Right) Pulmonary congestion: lung comets are hyperechogenic, coherent vertical bundles with narrow basis spreading from the transducer to the further border of the screen.



T = 1: before UF and before TP
T = 2: before UF during TP
T = 3: after UF and before TP
T = 4: after UF during TP

MFI = microvascular flow index

†: no significant change from T=1 to T=2 ($p>0.05$)
*: significant change from T=3 compared to baseline T=1 ($p<0.001$)
\$: significant change from T=3 to T=4 ($p<0.001$)

Markers to Estimate Volume Status

TABLE 5. *AUC of the ROC curve for each marker to distinguish overhydrated patients determined by other markers*

	Overhydrated group determined by each marker				
	OVERctr	OVERivc	OVERanp	OVERbv	OVERlp
AUC of ROC curve					
CTR		0.569	0.623 (0.598)	0.528	0.507
IVCe	0.570		0.778 (0.687)	0.725	0.750
ANP	0.623	0.870		0.708	0.796
Δ BV/TUF	0.625	0.756	0.727 (0.640)		0.711
Lpst	0.668	0.829	0.913 (0.787)	0.875	

The numbers in parentheses indicate the values when 60.0 pg/mL is adopted as the ANP cut-off instead of 43.0 pg/mL. ANP, concentration of atrial natriuretic peptides; AUC, area under the curve; Δ BV/TUF, ratio of the magnitude blood volume variation in percentage and total ultrafiltration volume; CTR, cardio-thoracic ratio; IVCe, diameter of inferior vena cava at quiet expiration; Lpst, standardized filtration coefficients; OVERanp, overhydrated patients group determined by ANP; OVERbv, overhydrated patients group determined by Δ BV/TUF; OVERctr, overhydrated patients group determined by CTR; OVERivc, overhydrated patients group determined by IVCe; OVERlp, overhydrated patients group determined by Lpst; ROC, receiver-operating characteristic.

Markers to Estimate Volume Status

TABLE 5. *AUC of the ROC curve for each marker to distinguish overhydrated patients determined by other markers*

	Overhydrated group determined by each marker				
	OVERctr	OVERivc	OVERanp	OVERbv	OVERlp
AUC of ROC curve					
C	0.67	0.67	0.67	0.67	0.67
I	0.67	0.67	0.67	0.67	0.67
A	0.67	0.67	0.67	0.67	0.67
Δ	0.67	0.67	0.67	0.67	0.67
L	0.67	0.67	0.67	0.67	0.67

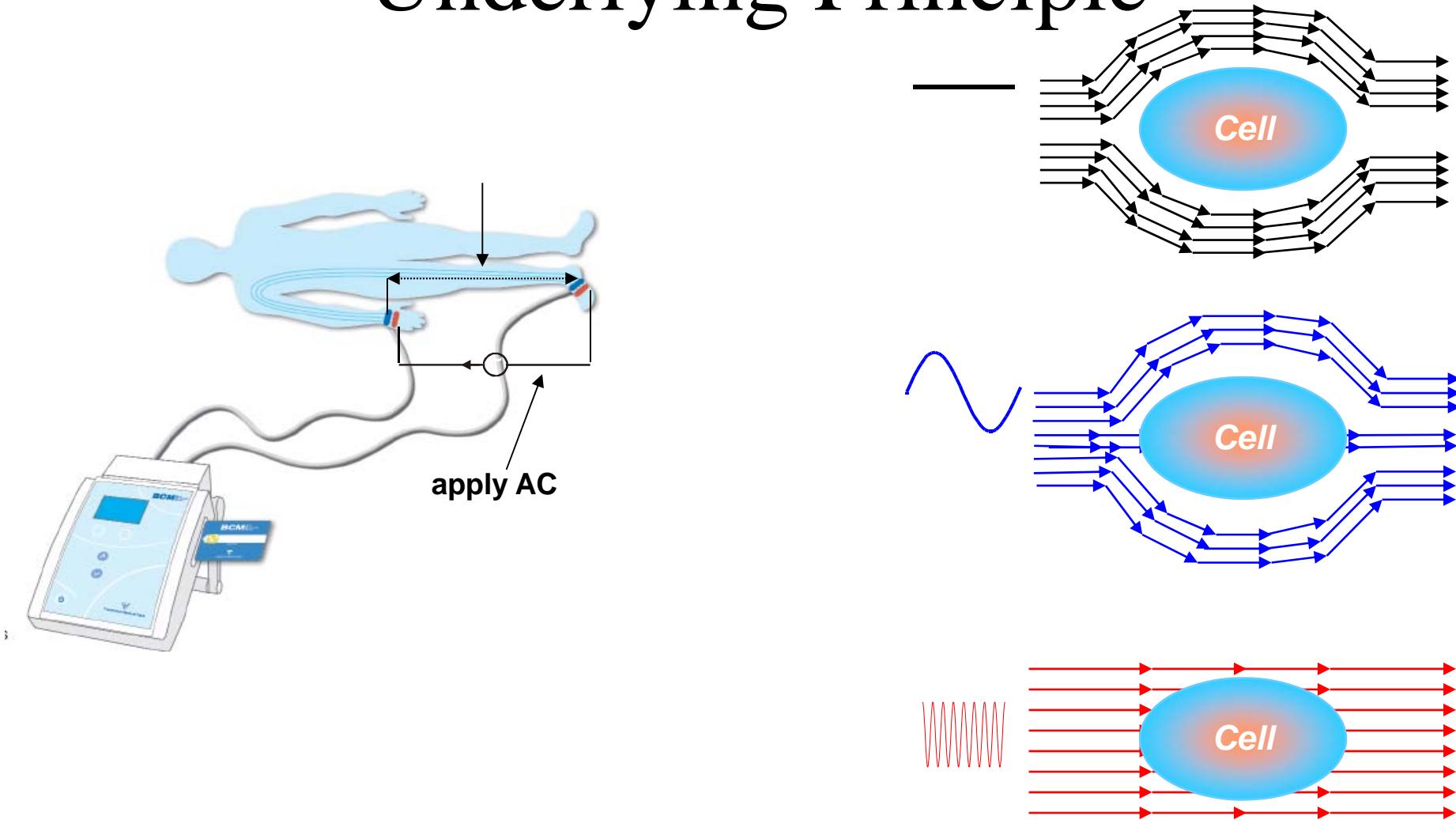
Volume status is complex and not a single compartmental issue

The numbers in parentheses indicate the values when 60.0 pg/mL is adopted as the ANP cut-off instead of 43.0 pg/mL. ANP, concentration of atrial natriuretic peptides; AUC, area under the curve; Δ BV/TUF, ratio of the magnitude blood volume variation in percentage and total ultrafiltration volume; CTR, cardio-thoracic ratio; IVCe, diameter of inferior vena cava at quiet expiration; Lpst, standardized filtration coefficients; OVERanp, overhydrated patients group determined by ANP; OVERbv, overhydrated patients group determined by Δ BV/TUF; OVERctr, overhydrated patients group determined by CTR; OVERivc, overhydrated patients group determined by IVCe; OVERlp, overhydrated patients group determined by Lpst; ROC, receiver-operating characteristic.

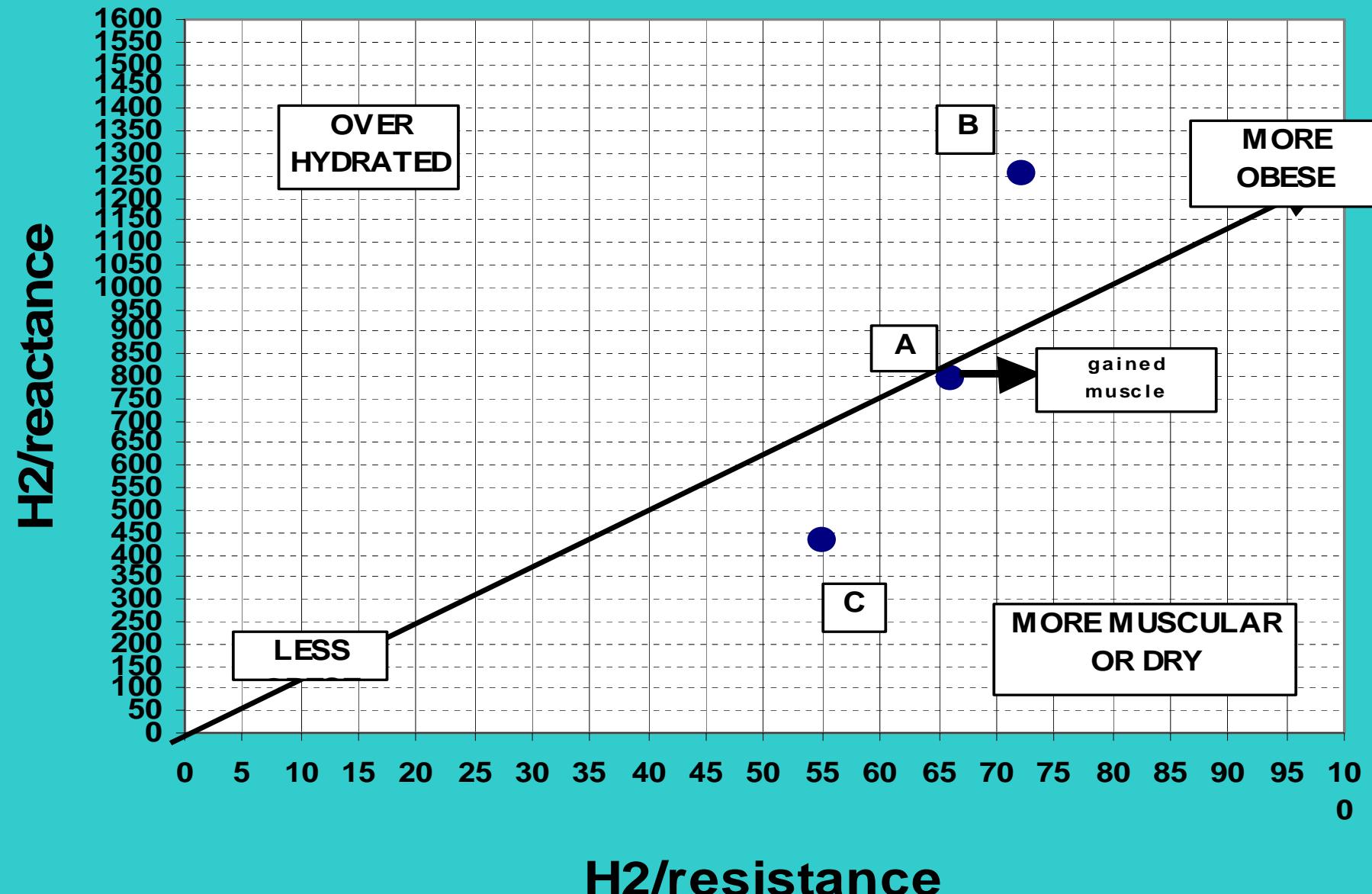
We do need tools to asses volume status of our patients



Bioimpedance spectroscopy: Underlying Principle



VECTOR PLOT



Caveats of Bio-impedance

2° The body is not a cilindre, and does not have “uniform permitivitty

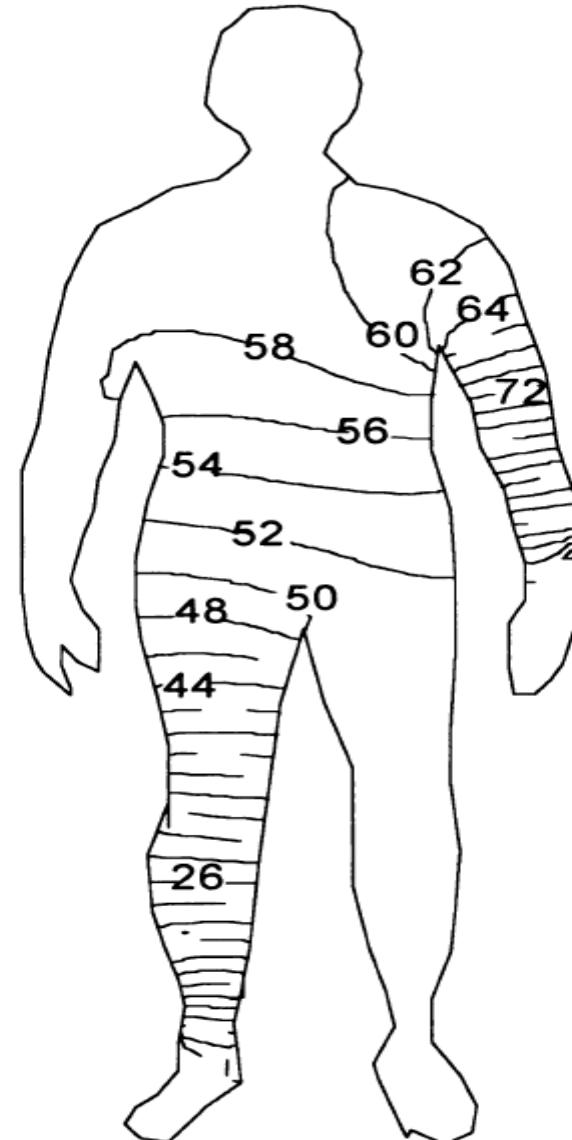


FIGURE 9. Distribution of impedance in the human body. Electrodes were on the wrist and ankle. Numbers indicate the cumulative fraction of impedance (%) relative to the ankle. Each contour is separated by 2% of the total body impedance.

Cole Cole plot

$$R_s = \frac{L}{A} \left[\frac{\rho}{1 + (2\pi f \epsilon' \epsilon_0 \rho)^2} \right] \approx \frac{L}{A} \rho \quad (9)$$

and

$$X = \frac{-L}{A} \left[\frac{2\pi f \epsilon' \epsilon_0 \rho^2}{1 + (2\pi f \epsilon' \epsilon_0 \rho)^2} \right] \approx \frac{-L}{A} [2\pi f \epsilon' \epsilon_0 \rho^2] \quad (10)$$

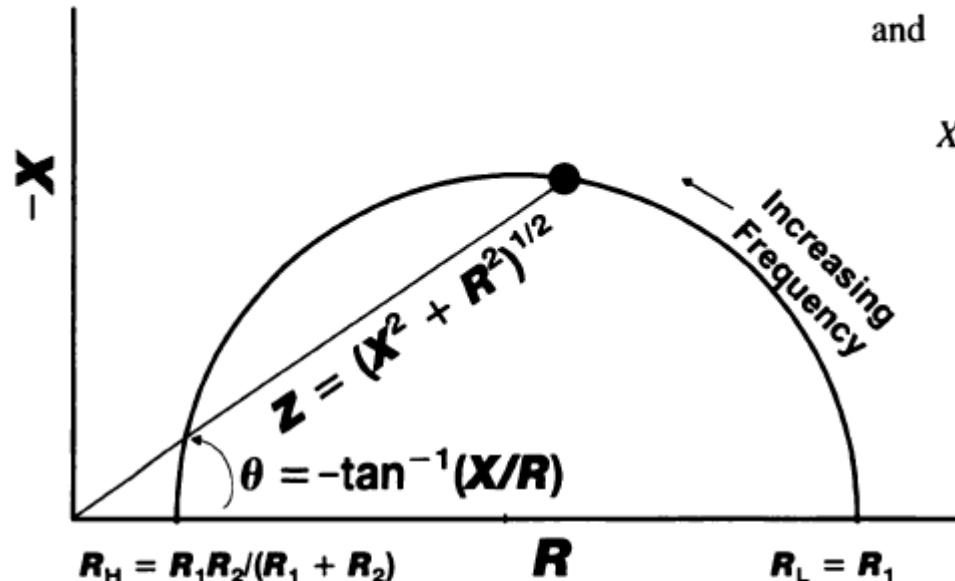
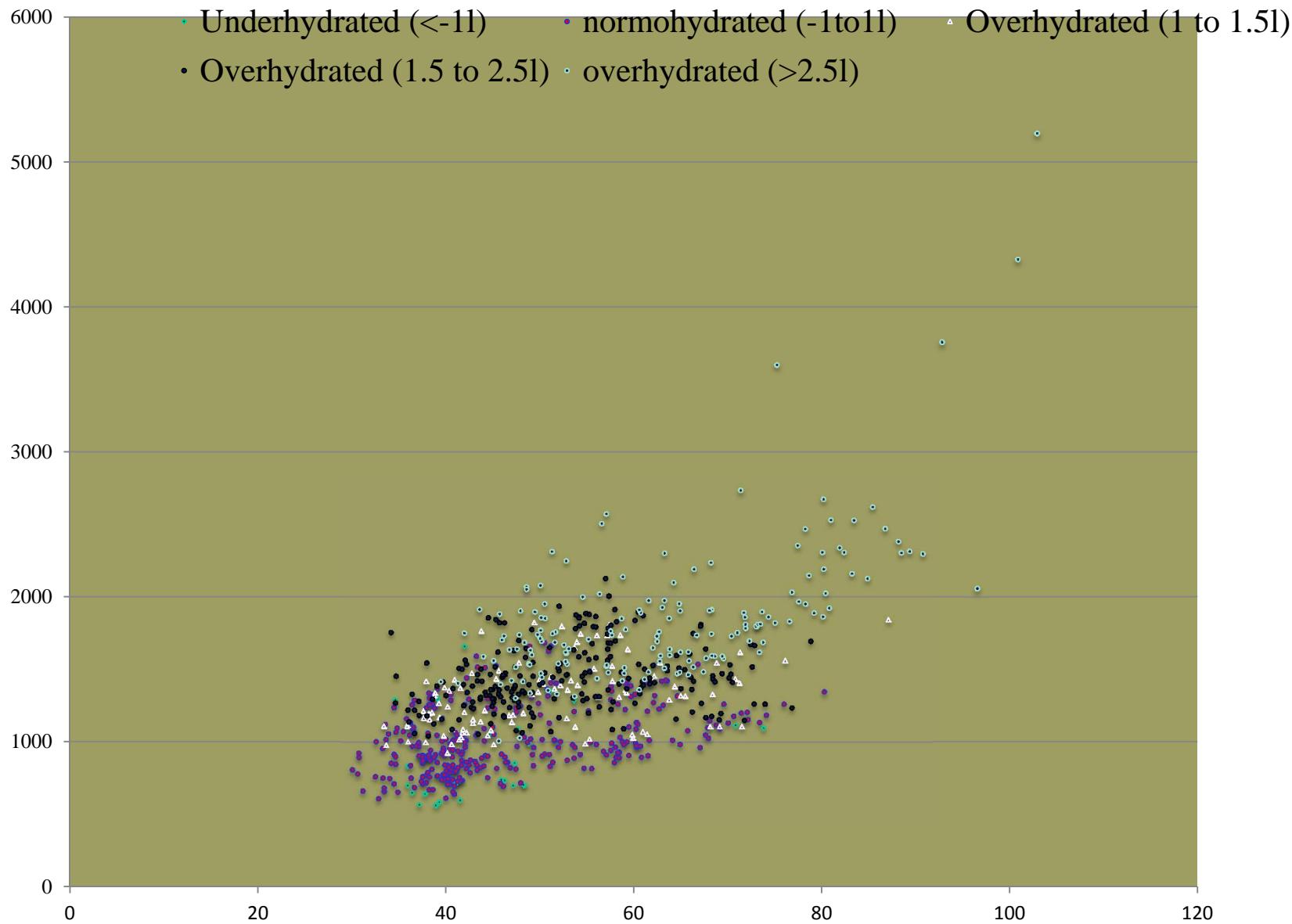


FIGURE 4. Plot of the impedance of the circuit shown in Figure 3 on the complex impedance plane, ie, the real versus the imaginary parts of the circuit impedance. A plot of the reactance X versus the resistance R at different frequencies results in a semicircle. The semicircle intersects the real axis (resistance) at the low- and high-frequency limits R_L and R_H , respectively. The phase angle (θ) and impedance magnitude Z at an arbitrary point are also shown.

Phase angle
Length of the vector

H²/R vs OH of BCM



Assessing methods for dry weight in HD patients

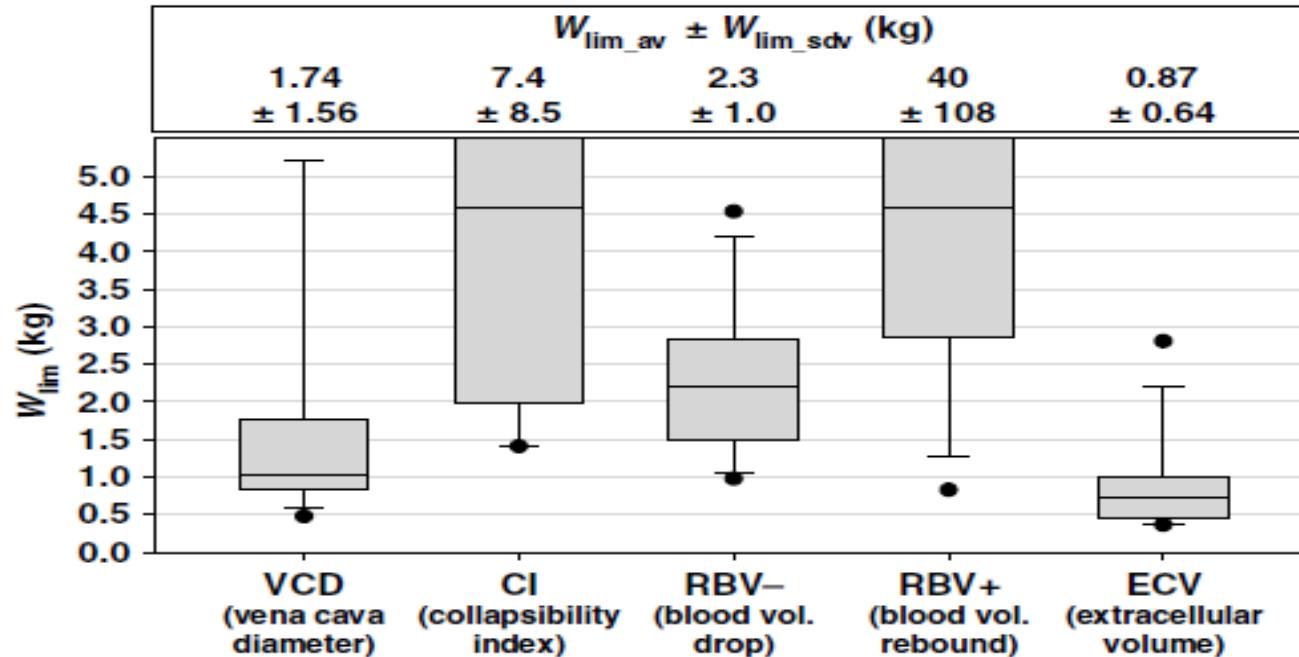
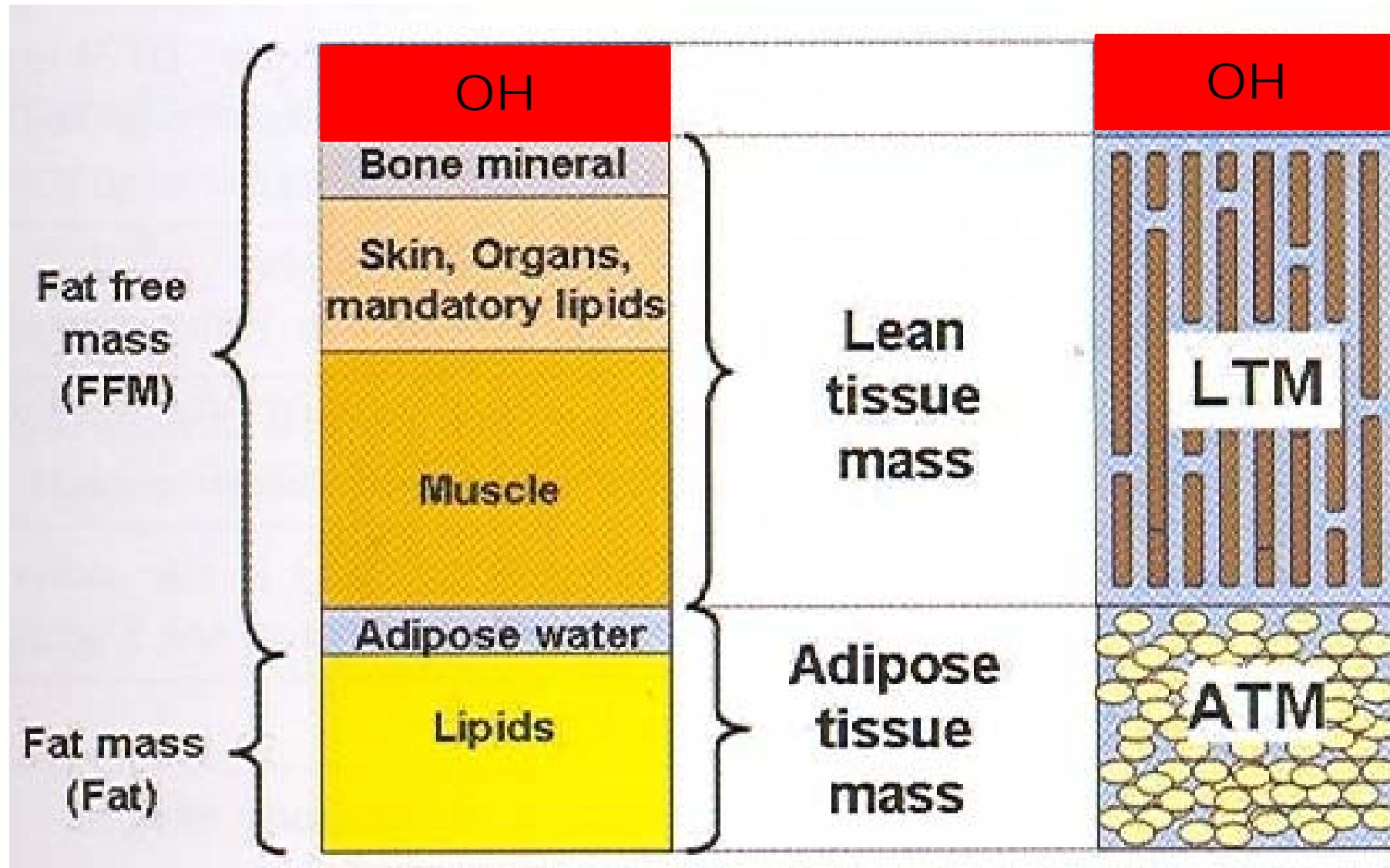


Figure 9 | Final ranking of the five candidate methods according to their detection limit W_{lim} for changes in fluid status: the box plot shows the median W_{lim} (horizontal line), the 25th and 75th percentiles (box range) and the 5th and 95th percentiles (whisker range) of the distribution of detection limits W_{lim} , measured in 13 patients. Solid circles show outliers beyond the 10th and 90th percentiles. The average (W_{lim_av}) and the s.d. (W_{lim_sdv}) of the detection limits are additionally listed. The best performance (lowest detection limit) is achieved with extracellular volume (ECV) measured with bioimpedance spectroscopy.

Multifrequency bio-impedance spectroscopy



Overhydration in “euvolemic” patients on dialysis

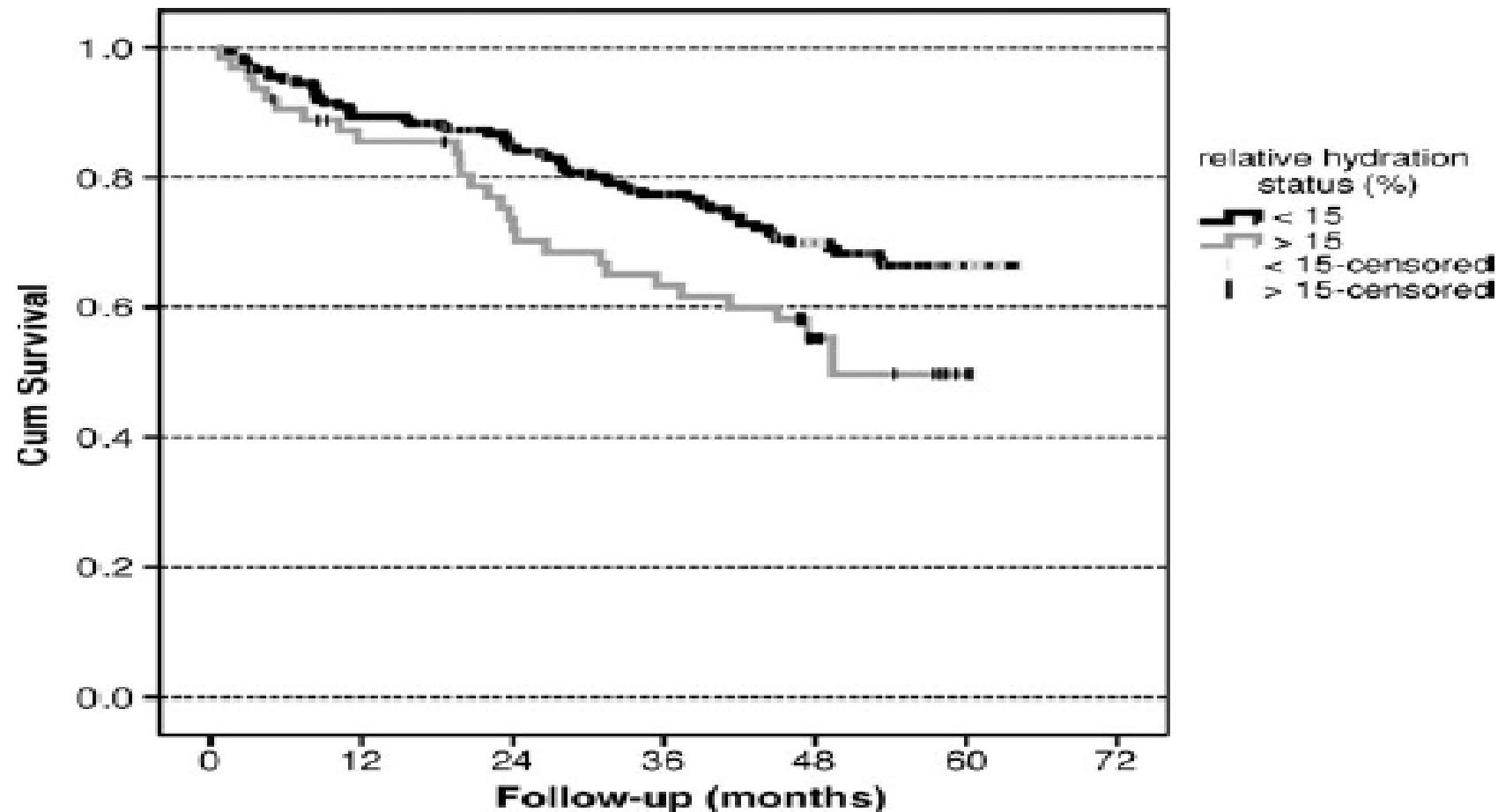


Fig. 1. Kaplan-Meier curve separating the patients for the relative hydration status ($\Delta HS > 15\%$).

Use of BVM control to reduce intradialytic hypotension

TABLE II
TREATMENT AND PATIENT PARAMETERS BY STUDY PHASE

	Standard HD	BV-controlled UF	p Value
Real treatment time (minutes)	252.4 ± 26.4	254.3 ± 28.4	0.041
Fluid removal (L)	2.30 ± 0.64	2.30 ± 0.55	0.647
Dry body weight (kg)	65.7 ± 11.6	65.7 ± 11.5	0.406
Body weight predialysis (kg)	68.2 ± 11.9	68.2 ± 11.8	0.748
Body weight post-dialysis (kg)	65.9 ± 11.7	65.9 ± 11.7	0.946
RBV end of session (%)	88.3 ± 5.8	89.7 ± 5.1	0.011

Values are means ± SD of the data, calculated from the means of all treatments of each patient in the respective study phase.
BV = blood volume; HD = haemodialysis; RBV = relative blood volume; UF = ultrafiltration.

...

Use of BVM control to reduce intradialytic hypotension

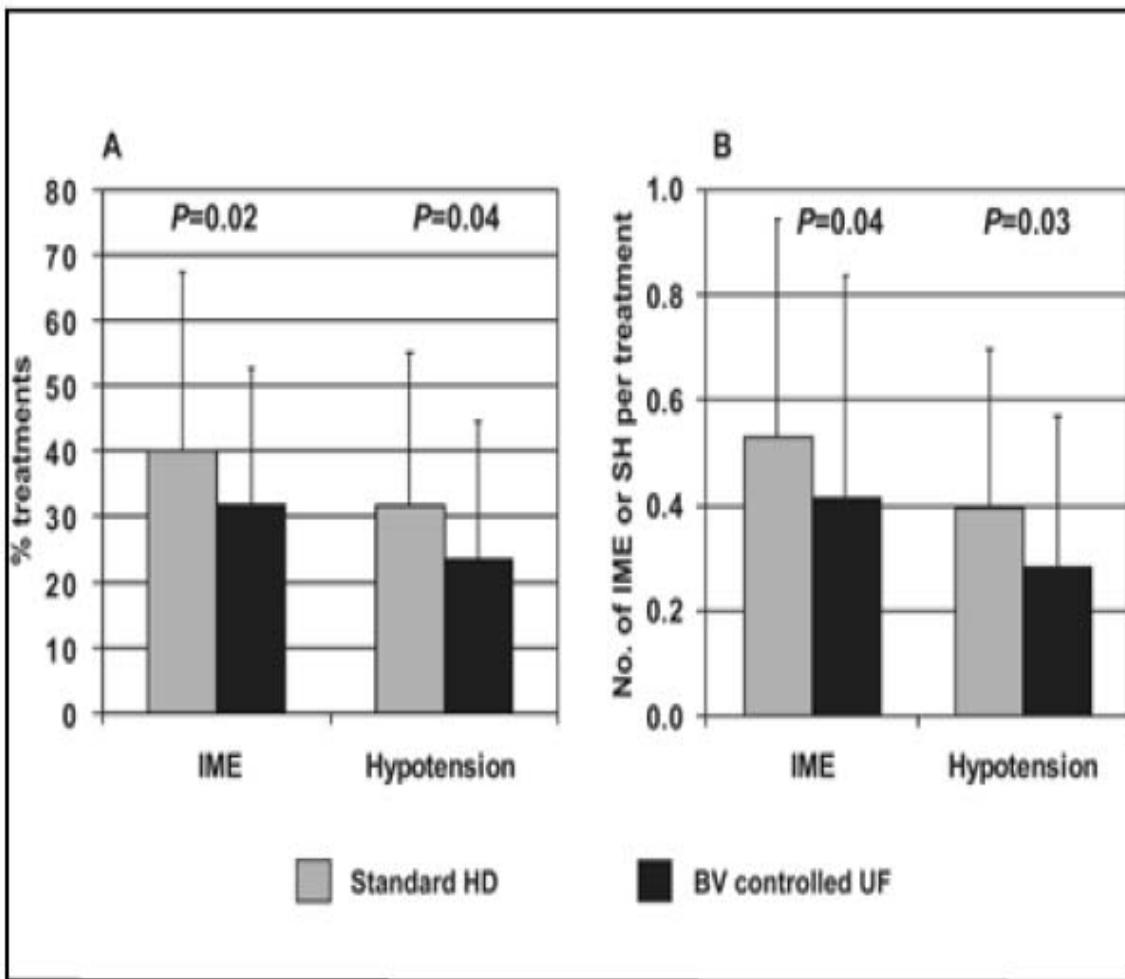


Fig. 1A, B - Haemodynamic effects of blood volume-controlled ultrafiltration by percentage of treatments (A) and number of intradialytic morbid events or symptomatic hypotension (B). BV = blood volume; HD = haemodialysis; IME = intradialytic morbid event; SH = symptomatic hypotension; UF = ultrafiltration.

Using BCM to guide fluid status in HD patients

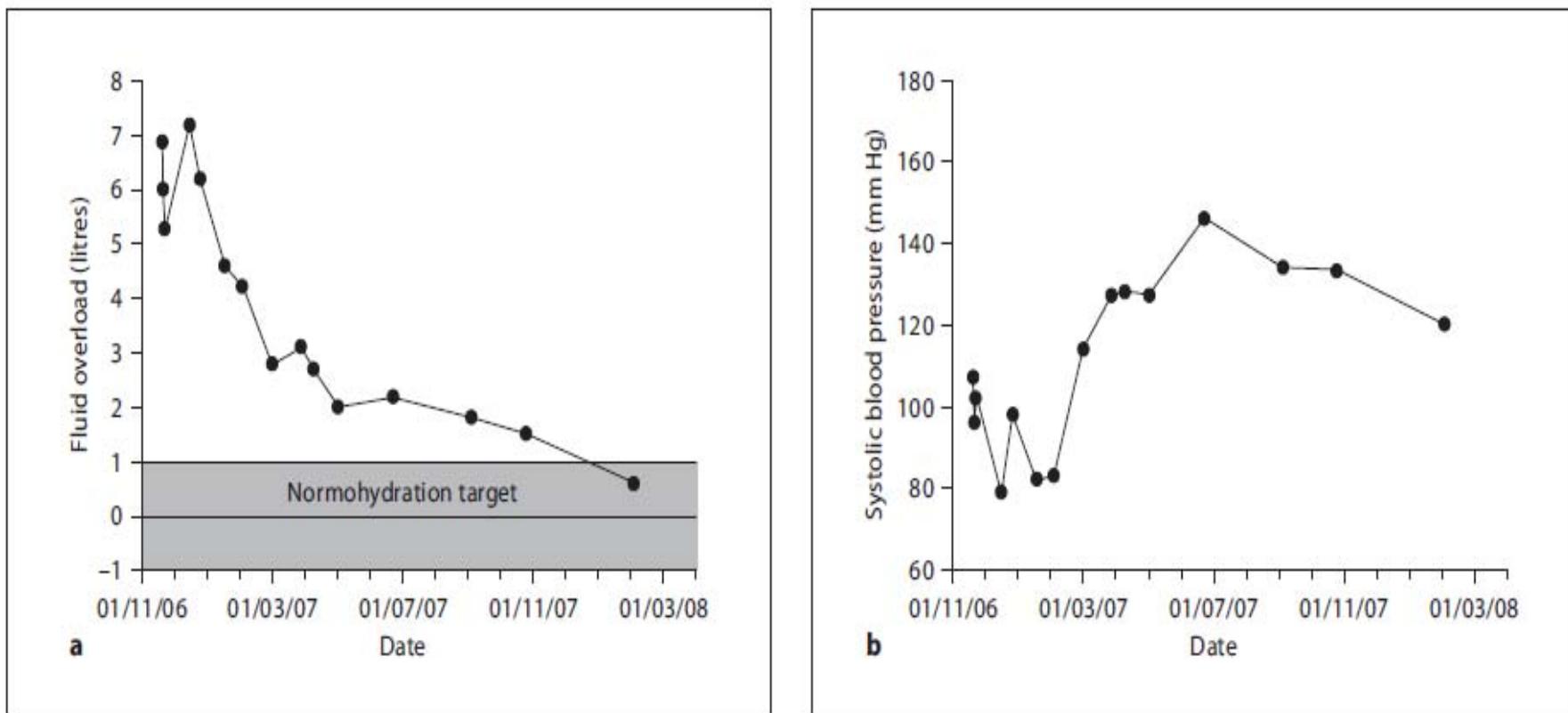


Fig. 1. Achieving the normohydration target in a patient with cardiac problems. The slow reduction in fluid overload targeted by the whole-body spectroscopy method improves the patient status dramatically. Shown are the fluid overload (a) and the systolic blood pressure (b) both measured before treatment.

Serum pro-BNP and mortality

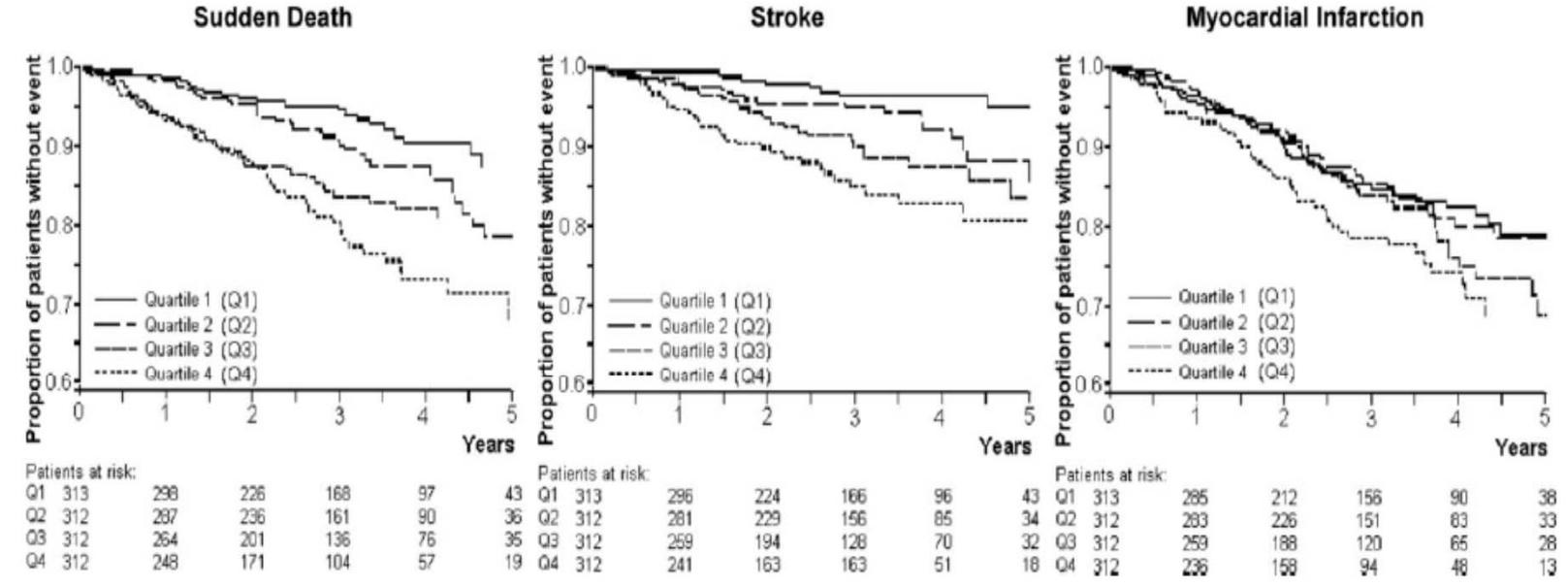


Figure 1 Kaplan-Meier estimates for time to sudden death, stroke, and myocardial infarction in subgroups of patients according to quartiles of baseline N-terminal-pro-B-type-natriuretic-peptide (Q1, Quartile 1: N-terminal-pro-B-type-natriuretic-peptide \leq 1433 pg/mL; Q2, quartile 2: N-terminal-pro-B-type-natriuretic-peptide 1434–3361 pg/mL; Q3, quartile 3: N-terminal-pro-B-type-natriuretic-peptide 3362–9251 pg/mL; Q4, quartile 4: N-terminal-pro-B-type-natriuretic-peptide \geq 9252 pg/mL).

European BCM study in PD

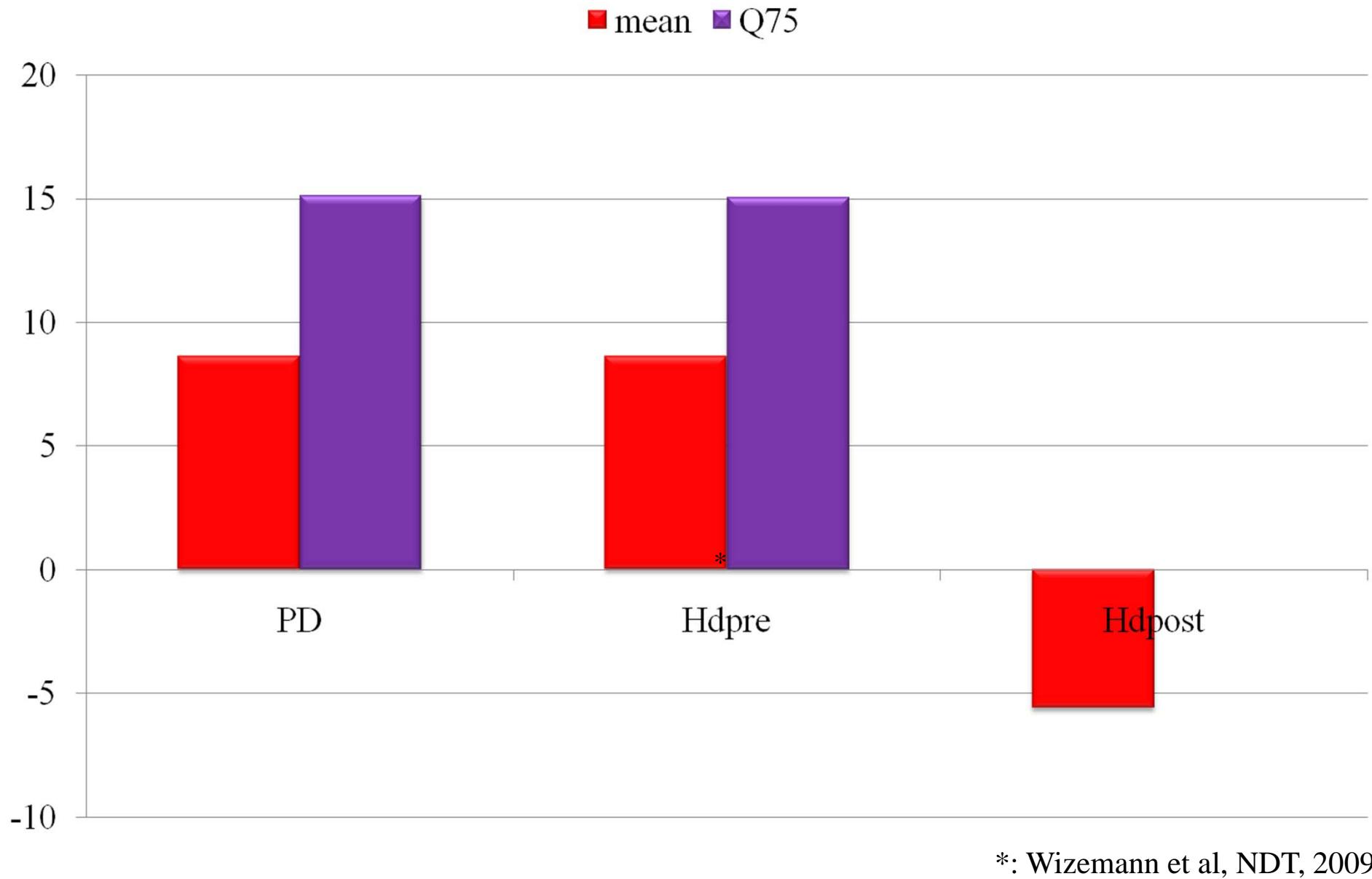


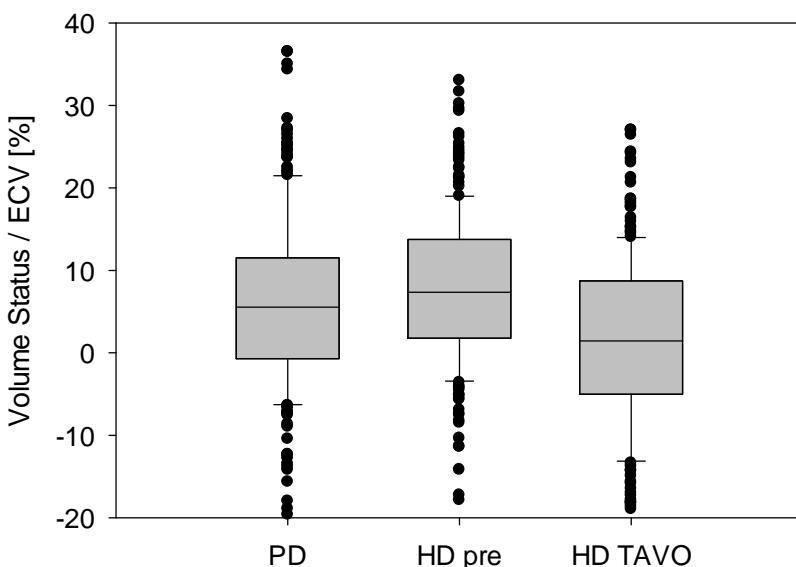
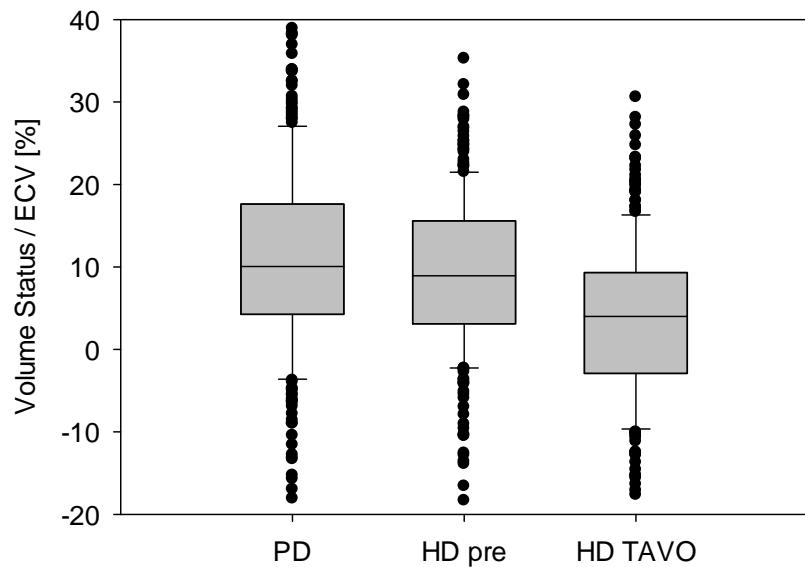
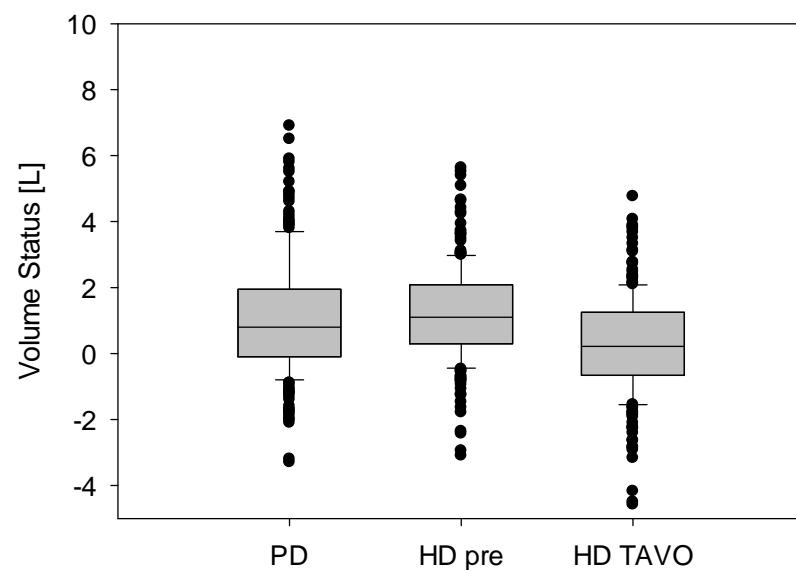
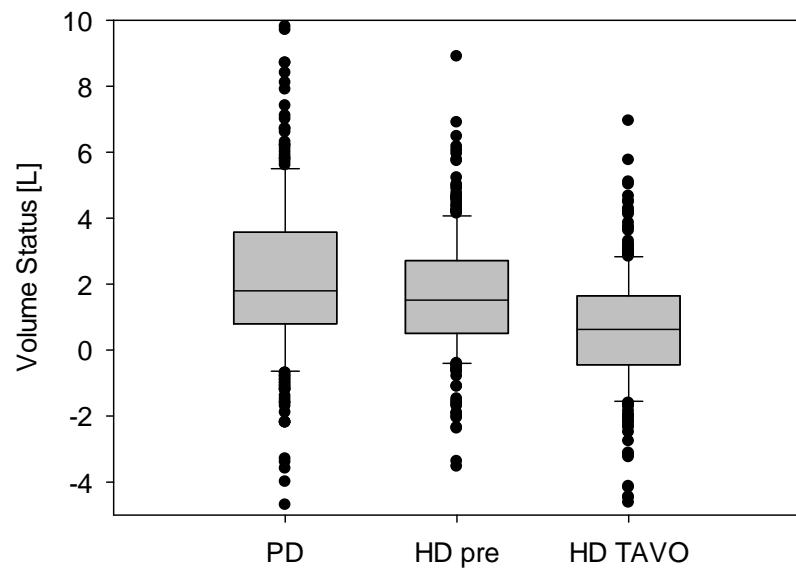
Volume status in BCM PD patients

	n	%
Overhydration Class		
<10th Percentile	43	6.7
Normal (10th - 90th Percentile)	255	39.9
> 90th Percentile	341	53.4
Total	639	100.0

(reference to normal population)

Relative overhydration (%) in PD vs HD

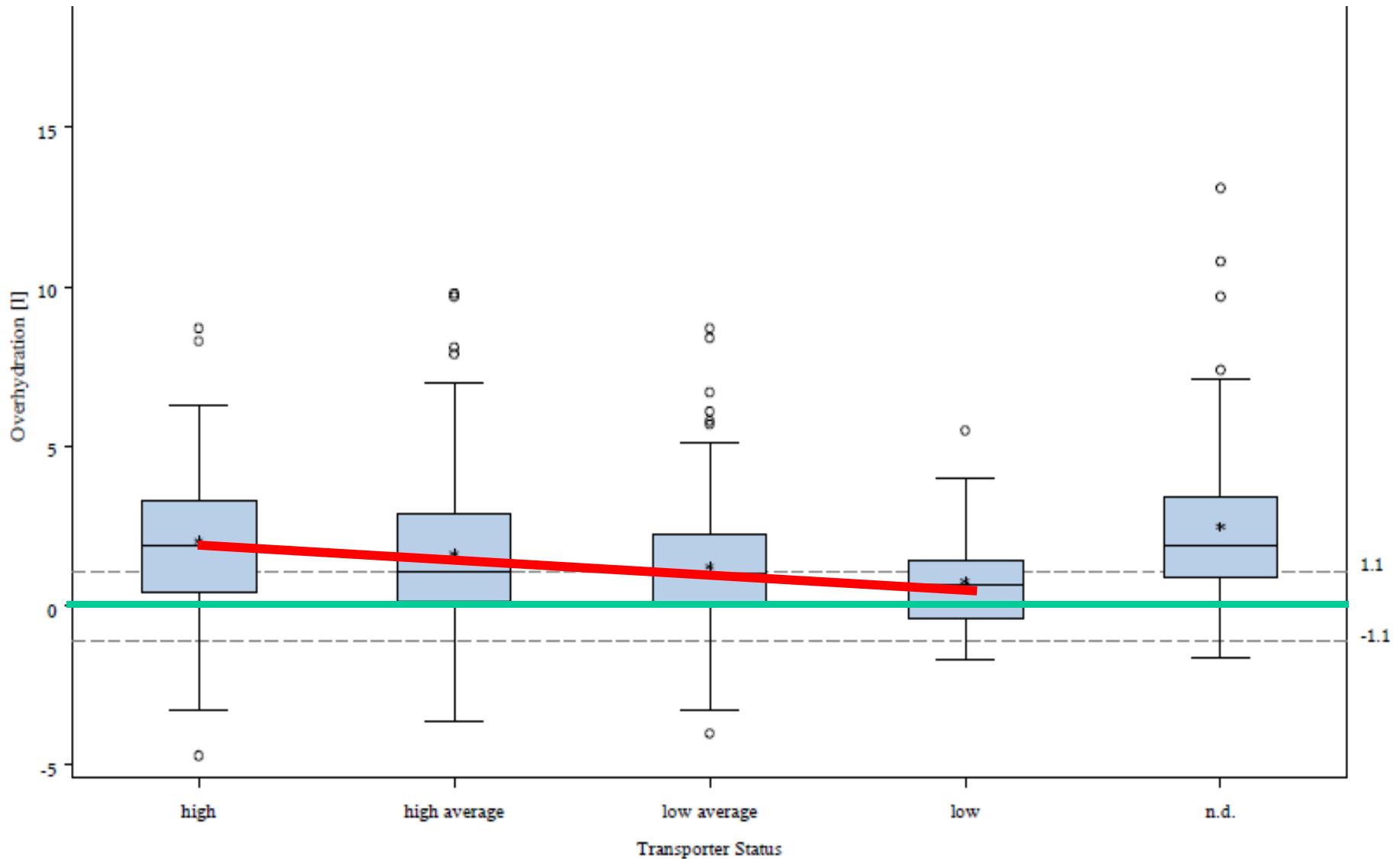




Male

Female

Relation transport status and overhydration



Volume status CAPD vs CCPD (inversed CAPD regimen)

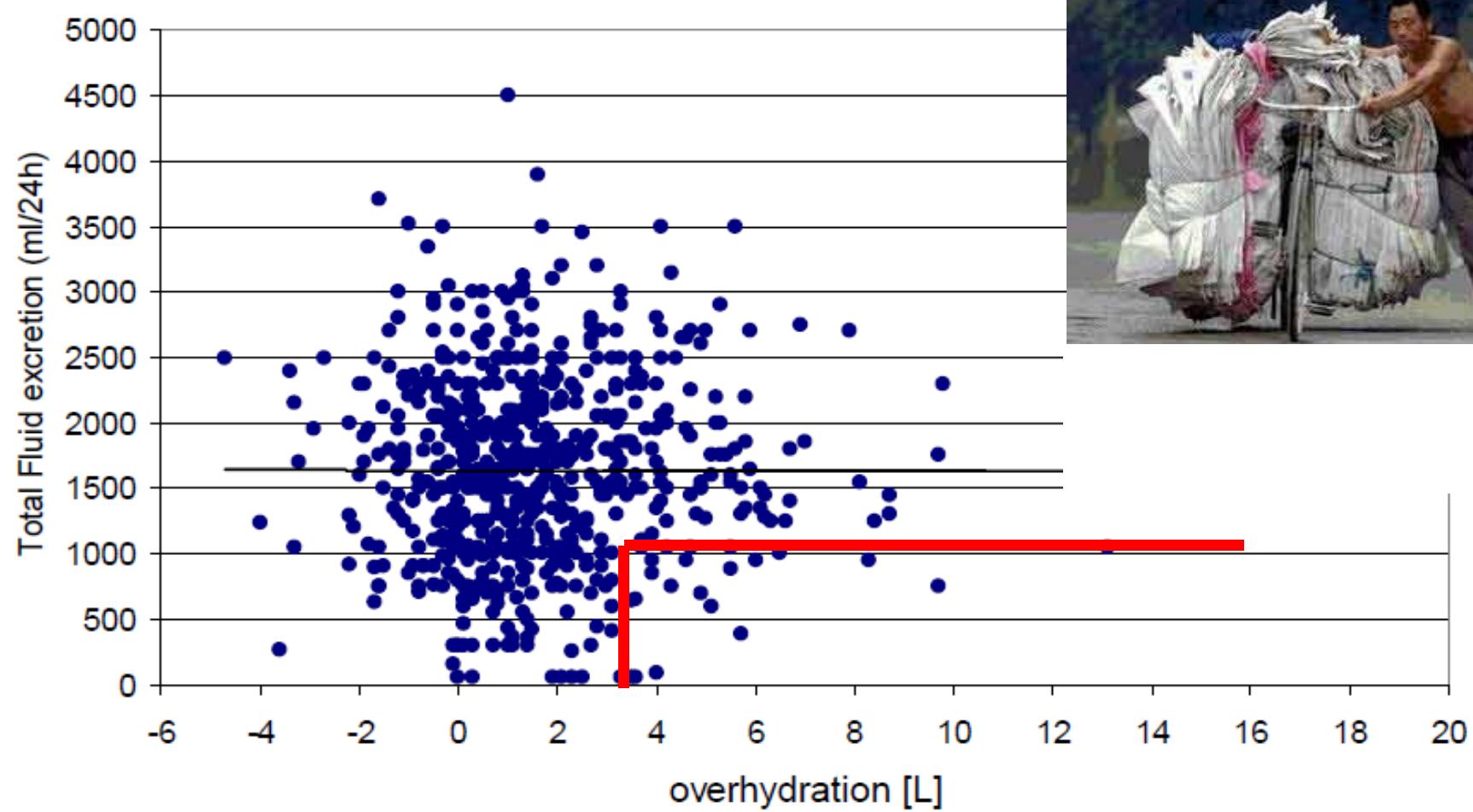
Table 3. Predictors of % ECFV/TBW^a

Variable	Bivariate Regression Analysis			Multivariate Regression Analysis		
	Slope (95% CI)	R ² (%)	P	Slope (95% CI)	R ² (%)	P
Modality CAPD (<i>versus</i> CCPD)	-0.07 (-1.73 to 1.59)	<0.1	0.931	0.71 (-0.44 to 1.86)	59.1	0.224
Age	0.16 (0.12 to 0.21)	24.8	<0.001	0.10 (0.06 to 0.14)		<0.001
Male gender	-0.77 (-2.41 to 0.88)	0.6	0.357			
Weight	-0.06 (-0.11 to -0.01)	4.6	0.016			
LBM	-0.18 (-0.23 to -0.13)	24.9	<0.001	-0.07 (-0.12 to -0.03)		0.001
Protein catabolic rate	-5.92 (-9.54 to -2.30)	6.4	0.002			
Time on dialysis (mo)	1.29 (0.13 to 2.45)	3.0	0.030			
Weekly Kt/V	-0.83 (-2.60 to 0.94)	0.6	0.356			
Residual CrCl	-0.04 (-0.07 to -0.02)	7.1	0.001			
Dialysate CrCl	0.11 (0.01 to 0.21)	3.1	0.029			
Daily ultrafiltration, per 100 ml	-0.07 (-0.16 to 0.02)	1.5	0.127			
Residual GFR	-0.41 (-0.63 to -0.19)	8.2	<0.001	-0.28 (-0.45 to -0.12)		<0.001
Daily dialysis prescription, per 1 L	0.22 (-0.34 to 0.77)	0.4	0.439			
D/P creatinine	8.83 (0.44 to 17.22)	2.8	0.039	7.64 (1.36 to 13.9)		0.018
Dialysate Na	0.01 (-0.07 to 0.09)	5.2	0.004			
Albumin	-0.02 (-0.10 to -0.05)	0.3	0.498			
Hemoglobin	-0.78 (-0.93 to -0.63)	40.1	<0.001	-0.49 (-0.64 to -0.34)		<0.001
Calcium (corrected for albumin)	-0.04 (-0.12 to 0.03)	0.9	0.250			
Phosphorus	3.79 (-1.10 to 8.68)	2.2	0.100			
Parathyroid hormone	-3.12 (-5.39 to -0.86)	4.6	0.007			
Na	-0.05 (-0.08 to -0.01)	4.7	0.007			
CRP	-0.53 (-0.78 to -0.29)	10.8	<0.001			
Icodextrin use	0.10 (0.02 to 0.18)	4.3	0.016			
Ischemic heart disease	0.40 (-1.32 to 2.12)	<0.1	0.649			
Congestive heart failure	1.71 (-0.27 to 3.70)	1.9	0.090			
Diabetes	3.73 (1.46 to 6.01)	6.4	0.001			
Hypertension	1.49 (-0.13 to 3.12)	2.1	0.072			
Charlson comorbidity index	0.71 (-1.21 to 2.63)	0.3	0.465			
Systolic BP	1.08 (0.78 to 1.38)	24.6	<0.001			
Diastolic BP	0.02 (-0.02 to 0.07)	<0.1	0.376			
Antihypertensive medication use	-0.10 (-0.17 to -0.02)	4.2	0.012			
Peripheral edema	-2.56 (-4.23 to -0.88)	5.7	0.003			
	1.11 (-0.59 to 2.80)	1.1	0.198	Davison et al, cJASN, 2009		

^aCI, confidence interval.

Volume status and output

Daily total water excretion (UF plus



Volume status CAPD vs CCPD (inversed CAPD regimen)

Table 3. Predictors of % ECFV/TBW^a

Variable	Bivariate Regression Analysis			Multivariate Regression Analysis		
	Slope (95% CI)	R ² (%)	P	Slope (95% CI)	R ² (%)	P
Modality CAPD (<i>versus</i> CCPD)	-0.07 (-1.73 to 1.59)	<0.1	0.931	0.71 (-0.44 to 1.86)	59.1	0.224
Age	0.16 (0.12 to 0.21)	24.8	<0.001	0.10 (0.06 to 0.14)		<0.001
Male gender	-0.77 (-2.41 to 0.88)	0.6	0.357			
Weight	-0.06 (-0.11 to -0.01)	4.6	0.016			
LBM	-0.18 (-0.23 to -0.13)	24.9	<0.001	-0.07 (-0.12 to -0.03)		0.001
Protein catabolic rate	-5.92 (-9.54 to -2.30)	6.4	0.002			
Time on dialysis (mo)	1.29 (0.13 to 2.45)	3.0	0.030			
Weekly Kt/V	-0.83 (-2.60 to 0.94)	0.6	0.356			
Residual CrCl	-0.04 (-0.07 to -0.02)	7.1	0.001			
Dialysate CrCl	-0.11 (-0.61 to 0.21)	0.1	0.822			
Daily ultrafiltration, per 100 ml	-0.07 (-0.16 to 0.02)	1.5	0.127			
Residual GFR	-0.41 (-0.63 to -0.19)	8.2	<0.001	-0.28 (-0.45 to -0.12)		<0.001
Daily urine volume	-0.23 (-0.36 to -0.09)	6.5	0.001			
B/P ratio	0.82 (0.41 to 1.22)	2.8	0.029	7.64 (1.36 to 12.0)		0.018
Daily urine Na	-0.04 (-0.07 to -0.01)	5.2	0.004			
Daily dialysate Na	-0.02 (-0.10 to -0.05)	0.3	0.498			
Albumin	-0.78 (-0.93 to -0.63)	40.1	<0.001	-0.49 (-0.64 to -0.34)		<0.001
Hemoglobin	-0.04 (-0.12 to 0.03)	0.9	0.250			
Calcium (corrected for albumin)	3.79 (-1.10 to 8.68)	2.2	0.100			
Phosphorus	-3.12 (-5.39 to -0.86)	4.6	0.007			
Parathyroid hormone	-0.05 (-0.08 to -0.01)	4.7	0.007			
Na	-0.53 (-0.78 to -0.29)	10.8	<0.001			
CRP	0.10 (0.02 to 0.18)	4.3	0.016			
Icodextrin use	0.40 (-1.32 to 2.12)	<0.1	0.649			
Ischemic heart disease	1.71 (-0.27 to 3.70)	1.9	0.090			
Congestive heart failure	3.73 (1.46 to 6.01)	6.4	0.001			
Diabetes	1.49 (-0.13 to 3.12)	2.1	0.072			
Hypertension	0.71 (-1.21 to 2.63)	0.3	0.465			
Charlson comorbidity index	1.08 (0.78 to 1.38)	24.6	<0.001			
Systolic BP	0.02 (-0.02 to 0.07)	<0.1	0.376			
Diastolic BP	-0.10 (-0.17 to -0.02)	4.2	0.012			
Antihypertensive medication use	-2.56 (-4.23 to -0.88)	5.7	0.003			
Peripheral edema	1.11 (-0.59 to 2.80)	1.1	0.198			

^aCI, confidence interval.

Ways to maintain euvoolemia



Multivariate regression for Overhydration

Table 3. Multivariate linear regression for Relative Δ Tissue Hydration from the subgroup of patients from Belgium, France and UK.

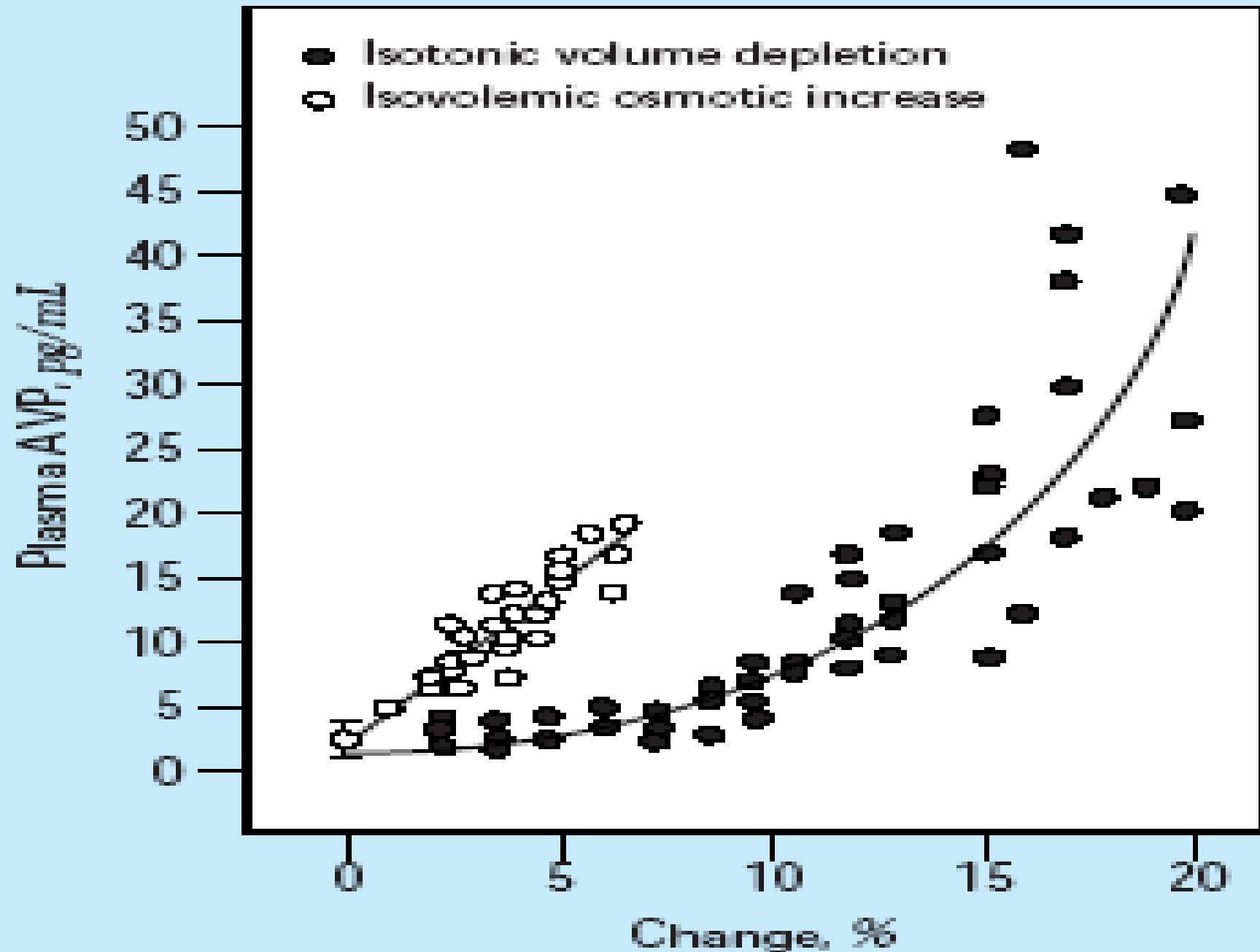
Parameter	Coefficient	95% CI	p-value
Intercept	30.27	20.65 39.88	<0.0001
Age (per year)	0.10	0.05 0.16	0.0002
Sex (female vs male)	-3.04	-4.55 -1.52	0.0001
Albumin per g/l	-0.75	-0.91 -0.59	<0.0001
BMI per kg/m ²	-0.66	-0.83 -0.50	<0.0001
Diabetes (vs no diabetes)	4.86	3.14 6.59	<0.0001
Systolic BP (per mmHg)	0.09	0.05 0.12	<0.0001
Glucose at least once 2.5% vs. 1.5% only	-0.73	-2.56 1.11	0.80
Glucose at least once 3.86/4.25% vs. 1.5% only	5.18	2.62 7.74	<0.0001
Not included due to p>0.1			
Ultrafiltration			0.86
Urine output			0.66
Hypertension stage			0.41
NYHA Stage			0.39
Liver disease			0.56
Time on PD per month			0.25
Transport status			0.83
Type of PD solution			0.12
PD modality			0.27

Model adjusted for country effects (Belgium, France and UK), total R² of the model = 0.57, n = 299.

NYHA = New York Heart Association classification of heart failure.

doi:10.1371/journal.pone.0017148.t003

Van Biesen et al, Plos 2011



UF= 2400grams out-2000ml in= 400ml?????



wrapping

Bag overfill



UF= 2400grams out-2000ml in= 400ml?????



In CAPD: do WEIGH the bags before and after instillation!!

wrapping



Remaining questions

EBPG opinion statement on peritoneal dialysis

Table 1. Peritoneal membrane transport types and their consequences for clinical management

Transport type	Properties	Recommendations
Fast transporter	<p>Fast, hyperbolic, equilibration of creatinine, typically with a $D/P_{creat} > 0.80$ after 4 h</p> <p>Fast dissipation of glucose from the peritoneal cavity, with negative ultrafiltration in dwells with 1.36% glucose longer than 180 min</p> <p>Limited sodium sieving, with 3.86% PET and small (<5 mmol/l) delta D_{sodium} (difference between the D_{sodium} at start and after 1 h)</p>	<p>Short dwells, preferably shorter than 180 min</p> <p>Icodextrin to be considered for longest dwell, unless sufficient residual diuresis</p> <p>Check inflammatory status (peritoneal protein loss). When negative, check transport status using larger fill volumes</p>
Average transporter	<p>Moderately fast equilibration of creatinine, with a steeper slope in the beginning than at the end of the dwell</p> <p>Moderately fast disappearance of osmotic agent.</p> <p>Negative ultrafiltration only in too long dwells (>240 min)</p>	<p>Too short (<120 min) and too long dwells (>300 min) should be avoided, except for one exchange/day (the ‘long dwell’)</p>
Slow transporter	<p>Slow, semi-linear equilibration of creatinine, typically with a $D/P_{creat} < 0.55–0.60$ after 4 h</p> <p>Sustained ultrafiltration even in dwells longer than 240 min</p> <p>Important sodium sieving, with 3.86%-PET and substantial delta D_{sodium} (>5 mmol/l) after 1 h (the peak of delta D_{sodium} could occur later in the dwell)</p>	<p>Long dwells, preferably longer than 240 min</p> <p>Use larger volumes rather than more dwells</p> <p>Icodextrin probably not necessary for longest dwell</p> <p>Be aware of sodium sieving when using dwells shorter than 180 min</p>

Icodextrin and residual renal function

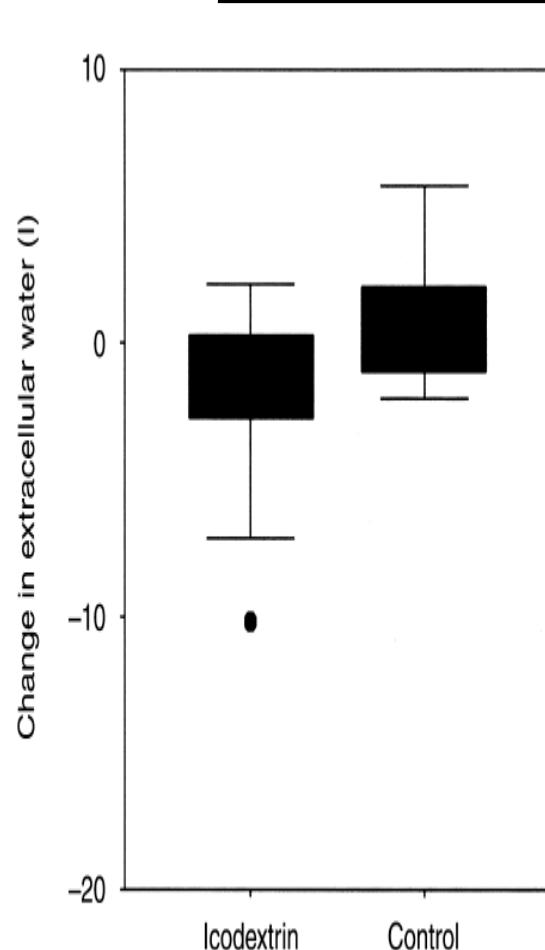


Fig. 1. Change in extracellular water in the icodextrin-treated control groups. Difference between icodextrin and control group $P = 0.013$. Box indicates 25th and 75th percentiles (thick line is median value) and capped bars indicate minimum and maximum value (excluding outliers)

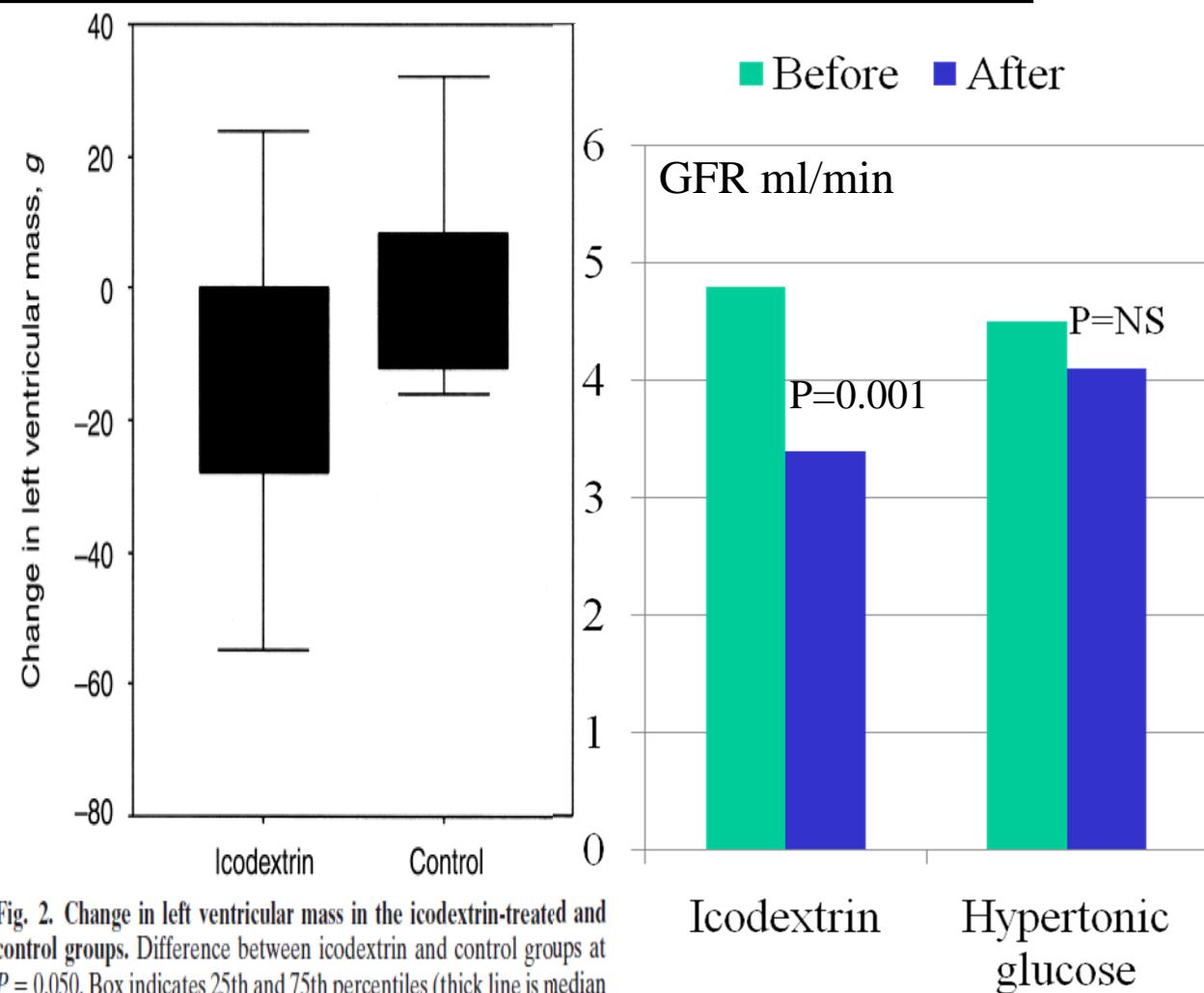
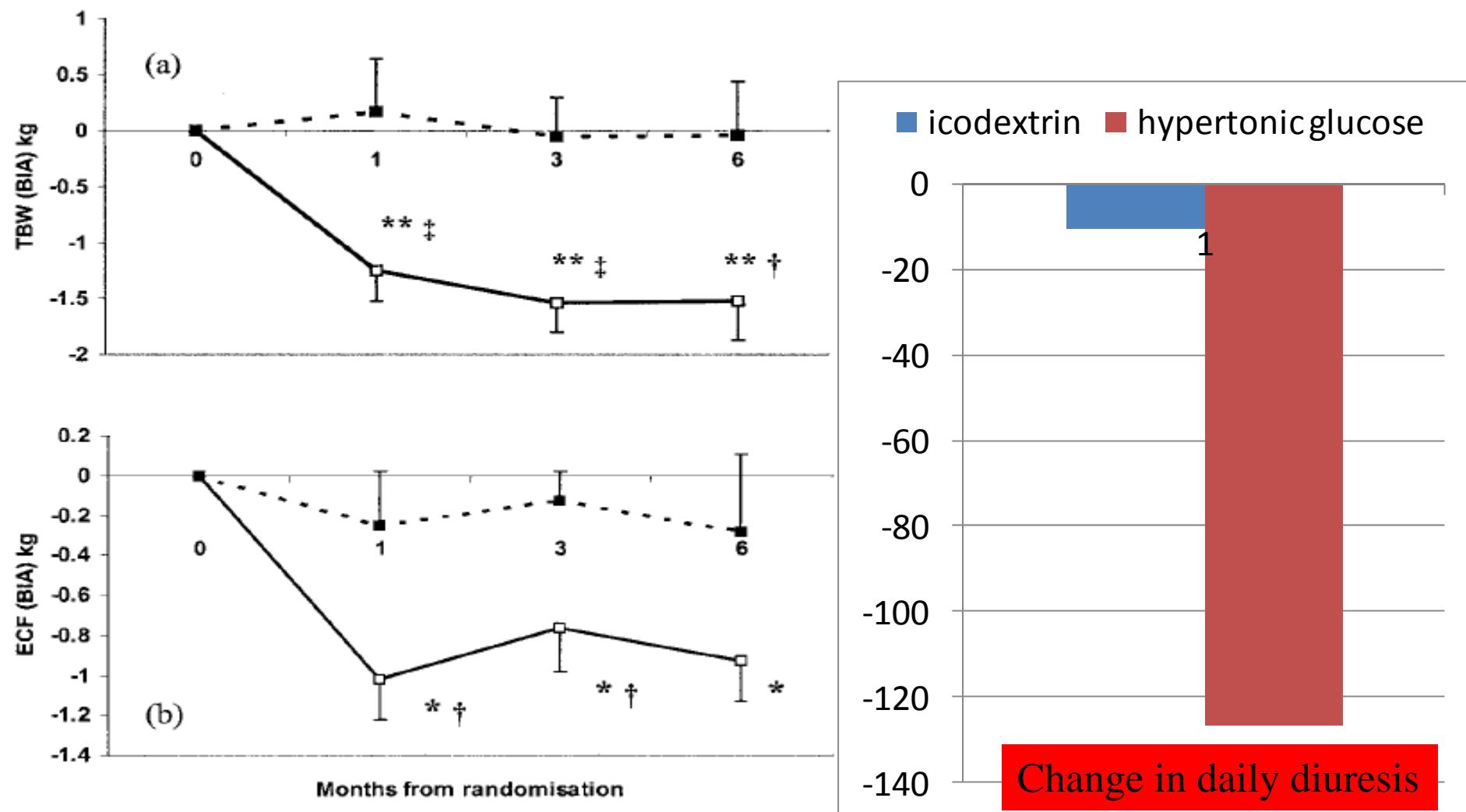


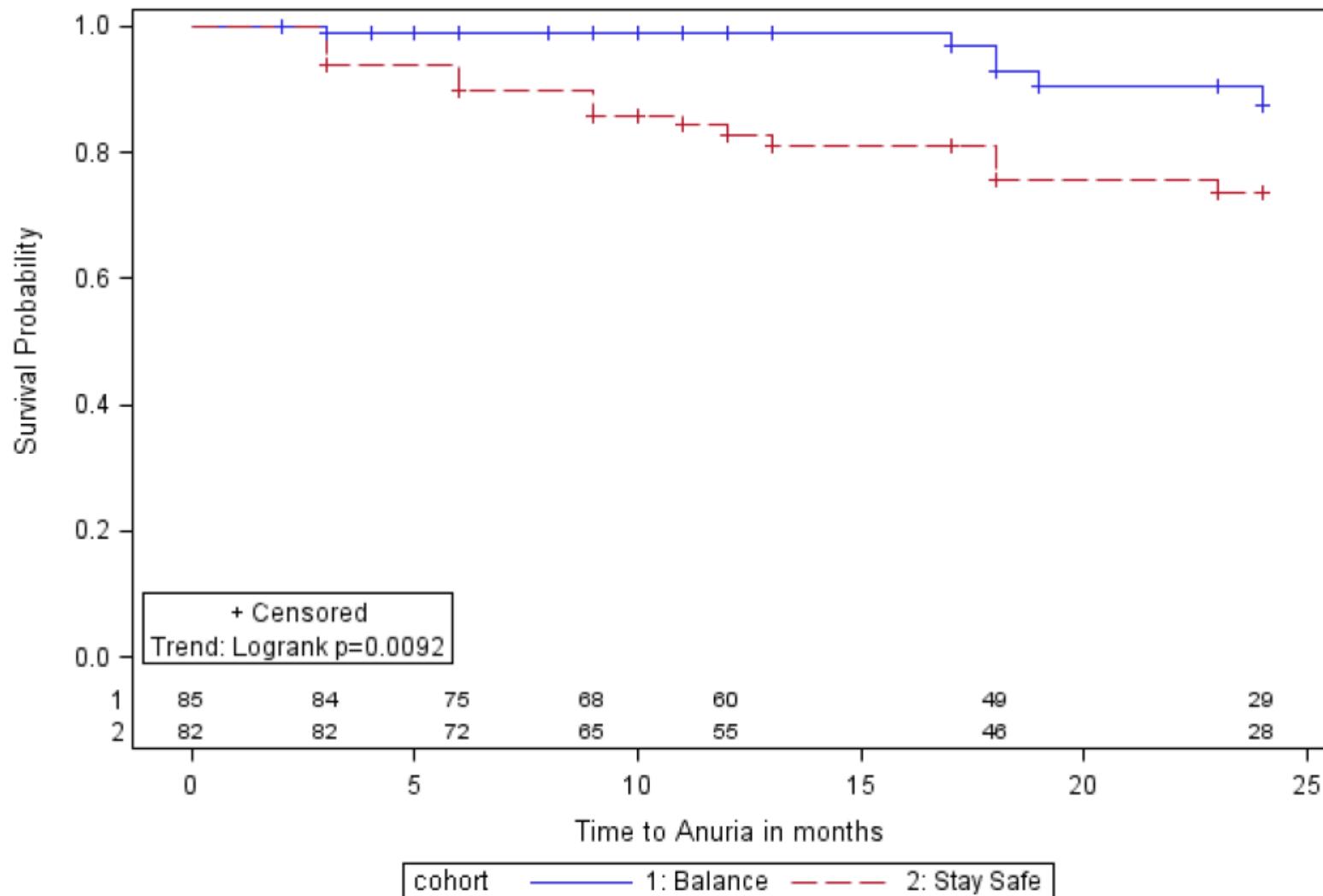
Fig. 2. Change in left ventricular mass in the icodextrin-treated and control groups. Difference between icodextrin and control groups at $P = 0.050$. Box indicates 25th and 75th percentiles (thick line is median value) and capped bars indicate minimum and maximum value (excluding outliers)

Icodextrin and residual renal function

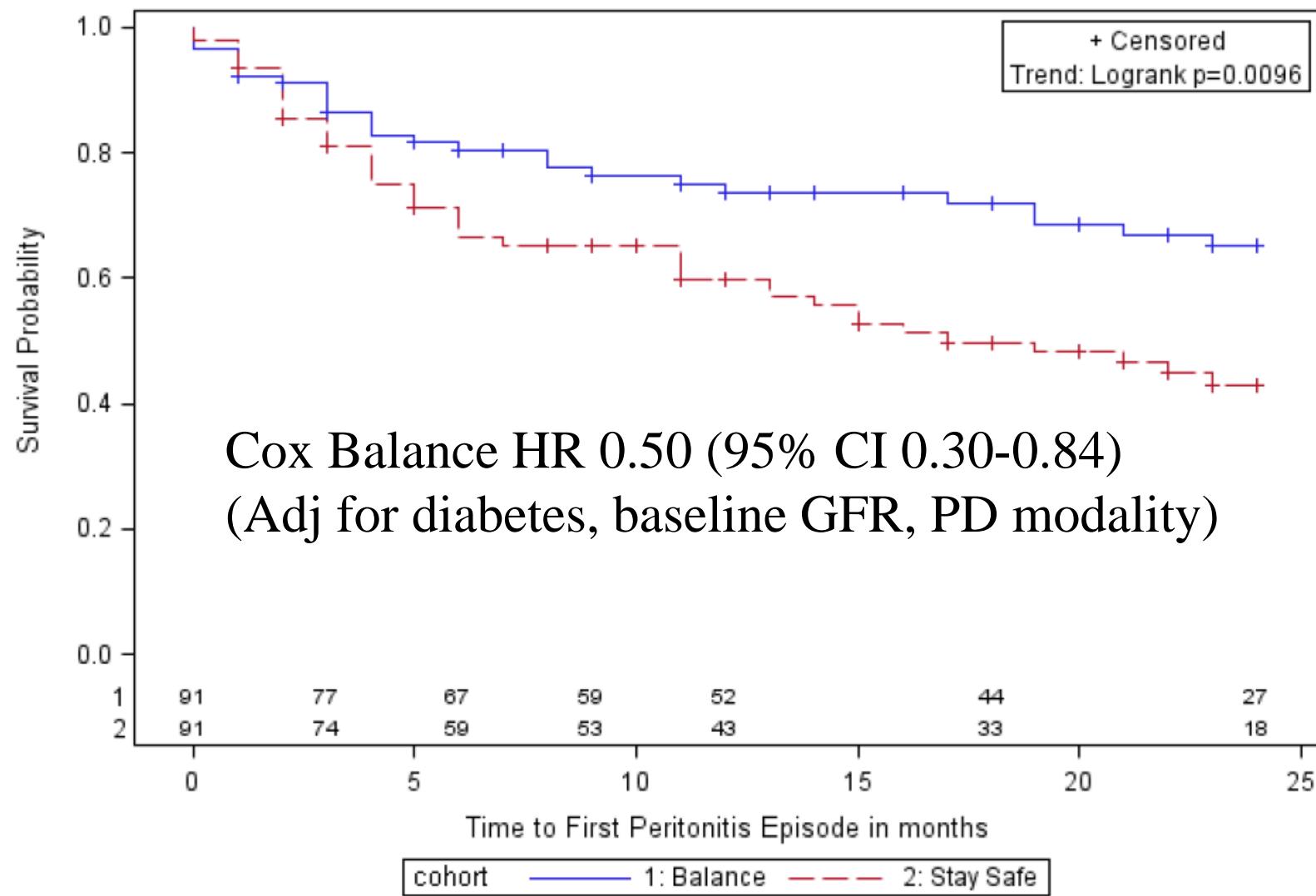


Davies et al, JASN 2003

BalANZ trial: Time to Anuria

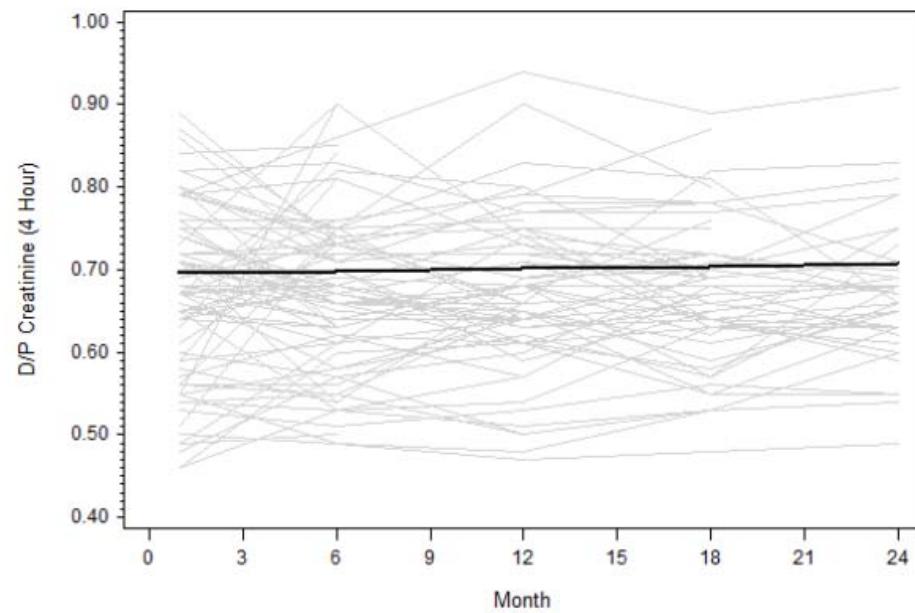


BalANZ: Peritonitis



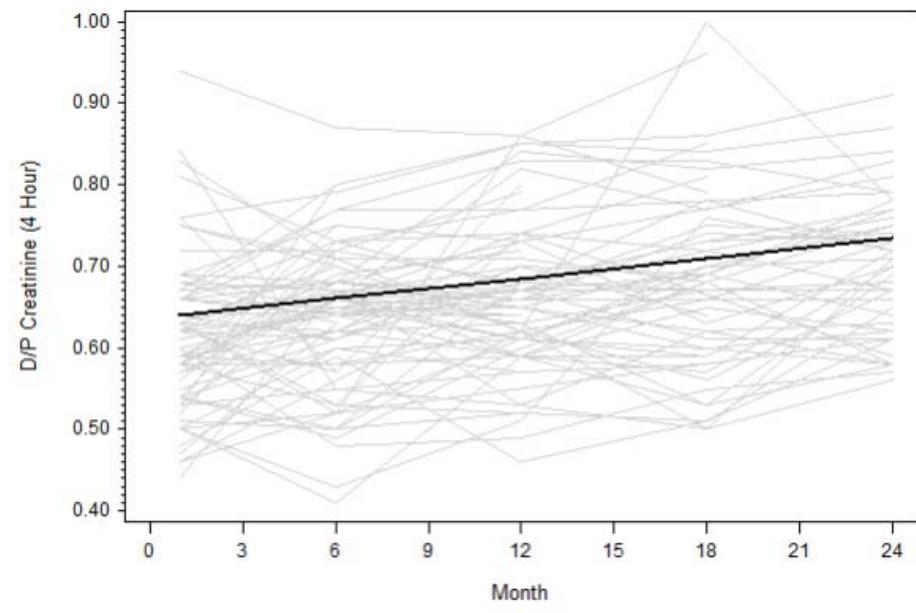
BaANZ: PET D:P Creatinine

Balance



0.001 per month
(95% CI -0.001 to 0.002)

stay.safe/sleep.safe
standard



P<0.001
0.004 per mth
(95% CI 0.003 to 0.005)



Adapt dwell length
Avoid hypertonic exchanges
Use biocompatible solutions
Avoid icodextrin

Preserve RRF

Preserve peritoneal membrane

Better controlled volume status

