Nephrol Dial Transplant (2003) 18: 1353–1360
DOI: 10.1093/ndt/gfg171

Nephrology Dialysis Transplantation

Original Article

Characteristics of hypotension-prone haemodialysis patients: is there a critical relative blood volume?

Claudia Barth[1], Walter Boer[2], Daniela Garzoni[3], Thomas Kuenzi[4], Wolfgang Ries[5], Ralf Schaefer[6], Daniel Schneditz[7], Theoharis Tsobanelis[8], Frank van der Sande[9], Ralf Wojke[10], Holger Schilling[10] and Jutta Passlick-Deetjen[10]

[1]KfH Dialysis Centre Koeln-Lindenthal, [5]Diakonissenkrankenhaus Flensburg, [6]KfH Dialysis Centre Marl, [8]KfH Dialysis Centre Frankfurt-Roedelheim and [10]Fresenius Medical Care, Bad Homburg, Germany, [2]University Hospital Utrecht and [9]University Hospital Maastricht, The Netherlands, [3]Kantonsspital St Gallen and [4]Stadtspital Waid Zürich, Switzerland and [7]Renal Research Institute, New York, USA

Abstract

Background. Intradialytic morbid events (IME, mostly hypotension) mainly due to ultrafiltration-induced hypovolaemia still are the most frequent complication during haemodialysis (HD). This study was performed to test the hypothesis that there is an individual critical relative blood volume (RBV_{crit}) in IME-prone HD patients.

Methods. In this prospective international multicentre study, 60 IME-prone patients from nine dialysis centres were observed during up to 21 standard HD sessions without trial-specific intervention. The RBV was monitored continuously by an ultrasonic method (BVM; blood volume monitor). Also, the ultrafiltration rate was registered continuously. Blood pressure was measured at regular intervals, and more frequently during IME. All IME and specific therapeutic interventions were noted.

Results. In total, 537 IME, some with more than one symptom, were documented during 585 HD sessions. The occurrence of IME increased up to 10-fold from the start to the end of the HD session. RBV_{crit} showed a wide inter-individual range, varying from 71 to 98%. However, the intra-individual RBV limit was relatively stable, with an SD of $<5\%$ in three-quarters of the patients. In patients with congestive heart failure, cardiac arrhythmia, advanced age, low ultrafiltration volume and low diastolic blood pressure, higher values of RBV_{crit} were observed. While all correlations between RBV_{crit} and patient characteristics alone were found to be of weak or medium strength, the combination of diastolic blood pressure, ultrafiltration volume and age resulted in a strong correlation with RBV_{crit}: the linear equation with these parameters allows an estimation of RBV_{crit} in patients not yet monitored with a BVM.

Conclusions. An individual RBV limit exists for nearly all patients. In most IME-prone patients, these RBV values were stable with only narrow variability, thus making it a useful indicator to mark the individual window of haemodynamic instabilities.

Keywords: haemodialysis; hypotension; hypovolaemia; intradialytic morbid events; relative blood volume; relative blood volume limit

Introduction

Intradialytic morbid events (IME), often a drop of blood pressure, are still the most frequent complication during haemodialysis (HD) treatment. This causes discomfort, reduces treatment efficacy and, thus, increases morbidity of the patients. Repeated severe symptomatic hypotension might result in brain and cardiac tissue damage, and correlates with long-term cardiovascular problems. These IME also contribute to increased monitoring and workload of nurses and physicians, thereby increasing treatment costs. The number of IME has not decreased despite considerable technical progress in HD during the last years [1,2].

Various factors contributing to IME have been discussed: underlying and concomitant diseases compromise the autonomic nervous system and the hormonal response. Medication and fluid status influence the adequate cardiovascular compensatory mechanisms, such as vascular compliance, venous capacity and cardiac function. During HD treatment, the fast removal of intravascular fluid, a slow refilling rate, an increase in body temperature, components of the

Correspondence and offprint requests to: Dr Ralf Wojke, Fresenius Medical Care Deutschland GmbH, Else-Kroener-Straße 1, D-61352 Bad Homburg, Germany. Email: Ralf.Wojke@fmc-ag.de

dialysis fluid (buffer, water and electrolytes), etc. may cause haemodynamic instability [1,3]. However, ultrafiltration leading to hypovolaemia is considered the main factor causing an acute decrease of blood pressure during HD treatment [4].

Continuous measurements of the relative blood volume (RBV) have confirmed hypovolaemia as the pivotal cause of arterial hypotension. Most patients showed symptomatic hypotension below a blood volume of 50 ml/kg body weight [5]. An individual limit for each patient to develop symptomatic hypotension was then postulated [6].

If such an individual limit does exist, then, by setting off an alarm and stopping ultrafiltration, IME may be prevented prior to the event, instead of applying measures after the event, as is usually carried out.

A further step is an algorithm which adapts the ultrafiltration rate to the decline in blood volume in each individual patient and, thereby, avoids the individual critical blood volume at which IME develops is reached.

The purpose of this study was to find an individual limit (RBV_{crit}) for each patient under strictly unchanged and individually standardized treatment conditions, and to investigate whether the intra-individual variability of this limit is small enough to use RBV_{crit} as a cut-off value predictive for hypotensive episodes to make the algorithm work. Secondly, the question was asked whether certain groups of patients (such as diabetics, patients with cardiac problems, aged patients or obese patients) show distinct patterns of critical blood volume behaviour.

Subjects and methods

Study design and patients

The study was designed as an open, non-controlled prospective multicentre trial. Nine dialysis units in Germany (four), Switzerland (two), The Netherlands (two) and the USA (one) participated in the study. The study was purely observational; the standard HD treatment prescription of the participating patients remained unchanged. The ultrafiltration rate was kept constant.

Local legal and administrative regulations were followed, and approval of the respective Ethics Committees was obtained.

All patients took part in the study voluntarily after giving written informed consent. Included were adult patients with end-stage renal disease, treated by intermittent HD three times a week during the last 3 months, and with a high rate of IME (at least four IME in the preceding 4 weeks).

An IME was defined in this study as a decrease in systolic blood pressure or a typical symptom (e.g. cramps, dizziness, vomiting, and in rare circumstances also loss of consciousness), severe enough to be treated by a medical intervention (e.g. stopping ultrafiltration, change in body position, saline administration). Neither a typical symptom nor a medical intervention alone (e.g. for prevention) was counted as an IME.

Besides the standard exclusion criteria (pregnancy, breastfeeding mother, infectious diseases, simultaneous participation in another clinical trial), trial-specific exclusion criteria were treatment regimens with varying dialysate sodium or planned changes in dialysate composition (due to expected changes in sodium balance) and/or erythropoetin dosage (due to expected changes in haematocrit) to keep constant those factors which might influence the blood volume.

Study parameters

Patient characteristics (such as age, gender, height and weight), medical history and co-morbid diseases [arterial hypertension, diabetes mellitus, congestive heart failure, cardiac arrhythmia, coronary heart disease, chronic hypotension (systolic blood pressure <100 mmHg), autonomic neuropathy and peripheral arterial occlusive disease] were recorded by the physician.

During the HD treatment the following parameters were monitored and documented:

(i) The blood volume was monitored continuously with a blood volume monitor (BVM). The BVM is a device which (after functional self-test and calibrating) continuously evaluates the RBV by measuring the blood density with ultrasound. An ultrasound transmitter produces sound pulses, and these pulses are then received on the opposite side of a cuvette integrated in the arterial line set. The blood density is determined from the transient time of the sound pulse through the blood sample. This device (described in detail elsewhere [7,8]) measures non-invasively, and has a high accuracy. The blood volume is expressed as a percentage of the starting blood volume, i.e. RBV.

(ii) The blood pressure was measured by a blood pressure monitor (BPM) every 30 min and additionally measurement was triggered manually during hypotensive events. BVM and BPM are both modules of the HD machine (Fresenius Medical Care, Europe: 4008, USA: 2008 H).

(iii) In addition to the RBV and the blood pressure, HD machine data such as blood flow rate, dialysate flow rate, ultrafiltration rate and volume were collected on-line by a connected PC.

(iv) All IME (as defined above) were recorded carefully in writing by the attending nurse.

Statistical evaluation

All data were entered into a database; statistical analysis was performed using SPSS for Windows, version 10.0.

Analyses were carried out by χ^2 test, Student's *t*-test, Mann–Whitney U-test, Wilcoxon signed rank test and correlation tests (Pearson, Kendall and Spearman) where appropriate.

Results are presented as mean $\pm$ SD. Correlation was classified as weak for $0.2 \leqslant |r| < 0.4$, medium for $0.4 \leqslant |r| < 0.6$, and strong for $|r| \geqslant 0.6$. Simple and multiple regression analyses were applied to examine the relationship between RBV_{crit} and various parameters. Predictors with at least a weak correlation were pooled and selected by a stepwise procedure with forward inclusion.

Results

Study population

Sixty IME-prone HD patients (37 females, 23 males) were enrolled. Their mean time on HD treatment was 3.3 ± 3.1 years (range 0–21 years). In addition to

Table 1. Concomitant diseases in the study population

	Prevalence (% of all patients)	Prevalence (% of female patients)	Prevalence (% of male patients)
Hypertension	64.4	75.0	47.8
Diabetes mellitus	44.1	55.6	26.1
Congestive heart failure	28.8	25.0	34.8
Coronary heart disease	27.1	27.8	26.1
Peripheral arterial occlusive disease	25.4	30.6	17.4
Autonomous neuropathy	18.6	22.2	13.0
Cardiac arrhythmia	15.3	13.9	17.4
Chronic hypotension	5.1	0.0	13.0

end-stage renal failure, they suffered from concomitant diseases: 90% of the patients had at least one concomitant disease, and 38% of the patients more than two concomitant diseases. We found a high prevalence of arterial hypertension and diabetes mellitus in the study population of IME-prone patients, both diseases being more frequent in females than in males (Table 1).

Although the males were taller and heavier, the average body mass index (BMI) was without significant differences between the two genders.

The mean systolic blood pressure measured at the start of the HD treatment was higher in females than in males, whereas the mean diastolic blood pressure did not show significant differences between genders (see Table 2).

Compared with non-diabetic patients, diabetic patients revealed a higher BMI and presented with higher blood pressure values. The mean systolic blood pressure measured at the start of the HD treatment was significantly higher in patients with diabetes mellitus compared with those without this disease, whereas the differences in the mean diastolic blood pressure was not significantly different (see Table 2).

Treatment

During the study, an average of 10 ± 6 HD sessions (range 2–21) per patient were documented. The mean duration of the sessions was 239 ± 37 min. The average ultrafiltration volume relative to body weight did not differ for gender or prevalence of diabetes mellitus (see Table 2).

IME

A total of 537 IME were registered during 585 HD sessions; on average, 0.92 events occurred per treatment. Some IME exhibited multiple symptoms (760 symptoms in total, see Table 3). Two-thirds of these symptoms were hypotension; other symptoms were muscle cramps, dizziness, nausea, headache and vomiting. The remaining symptoms (e.g. sweating, light headedness and unconsciousness) were reported as $<1\%$ of the number of symptoms and were therefore not listed in detail.

Figure 1 shows the frequency of IME during the HD session: it increased up to 10-fold from the start to the end of the HD session.

In 45% of the HD sessions, no IME, and in 31%, only a single IME, occurred, whereas multiple IME were reported in 23% of the treatments, with a maximum of five IME per HD session (see Table 4).

Critical relative blood volume

All individual time courses of all HD sessions were analysed, and an individual RBV_{crit} was calculated as an average of the RBV at all IME of each patient. The data are presented in Figure 2.

RBV_{crit} could be calculated for 58 out of 60 patients. Two patients did not experience IME during the HD sessions which were monitored by the BVM. RBV_{crit} presented with a wide inter-individual variability between the patients, varying from around the initial value of 100% down to 71%. The mean RBV_{crit} of all

Table 2. Patient characteristics according to gender and diabetes mellitus

	All patients	Female patients	Male patients	*P* (gender)	Patients with DM	Patients without DM	*P* (DM)
Distribution (%)	100	62	38		57	43	
Age (years)	66 ± 11	65 ± 11	68 ± 11	0.34	64 ± 8	68 ± 12	0.11
Weight (kg)	73 ± 16	71 ± 15	78 ± 15	0.11	77 ± 3	71 ± 3	0.05
BMI (kg/m^2)	26.6 ± 4.9	26.8 ± 5.2	26.2 ± 4.6	0.70	28.1 ± 3.9	25.4 ± 5.3	0.04
UFV (% of weight)	3.7 ± 1.4	3.6 ± 1.3	3.9 ± 1.5	0.47	3.8 ± 1.3	3.7 ± 1.5	0.15
sBP (mmHg)	147 ± 25	152 ± 24	136 ± 24	0.01	155 ± 28	140 ± 22	0.03
dBP (mmHg)	82 ± 18	84 ± 19	78 ± 17	0.23	85 ± 19	78 ± 17	0.12
RBV_{crit} (%)	88.7 ± 6.2	88.8 ± 5.9	88.6 ± 6.9	0.77	88.7 ± 6.2	88.8 ± 6.4	0.50
IME per HD session	1.1 ± 0.7	1.1 ± 0.8	1.0 ± 0.7	0.50	1.2 ± 0.8	0.9 ± 0.7	0.06

sBP/dBP, systolic/diastolic blood pressure at start of treatment; UFV, ultrafiltration volume (relative to dry weight). All values are given as mean $\pm$ SD.

Table 3. Summary of 760 reported symptoms during 537 intradialytic morbid events

Symptom	Frequency	Frequency (%)
Hypotension	508	66.8
Cramps	99	13.0
Dizziness	36	4.7
Nausea	23	3.0
Headache	15	2.0
Vomiting	13	1.7
Others	66	8.7
Total	760	100.0

Table 4. HD sessions with no, one and multiple intradialytic morbid events (IME)

No. of HD sessions	No. of IME per session	Frequency (%) of all sessions
265	0	45.3
183	1	31.3
79	2	13.5
41	3	7.0
12	4	2.1
5	5	0.9

patients was $88.7 \pm 6.2\%$. As shown in Table 5, 90% of the patients have an RBV_{crit} of between 80 and 100%, and about half of the patients between 80 and 90%.

These individual values showed narrow variability (Table 6). In 20% of our study population, an SD of $\leqslant 2\%$ was observed and, for $>75\%$ of the patients, the SD remained within 5%, indicating a relatively stable individual RBV_{crit}.

Predictive factors for IME

The mean number of IME per HD session tended to increase with body weight ($r = 0.23$, $P = 0.08$) and correlated with the BMI ($r = 0.40$, $P < 0.01$) of the patient. Low systolic ($r = -0.25$, $P = 0.06$) and diastolic blood pressure ($r = -0.21$, $P = 0.11$) at the end of the HD treatment showed a trend to correlate with the rate of IME. Diabetic patients were prone to more IME per treatment than non-diabetic patients (1.22 ± 0.75 *vs* 0.96 ± 0.71, $P = 0.06$). In the study population, no association was found between the rate of IME and gender, patient age or blood pressure at the beginning of HD.

Predictive factors for RBV_{crit}

Concerning patient characteristics, RBV_{crit} correlated with the age of the IME-prone patients ($r = 0.40$, $P < 0.01$): RBV_{crit} was generally high in elderly patients. A high RBV_{crit} was also seen for mean low diastolic blood pressure values at the beginning ($r = -0.45$, $P < 0.01$) and at the end ($r = -0.41$, $P < 0.05$) of the HD session, reflecting less haemodynamic stability. Gender, dry weight, BMI and mean systolic blood pressure (pre- and post-dialytic) showed no correlation to RBV_{crit}.

Concerning concomitant diseases, a higher RBV_{crit} was found in patients with congestive heart failure (92.0 ± 3.3 *vs* 87.6 ± 6.7, $P < 0.01$) and cardiac arrhythmia (94.0 ± 4.8 *vs* 87.8 ± 6.1, $P < 0.01$). Diabetes, coronary heart disease, chronic hypotension, autonomic neuropathy and peripheral arterial occlusive disease were not identified as predictors of RBV_{crit}.

Concerning treatment parameters, the following correlation was found: patients with a high mean ultrafiltration volume V_{UF} (relative to body weight) tend to tolerate a lower RBV_{crit} ($r = -0.41$, $P < 0.01$) than patients with less interdialytic weight gains.

All correlations between RBV_{crit} (as the dependent variable) and the above-mentioned parameters alone

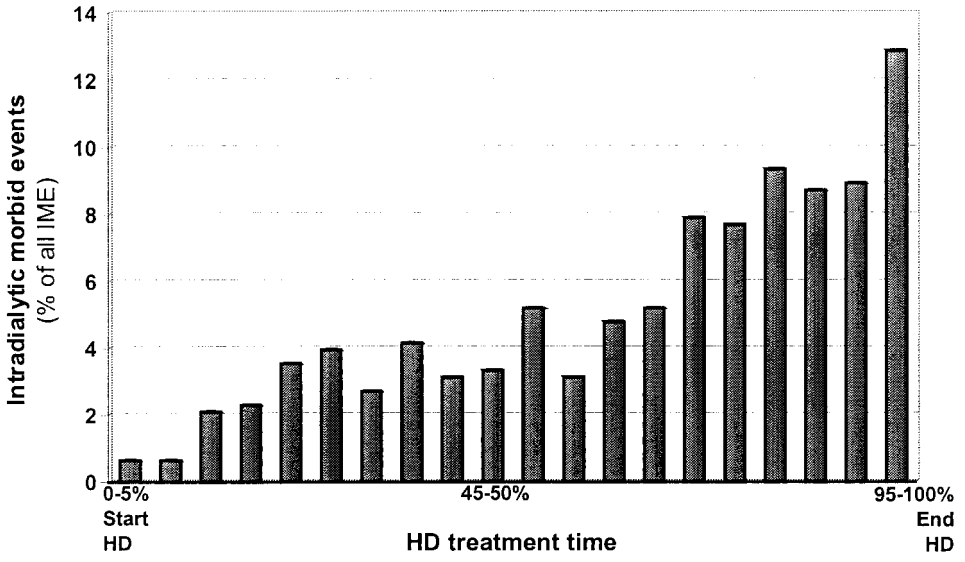

Fig. 1. Distribution of intradialytic morbid events (IME) over the HD session. Each bar represents the percentage of IME in the indicated 5% of the delivered treatment time.

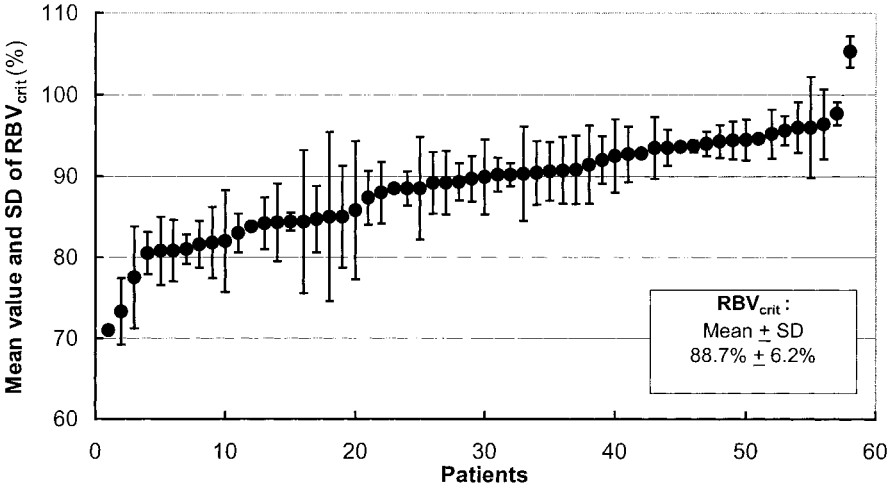

Fig. 2. Individual RBV_{crit} of all patients with intradialytic morbid events (IME). RBV_{crit} was calculated as the average of all RBV measurements during IME of the individual patient ($n = 58$).

Table 5. Cumulative patient distribution of the individual RBV_{crit}

RBV_{crit}	No. of patients	No. of patients (%)
$\leqslant 80$	3	5.0
$\leqslant 85$	19	31.7
$\leqslant 90$	30	50.0
$\leqslant 95$	51	85.0
$\leqslant 100$	57[a]	95.0[a]

[a]One patient with $RBV_{crit} > 100\%$, and two patients without RBV_{crit} during the observation period.

Table 6. Cumulative intra-individual variability of RBV_{crit}

SD	No. of patients	Sum (%)
$\leqslant \pm 1\%$	4	6.7
$\leqslant \pm 2\%$	12	20.0
$\leqslant \pm 3\%$	24	40.0
$\leqslant \pm 4\%$	35	58.3
$\leqslant \pm 5\%$	46	76.6
$\leqslant \pm 6\%$	47	78.3
All patients	60	100.0

Mean ± SD: 3.6 ± 2.1%.

were found to be of only weak or medium strength. Combined in a general linear model which encompasses both analysis of variance and regression with quantitative covariates (e.g. blood pressure, ultrafiltration volume, age) and qualitative fixed factors (e.g. prevalence of a co-morbid disease), the following strong correlation was found ($r = 0.65$, no case-mix adjustment):

$$RBV_{crit} = 97.8 - 0.08\,dBP - 1.4\,V_{UF}/Wt + 0.05\,age + 1.5\,arrh + 0.2\,CHF$$

where RBV_{crit} is the critical relative blood volume limit of an individual patient (%); dBP is the mean diastolic blood pressure at the start of dialysis (mmHg); V_{UF} is the mean ultrafiltration volume (l); Wt is the body weight of the patient's (kg); age is the age of the patient (years); arrh is the prevalence of cardiac arrhythmia (0 for absent, 1 for existent) and CHF is the prevalence of congestive heart failure stage I–IV (0 for absent, 1 for existent).

The RBV_{crit} values calculated from this equation were equivalent to the empirically found values within ±3% for the majority of patients (56.7%). For those 90% of the patients, who have an RBV_{crit} between 80 and 96%, the given equation describes RBV_{crit} rather accurately (the mean SD between calculated and measured RBV is 3.0%), whereas for patients with a very high or low RBV_{crit}, larger deviations between measurement and calculation are observed (see Figure 3).

Discussion

For the study population of IME-prone HD patients, we found a large inter-individual variability of the RBV_{crit}, whereas the intra-individual variability of the RBV_{crit} was small. The reason for these findings might be explained by both patient characteristics and treatment-specific parameters. While the vulnerability of patients with certain co-morbid diseases has to be accepted as a given fact, the specific treatment parameters (e.g. ultrafiltration, length of the session, sodium balance) might, at least partially, have an effect.

Hypovolaemia is the most important factor in the induction of arterial hypotension [4,5]. Drops in blood pressure are often paralleled by reductions in RBV [9,10]. However, hypotension during dialysis is not related solely to ultrafiltration; indeed isolated ultrafiltration without a simultaneous dialysis was a traditional method to avoid the risk of hypotension. Meanwhile, it is known that during isolated ultrafiltration, the body temperature decreases, while it increases

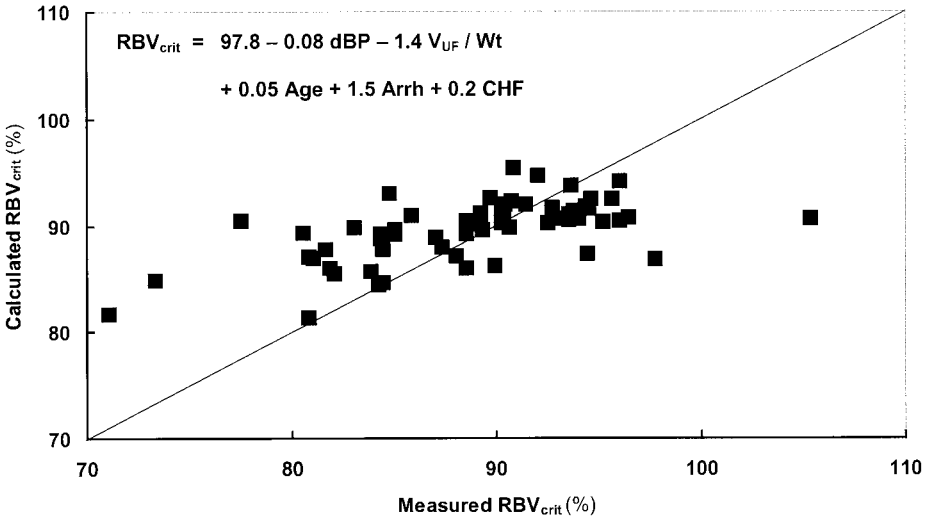

Fig. 3. Measured and calculated RBV_{crit}. The measured RBV_{crit} is derived from the intradialytic morbid events of the individual patient ($n = 58$). The calculated RBV_{crit} is derived from the formula (see above); the line of identity is indicated.

during conventional HD [11], and changes in the body temperature influence cardiovascular stability [3].

Ultrafiltration during HD treatment obviously generates hypovolaemia via reduction of RBV. The plasma refilling rate often increases in correlation to the ultrafiltration rate depending on the hydration status to counteract intravascular volume depletion [12]. IME mostly occur at the end of the HD session, close to dry weight and decreased plasma refilling rate. The cessation of ultrafiltration produces an increase of the RBV, and an increase in blood pressure.

In our study population of IME-prone patients, 60% of the patients suffered from hypertension. The increased systolic blood pressure values in women compared with men may be partly attributed to the fact that more diabetics (in whom higher mean blood pressure was also observed) were found among women (prevalence 56 *vs* 26%, see Table 1). The tendency to IME may be due to the fact that the autonomous nervous system and blood pressure regulation are impaired in diabetic patients. Patients with higher BMI also were especially susceptible to IME.

Our results confirm clinical knowledge of the elderly dialysis patient. These patients seem to have a low tolerance to volume changes since the intradialytic events occur at relatively high values of RBV_{crit}. This might possibly be due to the higher morbidity of these patients especially of the cardiovascular system, since congestive heart failure and cardiac arrhythmia were associated with a higher RBV_{crit}. Low pre-dialytic diastolic blood pressure may also be indicative for particular vulnerability to IME. This may be due to the low compliance of the vascular system because of calcification and stiffness of the vessels [13].

RBV_{crit} is a highly individual value (see also Donauer *et al.* [14]). Examples of totally different courses of the RBV during the dialysis session of two patients, a modest and an extreme decrease of RBV, are shown in Figure 4A and B. The diabetic patient experienced three IME in the RBV range above 89%. The RBV of the non-diabetic patient decreased to 65% before hypotension and severe muscle cramps made several interventions necessary. Since the critical RBV is highly individual, it does not seem feasible to start with monitoring towards a general limit but, for each patient, RBV_{crit} has to be determined carefully like the dry weight.

In a small-scale investigation, Stiller *et al.* [15] showed that the continuous monitoring of RBV to control the ultrafiltration reduces the frequency of IME. In a recent study, it was shown that control of both ultrafiltration and dialysate conductivity based on the current RBV leads to improved intradialytic cardiovascular stability [16].

Monitoring of RBV can be used as an appropriate method to detect overhydration. Overhydrated patients show a characteristic, seemingly paradoxical RBV behaviour during treatment: they have only a small decrease, sometimes even an increase, in RBV. Lopot *et al.* [17] detected that 30% of the patients showed no decrease in RBV during treatments: RBV remained constantly at $\sim 100\%$, indicating overhydration. We found one patient in our population whose behaviour corresponded to this (see Figure 2). Subsequently, Lopot reduced the dry weight of these patients, and finally found normal behaviour with decreasing RBV values.

In conclusion, our results, in accordance with the results of other authors, demonstrate that the continuous measurement of the RBV may be of clinical and practical importance in IME-prone HD patients. RBV_{crit} seems to mark the individual limit of cardiovascular stability. For IME-prone patients, a first approximation for RBV_{crit} might be determined by a simple equation (including the patient's age, mean diastolic blood pressure at the start of the HD treatment, mean ultrafiltration volume and cardiac comorbid diseases). By taking the calculated RBV_{crit} into

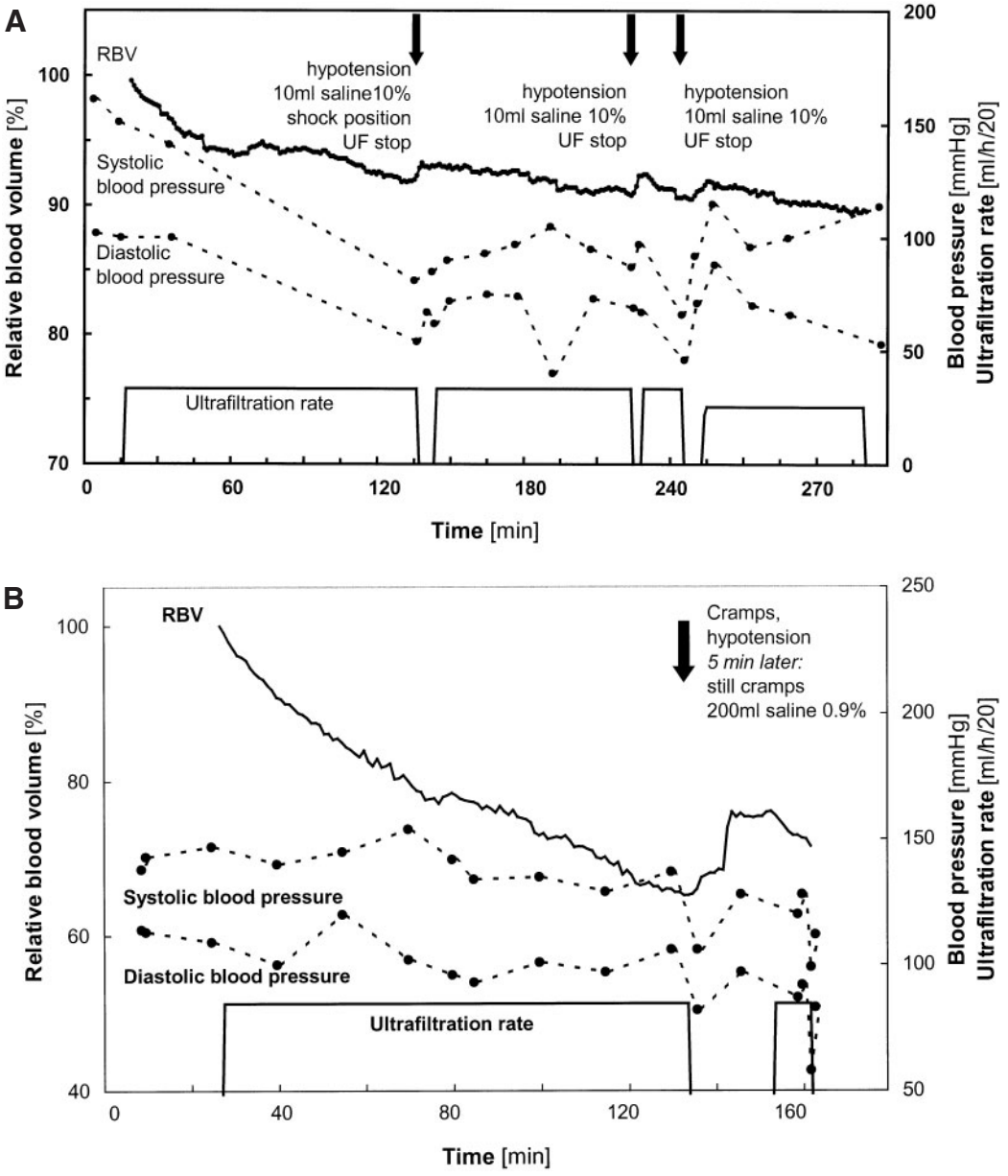

Fig. 4. Haemodialysis sessions of individual patients. The patients experienced three (**A**) or one (**B**) intradialytic morbid events, respectively. These two examples demonstrate the inter-individual variability of the RBV and the individual reaction of the patient to the dialysis regimen. Some patients may even tolerate a reduction of RBV by one-third (B).

account during the adjustment of the ultrafiltration rate, IME should be reduced. Moreover, patients with chronic fluid overload can be identified by RBV.

Due to the narrow variability of the critical RBV, we think that, during further treatment sessions, monitoring of RBV and timely reduction of ultrafiltration are useful to prevent IME and additional sodium load of the patient (due to reduced application of hypertonic saline). Certain dialysis patients might profit especially from ultrafiltration control according to the actual RBV measurements. Our data identify elderly patients, diabetic patients and females with high systolic blood pressure and high BMI as possible target groups to take special advantage of close RBV monitoring.

To clarify some of the open issues, the prospective IVORIC study with a multiple cross-over design (constant ultrafiltration rate *vs* blood volume-controlled ultrafiltration rate) was launched. The objective is to investigate whether the determination of the individual critical RBV followed by RBV-controlled ultrafiltration may help to reduce symptomatic hypotension. Preliminary results are promising [18].

Acknowledgements. This study received financial support by Fresenius Medical.

Conflict of interest statement. C.B. holds stock in Fresenius Medical Care, D.S. is currently conducting

research sponsored by Fresenius Medical Care, R.W. is an employee of Fresenius Medical Care and holds stock, H.S. was an employee of Fresenius Medical Care at the time of study and J.P.-D. is an employee of Fresenius Medical Care.

References

1. Daugirdas JT. Preventing and managing hypotension. *Semin Dial* 1994; 7: 276–283
2. Daugirdas JT. Pathophysiology of dialysis hypotension: an update. *Am J Kidney Dis* 2001; 36: 11–17
3. Maggiore Q *et al*. The effect of control of thermal balance on vascular stability in hemodialysis patients: results of the European randomized clinical trial. *Am J Kidney Dis* 2002; 40: 280–290
4. Boggard HJ, De Vries JPPM, De Vries PMJM. Assessment of refill and hypovolaemia by continuous surveillance of blood volume and extracellular fluid volume. *Nephrol Dial Transplant* 1994; 9: 1283–1287
5. Kim KE, Neff M, Cohen B *et al*. Blood volume changes and hypotension during hemodialysis. *Trans Am Soc Artif Intern Org* 1970; 16: 508–514
6. Steuer R, Leypoldt JK, Cheung AK *et al*. Hematocrit as an indicator of blood volume and a predictor of intradialytic morbid events. *ASAIO J* 1994: M691–M696
7. Schneditz D, Pogglitsch H, Horina J, Binswanger U. A blood protein monitor for the continuous measurement of blood volume changes during hemodialysis. *Kidney Int* 1990; 38: 342–346
8. Johner C, Chamney PW, Schneditz D, Kraemer M. Evaluation of an ultrasonic blood volume monitor. *Nephrol Dial Transplant* 1998; 13: 2098–2103
9. Lins LE, Hedenborg G, Jacobson SH *et al*. Blood pressure reduction during hemodialysis correlates to intradialytic changes in plasma volume. *Clin Nephrol* 1992; 37: 308–313
10. Ronco C, Bellomo R, Ricci Z. Hemodynamic response to fluid withdrawal in overhydrated patients treated with intermittent ultrafiltration and slow continuous ultrafiltration: role of blood volume monitoring. *Cardiology* 2001; 96: 196
11. Keijman J, van der Sande F, Kooman J, Leunissen K. Thermal energy balance and body temperature; comparison between isolated ultrafiltration and haemodialysis at different dialysate temperatures. *Nephrol Dial Transplant* 1999; 14: 2196–2200
12. Mann H, Stiller S, Gladziwa U, Königs F. Kinetic modelling and continuous on-line blood volume monitoring during dialysis therapy. *Nephrol Dial Transplant* 1990; [Suppl 1]: 144–146
13. Blacher J, Guerin A, Pannier B, Marchais S, London G. Arterial calcifications, arterial stiffness, and cardiovascular risk in end-stage renal disease. *Hypertension* 2001; 38: 938–942
14. Donauer J, Koelbin D, Bek M, Krause A, Boehler J. Ultrafiltration profiling and measurement of relative blood volume as strategies to reduce hemodialysis-related side effects. *Am J Kidney Dis* 2000; 36: 115–123
15. Stiller S, Mann H. Less symptomatic hypotension using blood volume controlled ultrafiltration. *Trans Am Soc Artif Intern Org* 1991; 37: 139–141
16. Santoro A *et al*. Blood volume controlled hemodialysis in hypotension-prone patients: a randomized, multicenter controlled trial. *Kidney Int* 2002; 62: 1034–1045
17. Lopot F, Kotyk P, Blaha J, Forejt J. Use of continuous blood volume monitoring to detect inadequately high dry weight. *Int J Artif Org* 1996; 19: 411–414
18. Boer W *et al*. Less intradialytic complications with blood volume control. *Nephrol Dial Transplant* 2002; 17 [Suppl 1]: M284

Received for publication: 5.8.02
Accepted in revised form: 5.2.03