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Change in Inferior Vena Caval Diameter Detected by Ultrasonography During and After Hemodialysis

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The diameter of the inferior vena cava (IVC) measured by ultrasonography is used as a parameter to estimate right sided cardiac function and central venous pressure. In the current study the IVC diameter during and after hemodialysis (HD) was measured in chronic HD patients to explore the determinant factors of the diameter, and these results were obtained: 1) the maximal diameter of the IVC during quiet expiration (IVCe) can be a marker of circulating blood volume during as well as after HD, because the linear correlation between IVCe and circulating blood volume during and after HD were significant and almost identical; 2) the amount of ultrafiltration is the major determinant of IVCe during HD, because IVCe and circulating blood volume decreased in parallel with the amount of ultrafiltration during HD; and 3) since the recovery of IVCe and circulating blood volume, which correlated with the increase in serum protein concentration during HD, was almost complete while the body weight remained unchanged after HD, plasma refilling rather than body fluid retention was considered important in the recovery of IVCe and circulating blood volume after HD. *ASAIO Journal* 1995; 41:105–110.

In hemodialysis (HD) patients, the maintenance of circulating blood volume (CBV) within an optimum range is critical to avoid circulatory complications. Volume excess causes hypertension and lung edema, whereas excessive hypovolemia leads to hypotension and circulatory collapse. Changes in the diameter of the inferior vena cava (IVC) detected by ultrasonography have recently been considered a useful parameter to assess right sided cardiac function and central venous pressure (CVP).[1-3] We have previously demonstrated that the decrease in IVC diameter correlates significantly with the reduction in body fluid, in particular CBV, during HD.[4] This suggests that ultrasonography of the IVC is useful in evaluating the volume status during HD.

Conversely, IVC configuration after HD remains unexplored, although a reciprocal increase in IVC diameter due to body fluid retention is assumable. In the current study, we examined the IVC diameter during and after HD, and explored the determinant factors of IVC diameter in HD patients.

Materials and Methods

Six stable hospitalized men on regular HD, who had no apparent cardiopulmonary diseases or diabetes mellitus, were selected to participate in the study **(Table 1).** Medications were not changed during the study.

Each patient underwent HD for 4 hr two or three times a week. The dialyzers used are listed in **Table 1.** Composition of the dialysate (AK Solita-C, Shimizu, Japan) was as follows (in mEq/L): Na 135, K 2.5, Ca 3, Mg 1.5, Cl 109, HCO3 27.5, acetate 7.5. The extracorporeal circuit was primed with 150 ml of saline and the flow rates of dialysate and blood during HD were 0.5 L/min and 150- 200 ml/min, respectively. At the end of HD, 150 ml of blood in the circuit and 200 ml of saline used for rinsing were returned to the patient. After each HD session, the patients were fasted for 3 hr (fasting period).

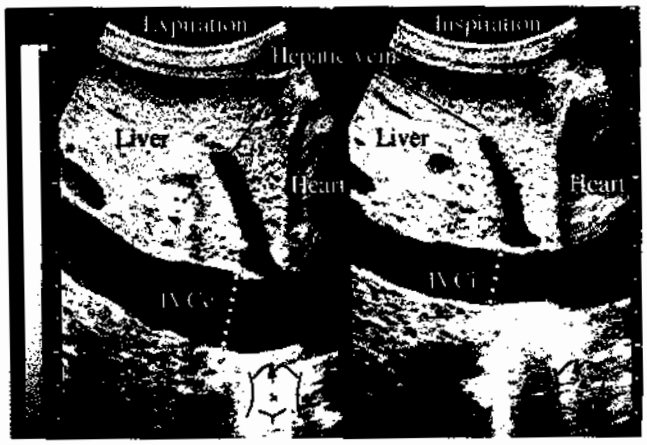

Figure 1. Measurement of IVC diameter. IVCe, the maximal diameter of the inferior vena cava during quiet expiration. IVCi, the minimal diameter of the inferior vena cava during quiet inspiration. Collapsibility Index (CI) = (IVCe-IVCi)/IVCe.

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Table 1. Patient Profile

Case	Age	Gender	Height (cm)	DW (kg)	HD duration (year)	Etiology	Dialyzer size (square m)	Membrane
1	62	M	165	49.5	11.5	CGN	1.5	Cu
2	61	M	161	50.0	6.0	CGN	1.5	PMMA
3	60	M	151	54.0	0.5	Pyelonephritis	1.5	Cu
4	40	M	170	52.5	11.2	CGN	2.1	Cu
5	61	M	164	52.2	2.2	CGN	1.5	Cu
6	40	M	166	55.0	0.1	CGN	1.5	Cu
Mean	54.0	—	162.8	52.3	5.3	—	1.6	—
SE	4.4	—	2.7	0.9	2.1	—	0.1	—

M, mm; HD, hemodialysis; DW, dry weight; CGN, chronic glomerulonephritis; Cu, cuprophane; PMMA, polymethylmethyacrylate.

As shown in **Figure 1,** a sagittal view of the IVC with the patient in the supine position was obtained by B-mode ultrasonography (model SSA650CL, Aloka, Japan). The maximal IVC diameter during quiet expiration (IVCe) and the minimal diameter during quiet inspiration (IVCi) were intermittently measured just below the junction of the IVC and hepatic vein for a period of 48 hr. ECG synchronized M-mode ultrasonography[2,3] was avoided, since measurement of IVCe and IVCi at the same point on the IVC was impossible with this method because of respiratory movement of the IVC together with the diaphragm and liver. In addition, when the IVC diameter is small, it is difficult to identify the anterior and posterior wall with M-mode. The variance for the diameter of the same IVC measured by 3 independent observers was less than ±1 mm. Collapsibility index (CI), an index of the CVP,[1] was calculated as

$$CI = (IVCe - IVCi)/IVCe$$

Blood samples were obtained from the predialyzer circuit during HD and from the venous side of the A-V fistula after HD. Serum Na concentration (S Na) was determined by an automated analyzer (Electroder, Analytical Instruments Co., Japan). Total protein concentration of serum (TP) was also measured by an auto analyzer (Hitachi 736-60, Hitachi, Japan). Plasma osmolality (Posm) was assessed by the freezing point depression method (Autostat OM-6010, Kyoto Daiichikagaku, Japan) and hematocrit (Ht) was measured by capillary centrifugation (KH1200M, Kubota Co., Tokyo, Japan). Circulating blood volume before HD (CBV_0) was determined by an ^{131}I-labeled albumin dilution method (Volumetron, Ames, IA). The CBV at any given time (CBV_t) was calculated by using the hematocrit and the following relationship:

$$CBV_t = CBV_0 \times Ht_0/Ht_t$$

where Ht_0 and Ht_t are the hematocrit at time 0 and at a given time, respectively.

Statistics

Data were expressed as mean ± SEM. Statistical analysis was performed by using paired Student's t-test. A difference

Table 2. Time Courses of Inferior Vena Caval Diameter and Other Parameters

	Before HD	End of HD	After HD (hr) 0	3	24	48
IVCe (mm)	16.2 ± 1.4	10.5 ± 1.3†	12.3 ± 1.6	15.0 ± 1.4§	15.3 ± 1.2‡	15.8 ± 1.1§
IVCi (mm)	6.3 ± 2.5	0.0 ± 0.0	2.0 ± 1.5	3.7 ± 1.4	6.5 ± 1.9‡	4.0 ± 2.2
CI	0.59 ± 0.15	1.00 ± 0.00*	0.86 ± 0.10	0.75 ± 0.09	0.58 ± 0.11‡	0.75 ± 0.12
BW (kg)	54.7 ± 1.2	52.0 ± 1.0†	52.4 ± 1.0	52.4 ± 1.0	52.6 ± 0.9‡	54.0 ± 1.0§
CBV (liter)	3.87 ± 0.19	3.54 ± 0.25*	3.64 ± 0.24	3.78 ± 0.22	3.72 ± 0.21	3.70 ± 0.20
SBP (mmHg)	140 ± 9	128 ± 13	135 ± 15	146 ± 16	138 ± 14	140 ± 15
DBP (mmHg)	74 ± 4	75 ± 4	80 ± 6	76 ± 7	76 ± 7	73 ± 6
HR (min)	77 ± 3	89 ± 3	86 ± 6	74 ± 5	79 ± 4	78 ± 5
TP (g/dl)	6.0 ± 0.4	6.9 ± 0.7*	6.7 ± 0.6	6.3 ± 0.5	6.5 ± 0.5	6.4 ± 0.5
S NA (mEq/L)	139 ± 1	142 ± 1	142 ± 1	—	140 ± 1	138 ± 1§
Posm (mOsm/kg)	317 ± 11	301 ± 4†	—	—	—	316 ± 9

* $p < 0.05$.
† $p < 0.01$ (vs. before HD).
‡ $p < 0.05$.
§ $p < 0.01$ (vs. after HD 0 hr).
IVCe, the maximal diameter of the inferior vena cava in quiet expiration; IVCi, the minimal diameter of the inferior vena cava in quiet inspiration; CI, collapsibility index; BW, body weight; CBV, circulating blood volume; SBP, systolic blood pressure; DBP, diastolic blood pressure; HR, heart rate; TP, serum total protein concentration; S Na, serum Na concentration; Posm, plasma osmolality; HD, hemodialysis.

with a p value less than 0.05 was considered statistically significant.

Results

Relationship Between Inferior Vena Cava Diameter and Body Weight or Circulating Blood Volume During Hemodialysis

IVCe and IVCi decreased concomitant with body weight and CBV, while CI increased reciprocally **(Table 2).** The percentage of change in IVCe significantly correlated with those for body weight and CBV **(Figure 2).** Since IVCi became zero and CI reached a maximum of unity during HD and did not reflect changes in body weight and CBV thereafter, IVCe was exclusively analyzed in the following study.

Time Course of Changes in Inferior Vena Cava During Quiet Expiration, Circulating Blood Volume, and Body Weight After Hemodialysis

After decrease of body weight, CBV, and IVCe during HD, these parameters were increased partially by the return of blood and saline at the end of HD (time 0 after HD; **Table 2**), following which, body weight remained constant during the fasting period, and increased slowly thereafter with the intake of food and water **(Figure 3).** Conversely, recoveries of CBV and IVCe were more rapid. At the end of the fasting period, CBV and IVCe had recovered to 96.3 ± 1.3% and 93.4 ± 4.9% of pre HD values, respectively, while body weight remained unchanged. Subsequently, these parameters increased more slowly to full recovery during the next 41 hr (body weight, CBV, and IVCe at 48 hr were 98.7 ± 0.7, 96.5 ± 1.4, and 99.7 ± 6.1% of those before HD, respectively).

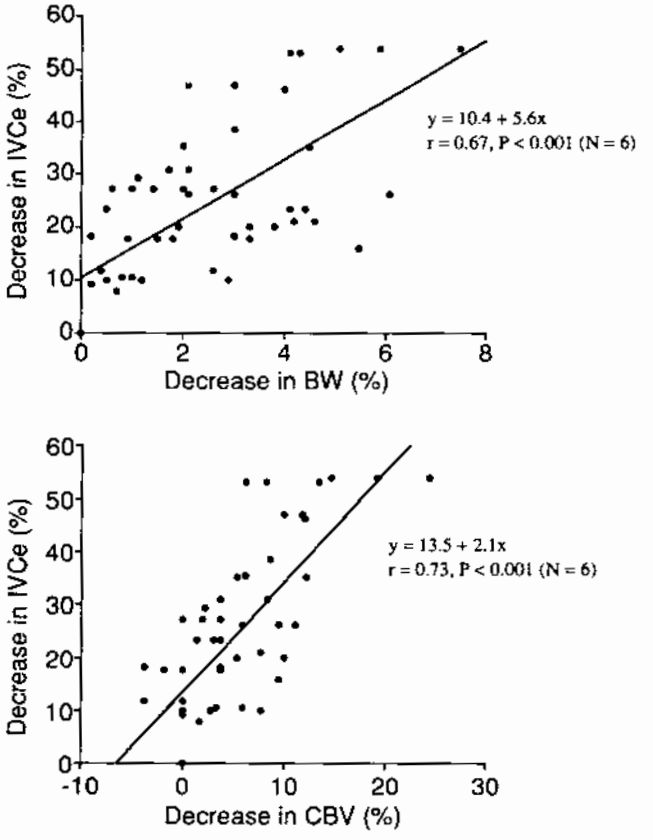

Figure 2. Relationships between percentage of change in IVCe and body weight or circulating blood volume during hemodialysis.

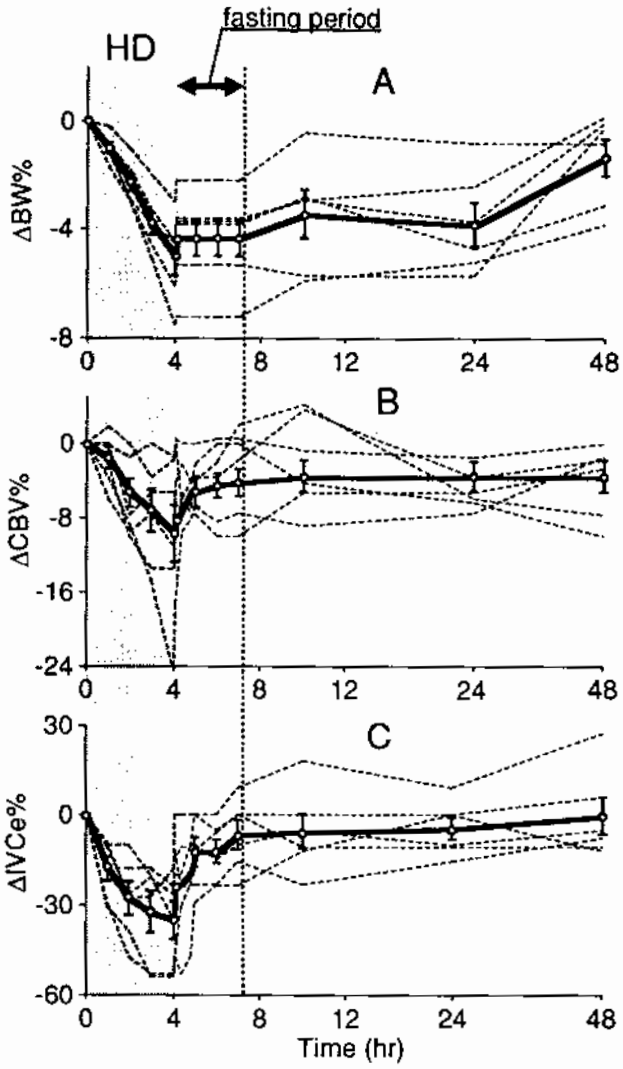

Figure 3. Time course of percentage of **(A)** changes in body weight, **(B)** CBV, and **(C)** IVCe during and after hemodialysis. Dotted line and solid line represent individual and averaged values, respectively. Of note, CBV and IVCe almost completely recovered, whereas body weight remained unchanged during the fasting period after hemodialysis.

Relationships Among Inferior Vena Cava during Quiet Expiration, Circulating Blood Volume, and Body Weight During vs After Hemodialysis

Figure 4A shows a representative record of IVCe, CBV, and body weight during and after HD in case 4. Comparison of during vs after HD showed that the regression curves be-

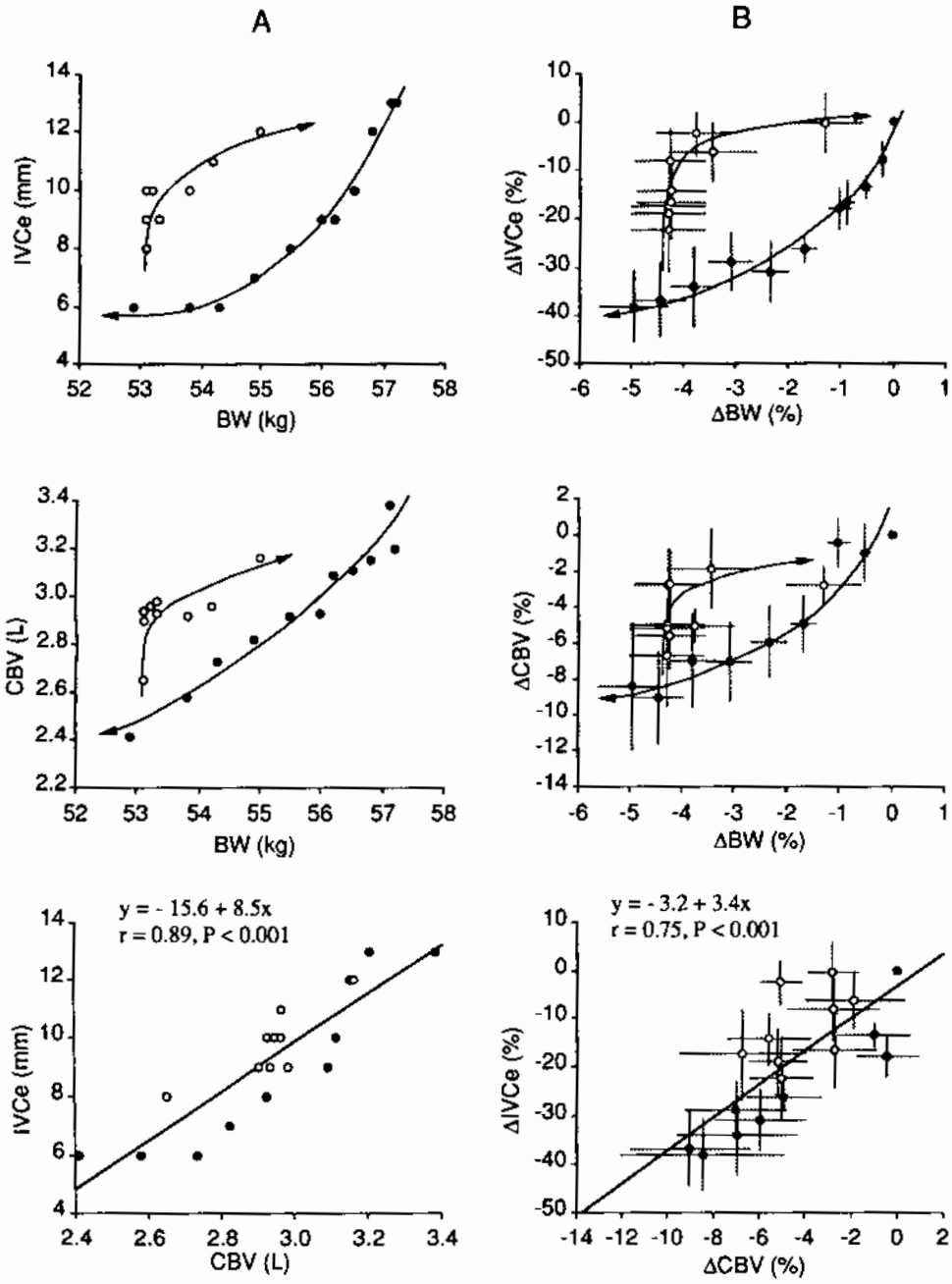

Figure 4. Relationships among body weight, circulating blood volume (CBV), and IVCe during *vs* after hemodialysis. **A.** Representative relationships among these parameters in Case 4. **B.** The averaged percentage of changes. Closed circles and open circles represent changes in these parameters during and after hemodialysis, respectively.

tween body weight and CBV or IVCe were dissociated. However, an identical linear correlation was seen between IVCe and CBV during and after HD. In **Figure 4B,** the percentage of change in these parameters is shown. The regression curves between %body weight and %CBV or %IVCe after HD were different from those during HD, whereas the correlation between %IVCe and %CBV was identical during and after HD.

Determinant Factors of the Inferior Vena Cava During Quiet Expiration During and After Hemodialysis

Because IVCe correlated with CBV during and after HD, we examined the relationships between IVCe and three major determinant factors of CBV, *i.e.*, the amount of total body fluid, and the serum concentrations of TP and Na (S Na).[5-12]

During HD, the decrease in IVCe and CBV correlated significantly with that of total body fluid as a result of ultrafiltration **(Figure 5).** However, TP before HD did not correlate significantly with the change in IVCe and CBV (r = 0.48, NS and r = 0.22, NS, respectively). S Na before HD did not correlate with these parameters either (r = 0.07, NS and r = 0.54, NS, respectively).

During the fasting period after HD, the amount of body fluid was obviously not related to the recovery of IVCe and CBV **(Figure 3),** or to the change in S Na during HD (r = 0.04, NS and r = 0.08, NS, respectively). Conversely, the recovery

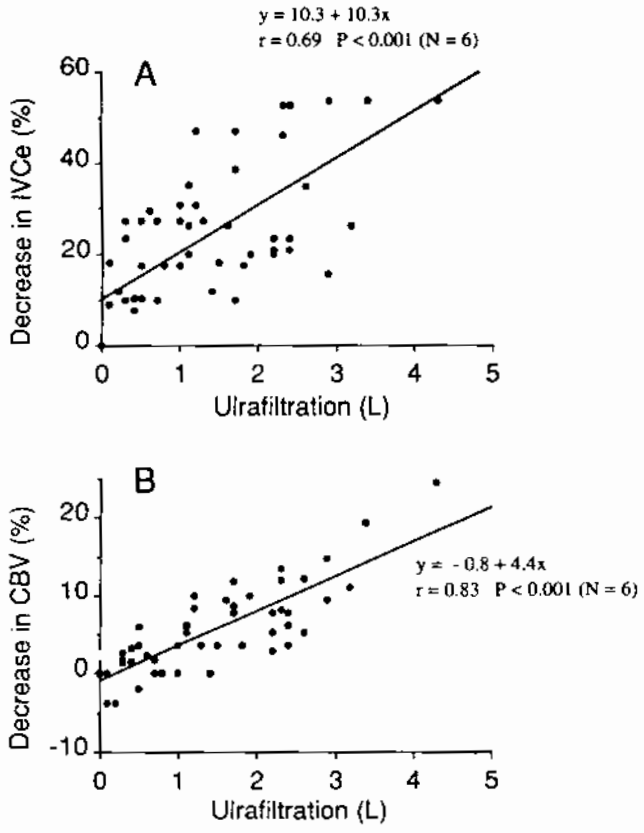

Figure 5. Relationships between the amount of ultrafiltration and changes in (**A**) IVCe or (**B**) circulating blood volume (CBV).

of IVCe and CBV during this period correlated significantly with the increase in TP during HD **(Figure 6).**

Discussion

The intravascular pressure of the IVC, *i.e.*, CVP, is a well established index of right sided cardiac function and body fluid status.[13,14] Also, IVC diameter has been found to be sensitive to change in CVP, because the IVC is a highly compliant vessel.[15] Indeed, Natori *et al.* reported that the respiratory change in IVC diameter measured by ultrasonography correlated with the CVP.[1] Several studies further reported the correlation between IVC diameter and right sided cardiac function.[2,3]

In terms of the change in IVC diameter during HD, the current study confirmed our previous observations[4,16]: the IVC diameter, CBV, and body weight were decreased by ultrafiltration, and the correlation between the change in IVCe and CBV or body weight was statistically significant **(Figure 2).** We further observed that the linear correlation between IVCe and CBV was maintained even after HD **(Figure 4),** despite the fact that the relationship between body weight and IVCe or CBV during and after HD were discrepant **(Figure 3).** These data argue that IVCe reflects CBV rather than the amount of total body fluid.

We, thus, explored how the determinant factors of CBV affect IVCe. The amount of total body fluid is a major determinant of CBV.[5-7] Serum concentration of TP and Na (S Na) are also known to affect CBV: TP provides oncotic force to recruit interstitial fluid into the circulation[8-10] and S Na modulates fluid shift between the intracellular and extracellular fluid.[11,12]

During HD, the decrease in CBV and IVCe correlated significantly with the amount of ultrafiltration **(Figures 2 and 5)** but not with TP or S Na before HD. Consequently, the change in total body fluid volume from ultrafiltration appeared to be the premier determinant of CBV and IVCe dur-

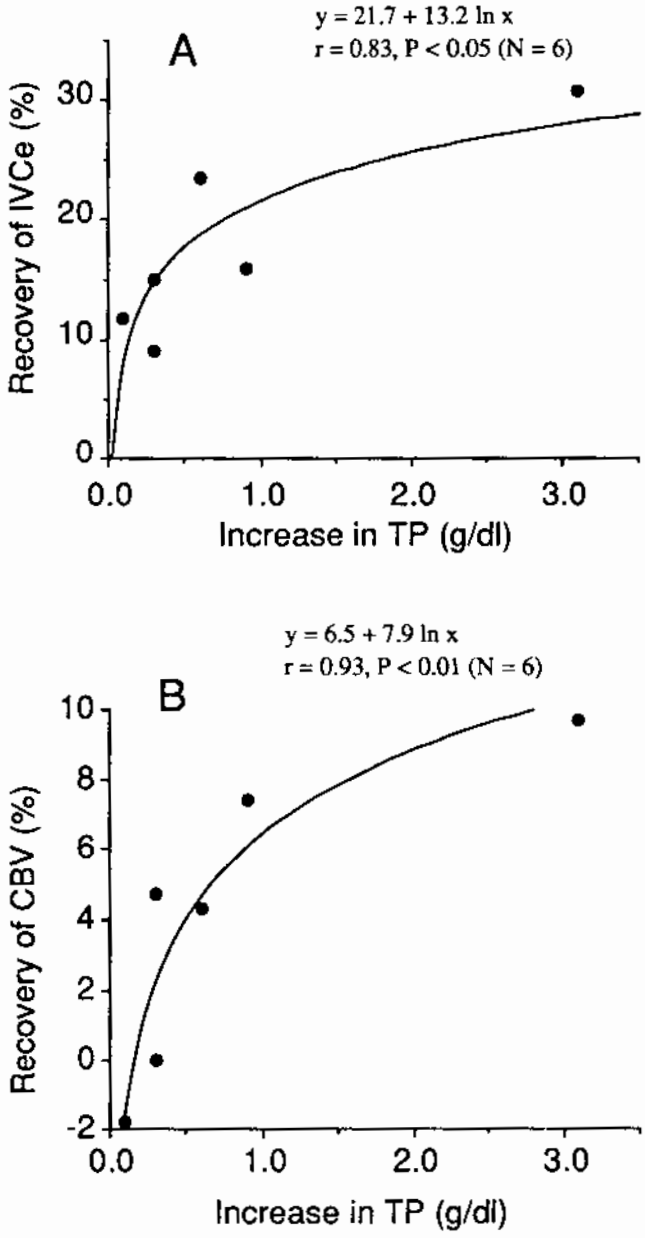

Figure 6. Relationships between the increase in serum total protein concentration during hemodialysis and the recoveries in (**A**) IVCe or (**B**) circulating blood volume (CBV) during the fasting period after hemodialysis.

ing HD. By contrast, the amount of total body fluid played little role after HD, because IVCe and CBV almost fully recovered without an increase in body weight during the fasting period. Instead, the recovery of IVCe and CBV significantly correlated with the increase in TP during HD **(Figure 6).** This is compatible with the view that increased colloid osmotic pressure due to ultrafiltration enhances the influx of interstitial fluid into the circulation.[8-10] The change in S Na during HD did not affect the recovery in IVCe after HD. The sodium dependent fluid shift between intracellular and extracellular spaces might have been too small to alter CBV, since the Na concentration of the dialysis solution (135 mEq/L) is not considerably different from the S Na before HD (139 ± 1 mEq/L).

The clinical implication of this study is that IVCe can be used as a marker of CBV during as well as after HD. In HD patients, it is essential to maintain total body water within an optimum range to prevent circulatory complications such as pulmonary edema and hypovolemic shock. Biochemical markers such as atrial natriuretic peptide[16-18] and cyclic guanosine monophosphate[19] are not suitable for immediate evaluation of body fluid status. Direct measurement of the CVP is unsuitable as a routine examination. In contrast, ultrasonographic measurement of the IVC diameter provides real time information of the CBV non-invasively.[4] Indeed, in our dialysis unit, the IVC diameter is measured routinely to evaluate the body fluid status and dry weight of dialysis patients.

We conclude that IVC diameter can be an indicator of the amount of body fluid, in particular CBV, in HD patients during and after HD. While ultrafiltration is the major determinant of IVCe during HD, plasma refilling plays an important role in the recovery of IVCe after HD.

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