

Original Article

Haemodynamics and electrolyte balance: a comparison between on-line pre-dilution haemofiltration and haemodialysis

Charles Beerenhout, Tom Dejegere, Frank M. van der Sande, Otto Bekers, Karel M. Leunissen and Jeroen P. Kooman

Department of Internal Medicine and Clinical Chemistry, University Hospital Maastricht, The Netherlands

Abstract

Background. An important advantage of convective therapies is improved vascular reactivity. However, it is not well known whether the vascular response during convective therapies remains superior when compared to haemodialysis (HD) with an adjusted temperature of the dialysate. It has also been suggested that convective therapies may impair small electrolyte removal through an effect on the Donnan equilibrium. In the present study, we compared the haemodynamic response and small electrolyte removal between pre-dilution on-line haemofiltration (HF) and HD procedures.

Methods. Cardiac output (CO), central blood volume (CBV) and peripheral vascular resistance (PVR) were assessed, using the saline dilution technique, in 12 stable patients during HF and HD with two different temperatures of the dialysate [36.5 and 35.5°C (HD^{36.5} and HD^{35.5})]. Balances for sodium, potassium, calcium and conductivity were assessed using total dialysate/filtrate collections. Target filtration volume for HF was 1.2 times body weight. The temperature of the infusate was 36.5°C.

Results. The change (Δ) in CBV was less during HD with a dialysate temperature of 35.5°C (-0.03 ± 0.14 l; $P < 0.05$) compared to HF (-0.16 ± 0.05 l) and HD^{36.5} (-0.11 ± 0.14 l), but the other haemodynamic parameters did not differ between the studied techniques. Δ PVR was significantly related to Δ CBV ($r = -0.46$; $P < 0.01$), whereas Δ CBV was related to ultrafiltration rate ($r = -0.34$; $P = 0.05$). Δ CO was related to Δ CBV ($r = 0.62$; $P < 0.001$). Solute balances did not differ between HF and HD.

Conclusion. Using the saline dilution method, no difference in the change in CO and PVR was observed between on-line HF vs HD^{36.5} and HD^{35.5}. Only CBV

declined to a significantly lesser degree during HD^{35.5}, although absolute differences were small. Changes in the other haemodynamic variables appeared more dependent upon the degree and rapidity of fluid removal than upon the treatment modality. No difference in small electrolyte balance was observed between HF and HD, suggesting that ionic removal is not impaired during on-line HF.

Keywords: central blood volume; electrolyte balance; haemodialysis; haemofiltration; on-line pre-dilution; vascular resistance

Introduction

It has long been known that vascular reactivity is better maintained during convective therapies compared with conventional haemodialysis (HD) treatment [1]. Evidence from the early 1980s, from the Maggiore group, showed that temperature-related factors played a major role in the improved vascular response during haemofiltration (HF) [2]. It was also first demonstrated by the Firenze group, and confirmed by others, that significant cooling over the extracorporeal circuit occurred during convective techniques [2,3]. This extracorporeal blood cooling antagonizes the increase in core temperature, which is an important cause for the inadequate peripheral vasodilation observed during standard HD therapy.

There is still debate in the literature as to whether the beneficial haemodynamic effects of convective therapies are primarily due to a cooling effect or to an enhanced removal of vasodepressor substances [4]. HF with on-line production of substitution fluid would appear an ideal model to study the haemodynamic relevance of convective clearance *per se*, due to the possibility to exchange very large volumes [5]. Studies with detailed haemodynamic measurements during on-line convective therapies are scarce. Moreover, even

Correspondence and offprint requests to: Jeroen P. Kooman, Department of Internal Medicine, University Hospital Maastricht, PO Box 5800, 6202 AZ Maastricht, the Netherlands.
Email: jkoo@groupwise.azm.nl

when the temperature of dialysate and infusate is equal, extracorporeal energy balance may differ between on-line convective techniques and HD [6]. In an *in vitro* study, the extracorporeal energy loss during on-line HF with an infusate temperature of 37.5°C appeared to approximate that of HD with a temperature of 36.5°C [7].

However, changes in electrolyte status may interfere with the cardiovascular response during renal replacement therapies. Whereas sodium balance is mainly of relevance for the preservation of blood volume, calcium and potassium balance may, respectively, influence the cardiac and vascular response during fluid removal. It is conceivable that during HF, the increased viscosity in the artificial membrane leads to a progressive adhesion of negatively loaded proteins, yielding a reduction in the Donnan factor and a reduced mass transport of positively loaded anions [8]. On the other hand, it has also been suggested that increased shear stress by the large infusion volumes during HF may actually reduce the thickness of this protein layer [9]. The convective transport of calcium during pre-dilution HF may also be influenced by dilution of plasma proteins [10].

Few data exist on electrolyte balance during on-line convective therapies, mostly based on calculation of sodium sieving coefficients. However, calculation of electrolyte balance from sieving coefficients may be hazardous during HF, as the protein layer at the surface membrane might increase during progressive haemoconcentration [8]. To our knowledge, electrolyte balance has not yet been compared between HD and on-line HF.

The aim of the present study was first to compare the haemodynamic response during pre-dilution on-line HF with HD using different dialysate temperatures and secondly to compare the mass balance of small electrolytes between HD and pre-dilution on-line HF.

Methods

During three different sessions, performed on the same day of the week with weekly intervals, the haemodynamic response was assessed during respectively pre-dilution on-line HF (infusate temperature 36.5), and HD using respective dialysate temperatures of 36.5°C (HD^{36.5}) and 35.5°C (HD^{35.5}). Sessions were performed in random order. Electrolyte mass balances were assessed during on-line HF and the HD session with the dialysate temperature of 36.5°C. The patients underwent treatment with standard HD sessions (dialysate sodium 140 mmol/l) in between the two different study sessions.

The target infusate volume during HF was aimed at 1.2 times body weight. Mean blood flow rate during HD sessions was 375 ± 33 ml/min. The treatment time was 4.1 ± 0.3 h for both HD and HF treatments. Electrolyte composition of the dialysate and infusate was equal: sodium 140 mmol/l, potassium 2 mmol/l, calcium 1.50 mmol/l, glucose 5.6 mmol/l, bicarbonate individualized between 32 and 36 mmol/l. HD and HF were both performed with polyamide membranes (Polyflux 8L; surface area 1.7m² and Polyflux 24S, surface

Table 1. Baseline characteristics

Age (years)	69 ± 6
Sex (M/F)	8/4
Weight (kg)	71 ± 11
Body surface area (kg/m ²)	1.82 ± 0.18
Systolic blood pressure (mmHg)	137 ± 17
Diastolic blood pressure (mmHg)	78 ± 10
Number of antihypertensives	1.6 ± 1.0
Inferior caval vein diameter (mm/m ²)	9.6 ± 2.3
Extracellular volume (l/kg)	0.26 ± 0.03
Haemoglobin (mmol/l)	7.6 ± 0.6
Serum albumin (g/l)	36.1 ± 2.7
C-reactive protein (mg/l)	9.2 ± 8.4
Serum sodium (mmol/l)	140.4 ± 2.9
Serum potassium (mmol/l)	5.3 ± 0.6
Serum calcium (mmol/l)	2.35 ± 0.17
Serum phosphate (mmol/l)	1.74 ± 0.41

area 2.4 m², respectively; Gambro, Lund, Sweden). During HD, sterile dialysate was used (<1 c.f.u./l; endotoxins <0.03 IU/l), using two U-8000S polyamide filters (Gambro). During HF, substitution fluid was sterilized according to the three-filter system (two U-8000S and one disposable U-2000).

Twelve stable patients were included. Exclusion criteria were severe coronary or congestive heart failure (NYHA III or higher), diabetes mellitus. Patient characteristics are summarized in Table 1. Antihypertensive agents used were angiotensin converting enzyme inhibitors/angiotensin receptor antagonists (*n* = 7), beta blocking agents (*n* = 7) and calcium antagonists (*n* = 5). Antihypertensive agents were withheld on the day of the study. None of the patients were treated with central venous catheters. The Ethical Committee of the University Hospital Maastricht approved the study. All patients gave written informed consent.

Fluid status was assessed in the patients during an interdialytic day by means of echography of the inferior caval vein (criteria for normovolaemia 8.5–11.5 mm/m²) and by assessment of extracellular water by multifrequency bioimpedance analysis (Xitron BIS 4000; San Diego, CA).

Haemodynamic measurements

Cardiac output (CO), central blood volume (CBV) and peripheral vascular resistance (PVR) were assessed by the saline dilution technique (Transonic HD 01[®]; Transonic Systems, Ithaca, NY) as described in detail elsewhere [11]. In short, a heated (37°C) bolus of 30 ml of NaCl 0.9% (indicator) is injected into the venous line with the blood pump speed set at 200 ml/min, and the change in velocity of ultrasound waves produced by the returning dilution curve (S) is detected by a probe attached to the arterial line. By comparing the dilution curve with a calibration curve (S_{cal}), produced by injecting 10 ml of isotonic saline in the venous bubble trap, CO is calculated by the formula: 3 * blood flow * (S / S_{cal}). CBV, which is considered to be the blood in the heart, great vessels (pulmonary artery and veins and descending aorta) and the lung capillaries, is calculated by multiplication of CO with the mean transit time of the indicator, corrected for travel time in the arterial and venous blood line. PVR is calculated by dividing mean arterial pressure by CO.

Measurements were performed immediately after the start and at the end of the treatment, and in the middle of the dialysis session.

Measurements were performed in duplicate and the mean value was used in the analysis. Coefficient of variation between the duplicate measurements was 8.3% for CO, 8.8% for CBV and 9.1% for PVR. Access recirculation was 0% in all patients.

The change in relative blood volume (RBV) was assessed with the blood volume sensor (BVS) system (Gambro). Blood pressure was measured manually (Maxi Stabil 3; Speidel and Keller, Jungingen, Germany).

Body temperature was measured with an ear thermometer (Genius First Temp Model 3000A; Sherwood Medical, St Louis, USA).

Calculation of solute balance

Solute balances (mmol/session) during HD were calculated according to the following formula: $V_{out} \times C_{out} - V_{in} \times C_{in}$, in which V_{out} = volume of spent dialysate, C_{out} = concentration of solute in spent dialysate, V_{in} = volume of fresh dialysate, C_{in} = concentration of solute in dialysate [8]. During HF, the formula for solute mass balance is $[V_{f_{out}} \times C_{f_{out}}] - [V_{f_{in}} \times C_{f_{in}}]$ [8]. $V_{f_{out}}$ and $C_{f_{out}}$ are, respectively, the filtrated volume and the concentration of the solute in the filtrate. $V_{f_{in}}$ and $C_{f_{in}}$ are the infused volume and the concentration of the solute in the infusate. During on-line HF, mixing purified water with concentrates produces infusate. However, not all of the fluid which is produced in this way is infused in the patient, and the unused fluid is directly removed through the bypass of the module, entering the collection box through the same port as the filtrate which is removed from the patient. Thus, the collection box contains a mixture of filtrate and unused fluid and a correction factor has to be applied. The filtrate can be calculated as the sum of infusate and ultrafiltration volume, and the unused fluid as the product of the 'total fluid' flow rate (which is read as dialysate flow on the monitor) and dialysis time. Thus, a ratio (R) between filtrate volume and unused fluid can be calculated as follows: filtrate volume divided by ('total fluid flow rate' \times dialysis time). In this way, the corrected concentration of the solute can be calculated as follows: $C_{f_{out}} = [(C_{f_{collection\ box}} - (R \times C_{f_{in}})) / (1 - R)]$. $C_{f_{out}}$ can then be used in the basic formula for solute mass balance for HF.

Alternatively, the amount of solutes removed from the patient during HF can be calculated according to the formula: $(V_{f_{in}} - C_{f_{in}}) - [V_{f_{out}} \times C_{f_{out}} - R \times (V_{f_{in}} \times C_{f_{in}})]$, which yielded approximately the same results as the previous approach.

We also used conductivity balance in addition to sodium mass balance. Dialysate conductivity is mainly determined by dialysate sodium [12]. We included a secondary method for

the assessment of sodium balance, as due to the inherent variability of electrolyte measurements and the large volumes, calculation of electrolyte mass balances during dialysis may suffer from some inaccuracy.

Electrolyte concentrations were assessed by indirect ionometry (Synchron LX 20; Beckman Coulter, Brea, CA). In contrast to direct ionometry, indirect ionometry does not need a correction factor when assessing sodium in aqueous media and yields results comparable to flame photometry [13]. Two samples were taken and the mean of the two used for calculations. The coefficient of variation for sodium measurements in dialysate in the present study was 0.7%.

Statistics

Values are expressed as mean \pm SD. Differences between the three treatment modalities were assessed using repeated measurements ANOVA. The change in parameters during a single session was analysed using the paired Student *t*-test. Multiregression analysis was also used to assess the contribution of the treatment modality to haemodynamic changes. Correlation between haemodynamic variables were assessed using Pearson's *r*.

Results

In one patient, transmembranous pressure (TMP) immediately increased to maximal levels during HF, and the treatment had to be terminated. Thus, the study was completed in 11 patients. Ultrafiltration volume was comparable between the three treatment sessions (HF: 2.4 ± 1.0 l; HD^{36.5}: 2.4 ± 0.8 l; HD^{35.5}: 2.7 ± 0.8 l). Mean filtration volume achieved during HF was 75 ± 9 l.

RBV decreased significantly during HF ($-9.7 \pm 3.1\%$), HD^{36.5} ($-8.0 \pm 3.4\%$) and HD^{35.5} ($-7.7 \pm 4.0\%$) ($P < 0.001$). The change in body temperature did not differ between HF ($0.1 \pm 0.6^\circ\text{C}$), HD^{36.5} ($0.3 \pm 0.6^\circ\text{C}$) and HD^{35.5} ($0.0 \pm 0.4^\circ\text{C}$). Systolic and diastolic blood pressure (BP) did not change significantly during either HF (-1.6 ± 19.8 and -7.1 ± 9.9 mmHg), HD^{36.5} (-0.8 ± 22.7 and -3.8 ± 12.4 mmHg) and HD^{35.5} ($-6.0 \pm 2 + 2.5$ and -4.1 ± 7.6 mmHg).

Haemodynamic data obtained by the saline dilution technique are summarized in Table 2. During HF and HD^{36.5} but not during HD^{35.5}, CBV declined significantly ($P < 0.05$ compared to the other treatment

Table 2. Haemodynamic measurements during the different treatment modalities

	CO start (l/min)	CO end (l/min)	Δ CO (l/min)	CBV start (l)	CBV end (l)	Δ CBV (l)	PVR start (mmHg/min/l)	PVR end (mmHg/min/l)	Δ PVR (mmHg/min/l)
HF	6.9 ± 1.3	$6.0 \pm 1.2^*$	-0.8 ± 1.0	1.43 ± 0.34	$1.27 \pm 0.29^*$	-0.16 ± 0.05	15.2 ± 3.6	16.4 ± 4.1	1.2 ± 2.3
HD ^{36.5}	6.5 ± 1.1	6.1 ± 1.3	-0.4 ± 1.0	1.37 ± 0.33	$1.27 \pm 0.29^*$	-0.11 ± 0.14	14.7 ± 2.1	15.5 ± 3.0	0.8 ± 1.5
HD ^{35.5}	6.2 ± 1.2	5.7 ± 1.0	-0.5 ± 0.9	1.27 ± 0.33	1.24 ± 0.30	-0.03 ± 0.14	17.3 ± 5.4	17.5 ± 4.1	0.2 ± 3.4

HF, haemofiltration; HD^{36.5}, haemodialysis with dialysate temperature of 36.5°C ; HD^{35.5}, haemodialysis with dialysate temperature of 35.5°C ; CO, cardiac output; CBV, central blood volume; PVR, peripheral vascular resistance; Δ , change during treatment.

* $P < 0.05$ compared to start of treatment.

Table 3. Solute balance during haemofiltration (HF) and haemodialysis (HD)

	HF	HD
Sodium (mmol/treatment)	-436 ± 278	-365 ± 233
Potassium (mmol/treatment)	-92 ± 28	-88 ± 22
Calcium (mmol/treatment)	-4.6 ± 7.1	-4.8 ± 6.5
Phosphate (mmol/treatment)	-30.4 ± 6.0	-29.2 ± 9.0
Conductivity (mS/cm/treatment)	-61.5 ± 12.4	-52.4 ± 8.8

HF, haemofiltration; HD, haemodialysis.

modalities), whereas the decline in CO only reached significance during HF. Δ PVR and Δ CO did not differ between the various treatment modalities. Pooling all treatments, Δ CO and Δ CBV were significantly and positively related ($r=0.62$; $P<0.001$), whereas Δ CBV and Δ PVR were inversely related ($r=-0.46$; $P<0.01$). Δ CO was significantly related to Δ systolic BP ($r=0.36$; $P<0.05$) and Δ diastolic BP ($r=0.53$; $P<0.001$). Multiregression analysis only identified treatment modality as an independent predictor for Δ CBV, but not for Δ PVR or Δ CO.

When corrected for weight loss, Δ RBV was related to both Δ CO ($r=-0.56$; $P<0.001$) and Δ CBV ($r=-0.34$; $P=0.05$). Ultrafiltration rate was related to Δ RBV:weight loss ($r=0.43$; $P<0.001$), ultrafiltration rate was also related to Δ CBV ($r=-0.34$; $P=0.05$) and Δ CO ($r=-0.59$; $P<0.001$).

Regarding the balance studies, data are presented in Table 3. The balance for sodium, potassium, calcium and phosphate did not differ between HF and HD treatments. Also conductivity balance did not differ between HF and HD. Sodium concentration of infusate and fresh dialysis fluid was, respectively, 139.7 ± 0.8 and 140.0 ± 2.0 mmol/l. The mean sodium concentration in spent dialysate (140.8 ± 2.6 mmol/l) and filtrate (140.6 ± 2.2 mmol/l) (applying the correction factor for the unused fluid) was comparable. With HF, the correlation between sodium balance and ultrafiltration volume was highly significant ($r=-0.93$; $P<0.001$). With HD, this relation was less strong, but still significant ($r=-0.61$; $P<0.05$).

Urea reduction ratio was $61 \pm 5\%$ for HF and $71 \pm 6\%$ for HD ($P<0.05$).

The change in serum sodium (-0.4 ± 3.0 vs -1.0 ± 2.8 mmol/l), potassium (-1.6 ± 0.3 vs -1.6 ± 0.4 mmol/l), calcium (0.02 ± 0.2 vs -0.08 ± 0.2 mmol/l) and phosphate (0.9 ± 0.2 vs -0.9 ± 0.4 mmol/l) did not differ between HF and HD.

Discussion

In the present study, no major differences in the change in CO or PVR were observed between on-line pre-dilution HF (infusate temperature 36.5°C) and HD with dialysate temperatures of, respectively, 36.5 and 35.5°C (HD^{36.5} and HD^{35.5}). CBV was slightly,

but significantly, better maintained during HD^{35.5} compared to the other techniques.

Earlier studies by the Sardinia collaborative study group showed a convincing superior haemodynamic stability during pre-dilution on-line HF when compared with HD [4]. However, although the temperature of the dialysate and infusion fluid during on-line therapies were matched (37.0°C) in these studies, *in vivo* and *in vitro* data showed that pre-dilution on-line HF exerts a more pronounced cooling effect compared to HD even if the temperature of dialysate and infusate are equal [3,7].

In the present study, PVR was studied using the saline dilution technique. The saline dilution technique was recently introduced in dialysis therapy and yielded promising results in the assessment of the haemodynamic response during dialysis [13–15]. In the present study and in reports by others, the change in CO, which is independently measured by the saline dilution technique, was significantly related to changes in blood pressure. However, we were puzzled by the fact that, despite the fall in CO, PVR did not increase significantly during the treatment sessions. Also, in a study by Hoeben *et al.* [14], no differences in PVR were observed between cool dialysis and standard dialysis, whereas in the report by Prakash *et al.* [15], no increase in PVR was observed after ultrafiltration. The absence of a change in PVR during on-line HF is in contrast with earlier studies of our group using strain gauge plethysmography [3]. The reason for this discrepancy is not clear. Dilution techniques to measure PVR are well established in the intensive care unit. However, it should be kept in mind that in this setting, mean arterial pressure is usually assessed by direct intra-arterial monitoring, and not by indirect measurements, as in the present study. Also, in contrast to measurements by dilution techniques, strain gauge plethysmography mainly assesses the reactivity of the forearm skin blood vessels, which are highly sensitive to thermal changes. In a recent study in 13 HD patients, we observed a difference between the cutaneous vascular response assessed with laser Doppler flowmetry, and the systemic vascular response studied by the saline dilution technique. The treatments compared in this study were so-called thermoneutral HD (in which extracorporeal energy transfer is zero but core temperature increases) and isothermic HD (in which core temperature is maintained stable by removing energy from the extracorporeal circuit [21]). Despite significant differences in skin blood flow (which decreased more during thermoneutral dialysis compared to energyneutral dialysis; -0.93 ± 0.6 arbitrary units vs -0.45 ± 0.9 arbitrary units; $P<0.05$) [16], the change in PVR assessed by the saline dilution technique was comparable (5.5 ± 5.1 vs 6.0 ± 8.5 mmHg/l/min; $P=\text{NS}$). Therefore, it appears likely that differences in cutaneous vascular reactivity are not adequately detected by the saline dilution method.

Δ PVR was significantly related to Δ CBV, which was in turn related to the ultrafiltration rate and Δ RBV. Thus, in the present study, the change in PVR measured

by the saline dilution technique appeared to be more dependent upon the degree and rapidity of fluid removal than upon the treatment modality used. However, as discussed previously, local differences in vascular reactivity may be missed by the saline dilution technique.

Although the lack of a change in PVR might also theoretically be explained by relative overhydration of our patients, the normalized extracellular volume, assessed by bioimpedance analysis, was comparable to reported values of dialysis patients in an international study and to values observed in stable renal transplant patients [17,18].

Though absolute differences were small, the fall in CBV was lower during HD compared to the other techniques, especially during the first half of the dialysis treatment. In the study by Hoeben *et al.* [14], CBV was more sensitive than PVR in detecting haemodynamic changes between different techniques. The reason for the smaller fall in CBV during HD^{35.5} compared to the HF treatment is that extracorporeal blood cooling may still have been somewhat larger during the former treatment, resulting in improved peripheral vasoconstriction and mobilization of the peripheral blood volume to CBV. A more detailed thermal study should shed more light on this topic. However, the observed differences were small and of uncertain haemodynamic significance. Indeed, during HF and HD^{36.5}, the fall in CBV was small (± 100 ml) despite a mean ultrafiltration volume of 2500 ml and the significant fall in RBV. This might be an argument for adequate mobilization of fluid volume from the peripheral to the central compartments during these treatment modalities. Thus, an adequate mobilization of unstressed blood volume, resulting in only a minor decline in CO, may not necessitate a large increase in PVR in order to maintain blood pressure.

Apart from possible limitations of the haemodynamic measurements, other potential drawbacks of the present study are firstly the inclusion of stable patients. This was done because the scope of this study was to assess the cardiovascular response during different treatment modalities and not the frequency of intradialytic hypotensive episodes *per se*, which would have necessitated a different study design. However, differences in vascular reactivity between different dialysis techniques are not limited to unstable dialysis patients, but can be very well studied in stable patients, as shown in earlier studies by others and by our group [1,2,3,19]. Secondly, during the different techniques, fluid was removed with relatively modest ultrafiltration rates until dry weight. Haemodynamic differences might be more pronounced if more aggressive ultrafiltration would have been applied. However, in previous studies, we were able to show clear differences in the blood pressure response between different dialysis modalities using the same approach [19]. Moreover, the number of patients included was relatively small, although we and others [1,2,3,14] have shown profound haemodynamic differences between various dialysis modalities using approximately the same number of patients. In the

present study, we performed ear thermometry in order to investigate changes in core temperature, which may have yielded less precise results compared to our earlier studies, in which core temperature was measured by direct blood temperature monitoring. However, for technical reasons, this was not possible in the present study.

No differences in sodium, potassium and calcium balances were observed between on-line HF and HD, though, due to the inherent variability of the electrolyte measurements, the results should be interpreted with caution. However, no difference in conductivity balance was observed between the two techniques. Moreover, sodium concentration in spent dialysate and filtrate were nearly equal, whereas plasma sodium concentrations did not change during HF treatment. All these factors argue against hypotonic fluid removal during pre-dilution on-line HF.

Interestingly, we were able to calculate sodium mass balance during HF, yielding results that were highly significantly related to ultrafiltration volume, which is a necessity for the reliability of sodium balance measurements. However, the relation between ultrafiltration volume and sodium balance during HD was, although significant, far less strong. Thus, especially during HD, the results should be interpreted with caution. The reason for the lesser reliability of sodium balance measurements during HD is not clear but might be related to the higher volumes used in the formula for dialysate, augmenting errors due to the variation of the sodium measurements.

Our findings are in some contrast with an earlier study showing hypotonic fluid removal by pre-dilution HF [8]. On the other hand, David *et al.* [10] showed a reduction in sodium sieving during pre-dilution compared to post-dilution HF. Locatelli *et al.* [8] also observed a reduction in the Donnan factor (α) using pre-dilution HF. In the present study, we used far higher infusion volumes than in the study of Locatelli *et al.*, which because of the large dilution, is likely to have resulted in a lesser effect on α .

We chose to perform balance studies by the collection method instead of studies on electrolyte sieving, as the latter may change during the filtration treatment due to progressive protein adhesion to the artificial membrane. Indeed, a progressive rise of TMP, especially during the last hour of the HF treatment, may be a limiting factor in the prescription of the quantity of the filtration volume. This occurred in some of our patients and explains why the filtration volume achieved during on-line HF was, in individual cases, less than the prescribed volume.

Though not of direct relevance for the haemodynamic response, we also estimated phosphate removal, which was also not different between HD and HF. These results are in agreement with an earlier study comparing phosphate removal between conventional HF and HD [20]. Despite the fact that phosphate clearance is expected to be higher with the use of the larger and more permeable membrane during HF, phosphate removal might be influenced by restrictions

in phosphate transfer from different body compartments to the intravascular compartment [20] and by the limitations in the filtration volume.

In summary, using the saline dilution method, no difference in the change in CO and PVR was observed between on-line HF and HD^{36.5} and HD^{35.5}. Only CBV declined to a slightly, but significantly, lesser degree during HD^{35.5}.

In contrast, the change in PVR during the different dialysis strategies was strongly and inversely related to the change in CBV, which was in turn related to ultrafiltration rate and the change in RBV. Thus, the change in PVR, as measured by the saline dilution technique, appeared more dependent upon the degree and rapidity of fluid removal than upon the treatment modality. However, results should be interpreted with caution, as the saline dilution technique may fail to detect local differences in vascular tone. No difference in small electrolyte balance was observed between HF and HD, suggesting that ionic removal is not impaired during on-line pre-dilution HF.

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Conflict of interest statement. None declared.

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