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CKJ Review

Optimization of the convection volume in online post-dilution haemodiafiltration: practical and technical issues

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Abstract
In post-dilution online haemodiafiltration (ol-HDF), a relationship has been demonstrated between the magnitude of the convection volume and survival. However, to achieve high convection volumes (>22 L per session) detailed notion of its determining factors is highly desirable. This manuscript summarizes practical problems and pitfalls that were encountered during the quest for high convection volumes. Specifically, it addresses issues such as type of vascular access, needles, blood flow rate, recirculation, filtration fraction, anticoagulation and dialysers. Finally, five of the main HDF systems in Europe are briefly described as far as HDF prescription and optimization of the convection volume is concerned.

Keywords: convection volume; haemodiafiltration

EUDIAL objective

The general objective assigned to the EUropean DIALysis (EUDIAL) Working Group by the European Renal Association - European Dialysis and Transplant Association (ERA-EDTA) was to enhance the quality of dialysis therapies in Europe in the broadest possible sense. Given the increasing interest in convective therapies, the Working Group has started by focusing on haemodiafiltration (HDF) therapies. A EUDIAL consensus conference was held in Paris on 13 October 2011 to discuss definitions, safety standards, clinical outcome and educational issues. Since then, two reports of the EUDIAL group have been published. While the first report revisited the definition, dose quantification and safety of HDF [1], the second report described the relation between HDF and clinical outcome in a systematical review and meta-analysis [2]. In this report, various practical problems and pitfalls are discussed which are encountered when aiming for high convection volumes.

Introduction

Convective therapies are increasingly used in patients with end-stage kidney disease (ESKD) because of their capacity to remove middle molecular weight (MMW) uraemic toxins, such as β2 microglobulin (B2M) [3–6]. In high-flux haemodialysis (HD), the amount of convection is limited to <10 L per session [7] due to obligate backfiltration [8] to ensure volume balance. Owing to the development of sophisticated water treatment systems and online production of dialysate, the convection volume can reach much higher values in haemodiafiltration (HDF) [9]. Online produced substitution fluid can be delivered before the dialyser (pre-dilution HDF), after the dialyser (post-dilution HDF), both before and after the dialyser (mixed-dilution HDF) or in the middle of the dialyser (mid-dilution HDF). A detailed description of the dissimilarities and potential indications of these various HDF modalities can be found elsewhere as it is beyond the scope of the present manuscript [10]. As online post-dilution HDF is currently the preferred HDF modality in clinical practice worldwide, we will focus on this type of HDF in this review, in the following paragraphs abbreviated to ol-HDF [11]. In three large randomized controlled trials (RCT) comparing ol-HDF with either low- [12] or high-flux HD [13, 14], a stepped relationship was found between the magnitude of the convection volume and survival, making convection volume one of the key parameters of ol-HDF dosing and prescription [1, 15]. Just performing ol-HDF does not automatically result in

high convection volumes. In the CONvective TRAnsport STudy (CONTRAST) [12], the target convection volume of 24 L per treatment was reached in only 22% of the patients. For optimization, notion of its determining factors is essential. Recently, the CONTRAST group showed that treatment-related parameters, such as blood flow rate and treatment time, are most decisive in this respect, while patient characteristics, including albumin and haematocrit, play only a minor role [16]. To assess the probability of dose-targeting bias, this study also examined whether subjects achieving high-volume HDF were typified by a more healthy profile at baseline. Except for some variation in body size, patient characteristics did not differ across tertiles of convection volume. Therefore, beforehand, no distinctive patient profile identifies individuals most eligible for high-volume ol-HDF, although it seems plausible that larger patients can achieve higher convection volumes more easily than smaller subjects. As marked differences in the average convection volume were found between participating centres, together these findings support the idea that centre policy rather than patient characteristics determines the magnitude of the convection volume in everyday clinical practice [17].

Finally, filtration fraction (FF), which is a parameter unique to ol-HDF as it quantifies the relation between convective flow rate and blood flow rate, is also an important determinant for the amount of convection volume achieved [1]. The goal of this manuscript is to summarize the technical aspects and practical issues which are encountered when optimizing the convection volume in ol-HDF.

Optimization of convection volume in clinical practice

Practical and technical aspects of vascular access, needles and blood flow rate

As mentioned, besides treatment time, a high blood flow rate is crucial for obtaining a high convection volume [16]. Apart from individual patient characteristics, blood flow rate is mainly determined by the type of vascular access and the needles used.

Type of vascular access. Controversy exists as to whether patients with a central venous catheter (CVC) are eligible for ol-HDF. The Turkish HDF Study (THDFS) excluded patients with a CVC or patients who could not reach a blood flow >250 mL/min [14]. The Spanish ESHOL study excluded patients with a non-tunneled catheter [13], while CONTRAST did not exclude patients based on vascular access type [12]. A sub-study from the latter RCT demonstrated that patients with a CVC even had higher blood flow rates and higher convection volumes than those with an arterio venous fistula (AVF) or graft, which persisted after sensitivity analysis and adjustment for confounders [17]. Another study, however, showed that >21 L of convection volume was achieved in >84% of patients with AV shunts, and in only 33% of patients with a catheter [9]. Hence, it appears that an AV fistula or graft is preferable, but a catheter is not a contra indication for the performance of ol-HDF.

Needle size. For an AVF or a graft, the achievement of a high extracorporeal blood flow rate is not only dependent on the quality of the access, but also on the size of the needles used for puncture. Needle size is measured in gauges (G), which is derived from a standardized scaling system initially designed for iron wire manufacture and recently ratified by the International Organization for Standardization (ISO) of medical devices [18, 19]. The gauge of a needle refers to its outer diameter, while the inner diameter also depends on its wall thickness [20]. Standard values range from 14G to 18G (outer diameter 2.1 and 1.2 mm, resp.) [21].

Table 1. Matching blood flow rate and needle size

Set blood flow rate	Recommended needle gauge	Size equivalent[a] (mm)
<300 mL/min	17-gauge	1.5
300–350 mL/min	16-gauge	1.6
350–450 mL/min	15-gauge	1.8
>450 mL/min	14-gauge	2.1

Adapted from Fistula First Initiative's 'Cannulation of New Fistula Policy and Procedure' [25].
[a]Average cross-sectional outside diameter.

In several countries, the choice of a needle is made by the nursing staff, based on the type, vintage and expansion of the access, bleeding susceptibility, and preference of patients. As there is no evidence to support one practice over another, individual centre habits rather than proven advantages seem to play a crucial role. A common concern is that larger needles are associated with a poorer shunt outcome. However, in an observational study on predictors of unsuccessful puncture, the risk of complications was similar with 14G, 15G or 16G-needles, either used for an AVF or graft [22]. With the exception of initial cannulation, in most guidelines no specific gauge value is recommended and the sole statement made is that 'needle size should match the blood flow rate' [23]. Only in the Fistula First Initiative is a 15G-needle recommended for a blood flow between 350 and 450 mL/min (Table 1) [24].

Needle type. Indwelling cannulas are occasionally used instead of silicon-coated metal needles to decrease patients' discomfort or to allow some degree of movement. After puncture, the needle is removed while the covering catheter remains *in situ*. The size listed on these products corresponds to the central metal needle: a 16G catheter is one containing a 16G-metal needle (outer diameter). Once this needle is removed, the lumen for blood flow is roughly one-gauge greater than indicated on the packaging.

Single-needle post-dilution HDF. Given the current high convection volume goals, single-needle ol-HDF should not be encouraged. In single-needle systems, clamps on the arterial and venous lines are opened and closed alternately in order to pump blood from and to the patient through the same lumen. As a result, mean blood flow is lower than with a double-needle procedure. Moreover, as a result of the variable blood flow, both trans membrane pressure (TMP) and FF fluctuate uncontrollably, which may lead to an inadequate and unpredictable convection volume [26].

Access recirculation. When blood flow rate is increased, recirculation may occur [27]. This phenomenon is especially prominent in case of an insufficient arterial inflow, including low cardiac output, or obstruction in the venous outflow tract. As an increase in the size of the convection volume by recirculation is inefficient and undesirable, regular monitoring is advisable.

Effective versus set blood flow rates. It has been well established that the real blood flow rate is somewhat lower than the set value, and the higher blood pump speed, the wider the difference [25, 27]. This phenomenon is explained by partial collapse of the tubes at more negative pre-pump pressure. In addition, the type of access may also influence this discrepancy. In an elegant study, Canaud *et al.* showed that a set blood flow of 350 mL/min resulted in a markedly lower real blood flow in a CVC than in an AVF (316 ± 4 versus 342 ± 4 mL/min) [27]. Obviously, this phenomenon may be even more prominent in HDF because of a more negative pre-pump pressure than in conventional HD.

Practical and technical aspects of FF

Definition and recommendations. Strictly, FF is defined as 'the ratio of the ultrafiltration (UF) rate to the plasma water flow rate' [1], where UF represents the total amount of plasma water removed from the patient. In clinical practice however, blood flow rate (Q_b) is usually used as a surrogate for plasma water flow rate, as the former is readily available at the bedside. The formula proposed for clinical utilization and further used in this manuscript is the following:

$$\mathrm{FF} = \left(\frac{Q_{\mathrm{conv}}}{Q_{\mathrm{b}}}\right) \times 100 \tag{1}$$

or

$$\mathrm{FF} = \left[\frac{(Q_{\mathrm{subs}} + Q_{\mathrm{UF}})}{Q_{\mathrm{b}}}\right] \times 100 \tag{2}$$

where FF is in %, Q_{conv}, Q_{subs} and Q_{UF} are the convection flow rate, substitution flow rate and ultrafiltration flow rate, in mL/min (or L/h), respectively. It should be noted that UF refers to the actual quantity of UF programmed in the machine. This amount corresponds not only to the desired intra-dialytic weight loss, but also to the additional liquids removed during treatment to compensate for the priming procedure as well as oral and/or parenteral infusions (e.g. antibiotics or blood transfusion). The higher the FF, the greater the convection volume extracted from the blood. Because in post-dilution HDF substitution fluid is administered after the dialyser, haemoconcentration within the filter increases proportionately. As a result, fibre clotting and loss of membrane integrity with altered dialyser performance may occur [28]. In a recent report of the EUDIAL group [1], a FF of 20–25% was suggested. Nonetheless, values of up to 30% have been obtained using devices with automatic pressure-control [29, 30]. Currently, it is unknown whether FF is a useful tool to maximize convection volumes in every day clinical practice. If so, the desired convection (or substitution) flow rate can be found by rearranging equation (1) or (2):

$$Q_{\mathrm{conv}} = Q_{\mathrm{subs}} + Q_{\mathrm{UF}} = \mathrm{FF} \times \frac{Q_{\mathrm{b}}}{100} \tag{3}$$

An estimation of the final convection volume (V_{conv}) is shown in the equation:

$$V_{\mathrm{conv}} = Q_{\mathrm{conv}} \times \text{treatment time} \tag{4}$$

Caveats with the use of filtration fraction. First, as outlined before, set and real blood flow rates may diverge significantly at higher values. If FF calculation is based on the set value, the real FF may be underestimated. In order to provide an FF of 30% with a set blood flow of 400 mL/min, convective flow rate is (0.30 × 400) = 120 mL/min. If the real blood flow is 10% less, however, FF is actually higher: (120/[400 × 0.90] × 100) = 33.3%.

Second, as mentioned, actually FF is defined as 'the ratio of UF rate to the plasma water flow rate (Q_{pw})', which depends on haematocrit (Ht) and total protein concentration (TP, g/dL):

$$Q_{\mathrm{pw}} = Q_{\mathrm{b}} \times (1 - \mathrm{Ht}) \times (1 - 0.0107\mathrm{TP}) \tag{5}$$

or

$$Q_{\mathrm{b}} = \frac{Q_{\mathrm{pw}}}{[(1 - \mathrm{Ht}) \times (1 - 0.0107\mathrm{TP})]} \tag{6}$$

As a result, plasma water FF may vary at a given value of blood FF [31]. Suppose two patients, each treated with a convective flow rate of 100 mL/min and a blood flow rate of 400 mL/min. According to equation (1), FF is 25%. However, if patient A has a baseline Ht of 0.35 and patient B of 0.40, their plasma flow rate will differ (respectively 260 and 240 mL/min [equation (5), TP not taken into account]), and so will their plasma water FF (respectively 38 and 42%).

Third, as HDF is a dynamic process, parameters used to calculate the convection flow rate at the start of a session will change during treatment. Moreover, use of individualized UF profiles may cause deviations from the original FF. Finally, as blood viscosity increases during HDF, a high FF may be tolerated at the start, but not at the end of a session.

Increasing filtration fraction in clinical practice: from one machine to another. Treatment time, net UF and blood flow rate are usually pre-set parameters. Consequently, only one of the following interdependent parameters can be prescribed in order to resolve equation (2): FF, substitution flow rate or desired total substitution volume. In reality, as the attainment of the desired net UF has precedence over total convection volume, and as such requires a distinct prescription, none of the main dialysis systems which are currently on the market allows the setting of FF as a treatment parameter. In fact, the settable parameter (s) and their handling vary with the different dialysis machines. Table 2 shows a summary of 5 frequently used systems. In Table 3, an example is depicted to illustrate how treatment parameters can influence the convection

Table 2. Specificities of five HDF systems

	Machines				
	Nikkiso DBB-05™ and DBB-07™	Gambro AK 200™ ULTRA S	Gambro Artis® Dialysis System	Fresenius 5008 ONLINEplus™	B. Braun Dialog+ Dialysis System
Settable parameter(s) in volume-control mode	Substitution ratio (%) Substitution rate (L/h) Goal substitution volume (L/session)	Goal substitution volume (L/session)	Substitution rate (mL/min)	Goal substitution volume (L/session) Substitution rate (mL/min)	Substitution rate (mL/min) Substitution volume (L) FF alarm limits (%)
Proportioning ratio formula	Substitution ratio = Q_{subs}/Q_b	FF (QF/QB) = $(Q_{subs} + Q_{uf})/Q_b$	FF (QF/QB) = $(Q_{subs} + Q_{uf})/Q_b$	Not displayed	FF (QF/QB) = $(Q_{subs} + Q_{uf})/Q_b$
Blood flow rate used in ratio formula	Set	Effective	Effective	Effective	Set
Actual convective volume and rate displayed	No	Yes	No	No	No
Alternative modes	Not available	Pressure-control mode : TMP is fixed manually or automatically (ULTRAControl[a]); substitution rate varies accordingly	Pressure-control mode : TMP is fixed manually or automatically (ULTRAControl[a]); substitution rate varies accordingly	Autosubstitution mode : Substitution rate is automatically adjusted during the session according to various parameters (AutoSub[b])	Not available
Comments	Q_{uf} not taken into account in the formula; alarm if FF above determined threshold	FF displayed as a monitoring parameter but cannot be prescribed; Value of up to 30% recommended by manufacturer	FF displayed as a monitoring parameter but cannot be prescribed; Value of up to 40% recommended by manufacturer	Estimated subs volume at the end of session displayed with autosubstitution.	FF displayed as a monitoring parameter but cannot be prescribed; Value of up to 30% recommended by manufacturer

Q_{subs}, substitution flow rate; Q_b blood flow rate; Q_{uf}, net ultrafiltration rate; FF, filtration fraction; TMP, transmembrane pressure.
[a]ULTRAControl™: automatic scanning is performed to find the optimal TMP value providing the maximal total UF (convective) rate.
[b]AutoSub™: automatic adjustment of subs flow rate during the session based on the effective blood flow rate, haematocrit, total protein, net UF rate, dilution mode and filter type.

Table 3. Maximization of convection volume with optimization of treatment parameters: practical example using different dialysis systems

Post-dilution HDF treatment parameters	Set parameter with different dialysis systems[a]			Estimated final convection volume (L/session)[b]
	Nikkiso DBB-05™ and -07™ Substitution ratio (%)	Gambro AK 200™ ULTRA S Target substitution volume (L/session)	Fresenius 5008 ONLINEplus™, Gambro Artis® System and B. Braun Dialog+ Dialysis System Substitution flow rate (mL/min)	
First session: baseline parameters				
Time = 3h30	22	13.8	65	15.8
Q_b = 300 mL/min				
Net UF = 2L				
FF = 25%				
Following sessions: step-wise increase in the treatment parameters[c]				
↑time = 4 h	22	16.0	67	18.0
↑Q_b = 350 mL/min	23	19.0	79	21.0
↑Q_b = 400 mL/min	23	22.0	92	24.0
↑FF = 27%	25	23.9	100	25.9
↑FF = 29%	27	25.8	108	27.8
↑FF = 31%	29	27.8	116	29.8

Baseline parameters are selected as examples of a typical patient. For the sake of simplicity, the difference between set and real Q_b was not considered, and net UF does not vary between sessions.
Time, treatment time; Q_b, blood flow rate; UF, ultrafiltration; FF, filtration fraction.
[a]Set HDF parameter in order to obtain pre-specified FF using different machines. Calculation based on the formulas described in Table 2.
[b]Estimated final convection volume can be calculated by resolving equations (3) and (4) presented in the text.
[c]Only the increased parameter is shown. All the other ones remain at the same value as the immediately preceding session. For example, in the line where FF is increased to 27%, treatment time and Q_b are considered to be 4 h and 400 mL/min, respectively.

volume and how the target ol-HDF parameter varies with regard to the machine used. It is essential to realize that automated machine settings aim at optimizing filtration fraction at the lowest possible rate of machine alarms, but do not regulate the two main determinants of convection volume, that is treatment time and blood flow rate.

Nikkiso DBB-05™ and DBB-07™ Dialysis Systems. These machines allow the prescription of either the substitution ratio, substitution volume or substitution flow rate. Substitution ratio is similar to FF, with the exception that it does not take net UF into account. Therefore, the calculated FF will be higher than the substitution ratio, unless UF is nil. Consider a patient with a blood flow rate of 300 mL/min and a UF rate of 8 mL/min (480 mL/h). A substitution ratio of 25% will correspond to a substitution flow rate of 75 mL/min (300 × 0.25, Table 2). However, taking UF into account results in a calculated FF of 28% [(75 + 8)/300 × 100, equation (2)]. Moreover, as the substitution ratio is based on the set blood pump value and not on the real blood flow rate, actual FF may be even higher. For safety purposes, a 'blood flow rate control alarm' is designed to ensure that a maximum value of FF is not exceeded, even if the latter is not displayed.

Gambro AK 200™ ULTRA S and Artis® Dialysis System. These systems bear resemblances and dissimilarities. Both can be used in a pressure-control mode (fixed transmembrane pressure and variable substitution flow rate) and a volume-control mode. In the latter, the target substitution volume must be set in the AK 200™ ULTRA S system, while the substitution flow rate must be set in the Artis® machine. In the AK 200™ ULTRA S, the actual convection volume and convective flow rate are also shown. Both machines display the FF value online (as 'QF/QB'), based on the real blood flow rate. The maximal value recommended by the manufacturer, however, is different for both systems (Table 2).

Fresenius 5008 with ONLINEplus™. This machine (Fresenius Medical Care, Bad Homburg, Germany) has an automatic substitution mode (AutoSub™), in which the substitution rate is automatically regulated in response to variations in diverse patient- and treatment-related parameters throughout the session (Table 2). The estimated final substitution volume is displayed on the monitor. When this mode is disabled, it is possible to set the substitution rate or target substitution volume manually. In this system, FF is automatically regulated but not displayed on the screen.

B. Braun Dialog+ Dialysis System. The machine principle is based on volume control, where either substitution rate per minute or total substitution target volume can be set. The FF is calculated and displayed as the ratio between the total UF (includes both net UF and substitution rate) and the blood flow rate. Any parameter change immediately adapts the ratio according to the new settings. Individual alarm limits, which can be set in the System Configuration Mode, monitor the FF within the allowed alarm limit range.

Treatment time

As described before, treatment time is one of the major determinants of convection volume [17]. A simple calculation shows that an increase in treatment time with 1 h, at a given blood flow rate of 400 mL/min and a filtration fraction of 25%, augments convection volume with 6 L [16]. Thus, with respect to high-volume ol-HDF, a long treatment time can compensate for a low blood flow rate. This aspect becomes even more relevant as some of the most recent dialysis machines are able to manage filtration fraction and the major limiting factor for achieving high

Table 4. Summary of the technical and practical aspects to optimize convection volume in online post-dilution HDF

- Ensure adequate dialysis time
- Ensure adequate blood flow
  - Select a vascular access able to deliver high blood flow rate; a central venous catheter should not be automatically considered a contra indication
  - Tailor the needle size to the desired blood flow rate (usually 15G-needle), not the opposite
  - Recognize the difference between steel and plastic needles in terms of size of the lumen
  - Monitor for access recirculation
  - Consider discrepancy between set and real values for blood flow rate
- Optimize filtration fraction on an individualized basis
  - Become acquainted with the specificities of the dialysis machine(s) employed in your HDF unit; read user manual thoroughly
  - If automatic regulation of substitution flow is chosen, know which factors are involved
  - Establish pre-specified and optimal safety thresholds for system pressures and filtration fraction
  - Learn how to manage the various safety alarms
  - Appreciate the influence of high haematocrit on plasma water filtration fraction; if needed adjust anti-coagulation
- Chose a haemodiafilter with a high hydraulic permeability, a large surface area and short fibres with large internal radius
- Avoid single-needle circuit configuration
- Perform regular teaching and feedback for the nursing staff
- Re-evaluate on a frequent basis that the convection volume goals are met and sustained

convection volumes becomes thus the amount of blood volume processed, i.e. the product of blood flow rate and treatment time. Moreover, a prolonged treatment time *per se* has been shown to improve haemodynamic instability [32], which in turn may contribute to a high convection volume.

Other considerations

Anticoagulation. Because a high FF induces considerable haemoconcentration [33] and clotting within the dialyser, adequate anticoagulation with either unfractionated heparin or low molecular weight heparin (LMWH) is mandatory. Although these agents, which belong to the MMW class (2–20 kDa), are for the main part protein bound, large convective volumes in ol-HDF may alter their pharmacokinetics [34, 35]. In THDFS, the unfractionated heparin dose was ~10% higher in the HDF group when compared with HD patients [14]. A recent study, using heparin-coated membranes in ol-HDF, showed that the dose of LMWH could be reduced safely without an increased risk of clotting [36].

Dialysers. Ol-HDF can only be performed with high-flux membranes, defined as having a UF coefficient (KUF) of at least 20 mL/mmHg/h [1]. Theoretically, fibre length and diameter, as well as membrane material, membrane thickness, surface area, pore size and pore density all may influence solute sieving and convective transport [37, 38]. Yet, in a sub-analysis of CONTRAST, neither membrane surface area (1.7–2.2 m^2) nor KUF (56–85 mL/mmHg/h) showed any relationship with the magnitude of the convection volume [17]. Nevertheless, in order to avoid TMP alarms, it appears wise to avoid dialysers with a surface area <1.7 m^2 or dialysers with a high blood flow resistance [39]. Whether the use of high performance membranes, which eliminate MMW uraemic toxins better than more conventional high-flux devices, improves prognosis, remains to be established [40, 41].

Summary

In the past few years it has become increasingly clear that treatment with post-dilution ol-HDF is beneficial for patients with ESKD. A recent meta-analysis, comparing post-dilution ol-HDF with low- and high-flux HD, not only showed superiority of ol-HDF in terms of morbidity and mortality, but also a clear effect of the amount of convection achieved [2]. Considering the magnitude of the convection volume, a recent observational study showed that treatment time and blood flow rate are the most important determinants. Patient characteristics, such as haematocrit and albumin levels seemed to play only a minor role in this respect [17]. As the former two factors are potentially modifiable, optimization of the convection volume up to >22 L appears feasible in clinical practice. A summary of the technical and practical aspects to optimize convection volume in post-dilution ol-HDF is shown in Table 4.

In this review we described a number of practical issues and pitfalls that were encountered during optimization of convection volume in post-dilution ol-HDF. First, it appeared that no particular needle deserves priority and that use of a large bore needle (15G) is not associated with serious complications. Second, recirculation, as occurs in the case of an obstruction in the venous outflow tract, indeed enhances the magnitude of the convection volume, but does not contribute to the clearance of MMW substances. Third, the set blood flow rate may differ considerably from the real blood flow rate, especially at higher pump speed.

Apart from treatment time and blood flow rate, convection volume is to a large part determined by the fraction of blood that is ultrafiltered during ol-HDF. Although the ultrafiltrate originates from plasma water, in clinical practice it is more convenient to calculate FF as the proportion that is derived from the blood flow rate. Preliminary, non-published data of the ongoing Feasibility Study (NCT01877499) indicate that an FF of 33% is possible in the majority of patients. Manual adjustment and control of FF is a rather complicated process, as the various machines described either do not take net UF into account, or do not display the actual FF on the monitor.

Furthermore, neither vascular access nor the type of (high-flux) dialyser appears related to the magnitude of the convection volume. Yet, as local customs, such as the choice of needles and dialysers and fixed settings of treatment time and blood flow, appear overriding in this respect, it seems plausible that in everyday clinical practice the membrane surface area and capillary dimensions of dialysers should meet some minimal requirements. Due to haemoconcentration and the propensity for intradialyser clotting in online post-dilution HDF, adequate

anticoagulation is mandatory. Finally, it should be emphasized that a well-trained nursing staff with sufficient experience is crucial for the achievement of optimal convection volumes, as these professionals operate the dialysis machines on a daily basis and are the confidant for the patients.

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