
Core Curriculum

Fluid balance, dry weight, and blood pressure in dialysis

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Abstract

The total amount of sodium present in the body controls the extracellular volume. In advanced renal failure, sodium balance becomes positive and the extracellular volume expands. This leads to hypertension, and vascular changes that lead to adverse cardiovascular consequences in dialysis patients. Controlling the body sodium content and the extracellular volume allows one to better control hypertension and its consequences. This can be achieved by reducing the sodium input (sodium dietary restriction and reasonably low sodium dialysate) and/or by increasing the sodium output (ultrafiltration by convection). The discontinuous nature of hemodialysis causes saw-tooth volume fluctuations. This has led to the concept of dry weight (DW), a crucial component of dialysis adequacy. Assessment and achievement of DW is feasible on pure clinical grounds. But its relative lack of accuracy (and the physicians' progressive lack of interest in bedside examination) has led to several nonclinical methods of assessing DW in an effort to improve the assessment of fluid status in dialysis patients.

Key words: Hemodialysis, sodium, dry weight, extracellular volume, blood pressure, diet

INTRODUCTION

Sodium and water in normal conditions

Owing to the high hydraulic permeability of the cell membrane, water moves freely between intracellular (ICV) and extracellular volumes (ECV). This maintains an equal osmolality in all fluid compartments of the body. Osmoregulation involves thirst and antidiuresis. A decreased water intake increases osmolality, stimulates thirst, and antidiuresis. This does not (almost) affect the ECV size. Osmolality can be estimated from Natremia (corrected for hyperglycemia and hyperlipidemia): hypernatremia means water depletion and hyponatremia water excess. But the size of ECV relies on clinical evaluation.

The sodium distribution in the body is not homogeneous. About 90% of exchangeable sodium is in the ECV and only 10% in the ICV. The body sodium content determines the size of the ECV. Extracellular volume depletion is equivalent to sodium depletion and ECV overload to sodium overload. The ECV is subject to wide and instantaneous variation due to the variability of salt ingestion. The low sodium sensitivity of normal individuals¹ allows for wide ECV variations without significant blood pressure (BP) change. An increased sodium intake leads to thirst and water ingestion, which increases the ECV (Figure 1). This isotonic ECV overload increases the natriuresis in sufficient amount to restore a normal ECV within a few hours or days. A decreased sodium intake leads to a reduced natriuresis. The pressure-natriuresis curve is steep; a small change in blood pressure (1 mm-Hg) triggers a large (infinite gain) natriuretic response.²

Under normal conditions, the salt and water input (through gut) is exactly balanced by the kidney salt and water output, thus maintaining the size of the ECV

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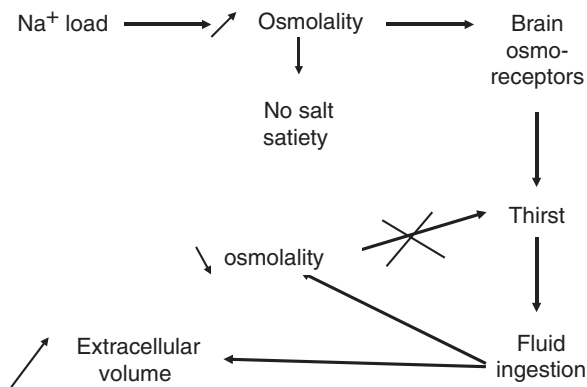


Figure 1 Effect of salt intake on osmolality and extracellular volume (ECV).

(Figure 2) by adjusting the daily sodium excretion between virtually zero to several hundreds millimoles per day.

Which intake of salt is optimal? A high salt intake leads to hypertension, left ventricular hypertrophy, and reduced arterial compliance. Conversely, the populations who eat a very small amount of sodium (e.g., Yanamamo Indians) have no hypertension.³ On the other hand, a low salt intake makes the body vulnerable to salt losses. A dietary intake of about 6 g salt (NaCl) per day appears reasonable in individuals with normal renal function.

Sodium and chronic renal failure (CRF)

Natriuresis, the only physiological exit route for sodium, is very often challenged by an excessive salt intake (more than 5–6 g NaCl i.e., 2 g Na/day). In patients with kidney disease, the blood pressure (BP) rises early, even when the inulin clearance is still normal. Achieving a normal

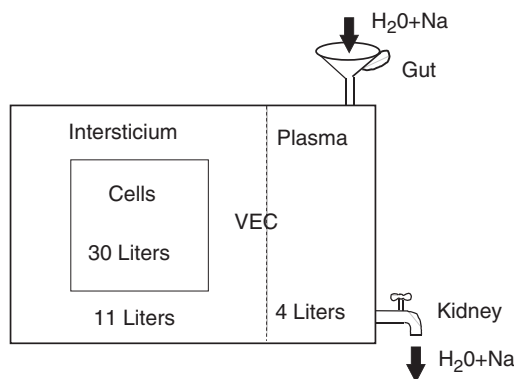


Figure 2 Extracellular volume, salt, and water balance.

Table 1 Volume loading hypertension in dogs (Guyton)

	Week#1	Week#2	Week#3	Week#4
Na ⁺ load	++	—	—	—
ECV	+++	++	+	+
CO	N	++	N	N
TPR	N	N	+	++
BP	N	++	++	++
Na ⁺ U	N	+	++	+

BP=blood pressure; CO=cardiac output; ECV=extracellular volume; N=normal; Na⁺U=Natriuresis; TPR=total peripheral resistance.

sodium (and ECV) body content is an essential goal of chronic renal failure treatment. When it is adequately implemented, it maintains a normal BP without need for antihypertensive medication. Maintaining a normal BP is the most effective way to delay renal failure⁴ in diabetic⁵ as in nondiabetic patients.⁶ Progressively, as renal failure worsens, the capacity of the kidney to excrete sodium decreases, salt sensitivity increases,⁷ and the incidence of hypertension increases.⁸ About 90% of end-stage renal failure patients are hypertensive at the start of dialysis.^{9,10} Excess sodium (or ECV) is the dominant factor of hypertension in end-stage renal disease.¹⁰

How does sodium excess induce hypertension? A sodium load essentially acts by expanding the ECV. Guyton examined dogs with 70% reduction of renal mass submitted to a sodium load (Table 1).¹¹ After 4 days, hypertension is nearly maximal. In this initial phase, ECV expands and venous return and cardiac output increase. The rise in blood pressure enhances renal perfusion and natriuresis, thus limiting the rise in ECV. After 2 weeks, the cardiac output normalizes but total peripheral resistances (TPR) increase so that hypertension persists. This maintenance phase is characterized by a vasoconstriction induced by tissues over perfusion. The mechanism of adaptative autoregulation¹² is not very clear. Other hemodynamic models have been described¹³ but Guyton's pathophysiological hypothesis remains the most compatible with the observed facts. In advanced renal failure, on top of sodium retention the partitioning of extracellular fluid becomes abnormal and the intravascular volume is relatively more expanded than the interstitial space.^{14–16}

Volume expansion causes hypertension only when TPR are inappropriately high in relation to cardiac output. Explanations for such an inadequate adjustment of TPR include insufficient vasodilatation,¹⁷ inappropriately high angiotensin II activity,¹⁸ sympathetic overactivity,^{15,16} and vascular remodeling with structurally fixed elevation of resistance.¹⁹

Sodium and ECV in dialysis

Sodium balance has a strong impact on morbidity and mortality of patients on hemodialysis (HD). The BP sensitivity to salt decreases once dialysis has been initiated and is eventually restored to normal.²⁰ The sodium balance affects cardiovascular mortality of dialysis patients not only by raising BP through increased ECV,²¹ increased intracellular sodium content, and increased TPR, but through an independent effect on heart hypertrophy and dilatation,²² on vascular smooth muscle cells' hypertrophy,²³ on reactive oxygen species promotion, and break-down reduction.²⁴

ECV AND BP CONTROL, THE DRY WEIGHT (DW) CONCEPT

By demonstrating that malignant hypertension could be controlled by a strict ultrafiltration (UF) policy in 1960,²⁵ Scribner gradually convinced the nephrology community that ECV normalization was the cornerstone of BP control in dialysis patients. Indeed, combining a long HD and low-salt diet has been shown to normalize BP in over 90% of HD patients during the first decade of dialysis^{10,26–33} (Table 2). However, with dialysis sessions getting shortened universally using a higher dialysate sodium became a common practice to avoid intradialytic morbidity. The value of a low-salt diet was progressively “forgotten” (Figure 3), resulting in a progressive loss of control of blood pressure.³⁴

The concept of controlling BP by achieving the lowest possible ECV on dialysis was termed as “dry weight” by Thomson.²⁹ The author stated “the reduction of BP to hypotensive levels during UF, represented the achievement of a dry weight status.” (This original definition of DW needs an important qualifier, i.e., in the absence of antihypertensive medication. As a matter of fact, hypotension on dialysis in a patient receiving antihypertensives may be due to the proper vasoactive effect of the medication and cannot be used as evidence that DW has been achieved. Hence, a more adequate DW definition could be “the post-dialysis weight at which the patient is and remains normotensive until the next dialysis in spite of the interdialytic fluid retention without anti-hypertensive medication.”³⁵)

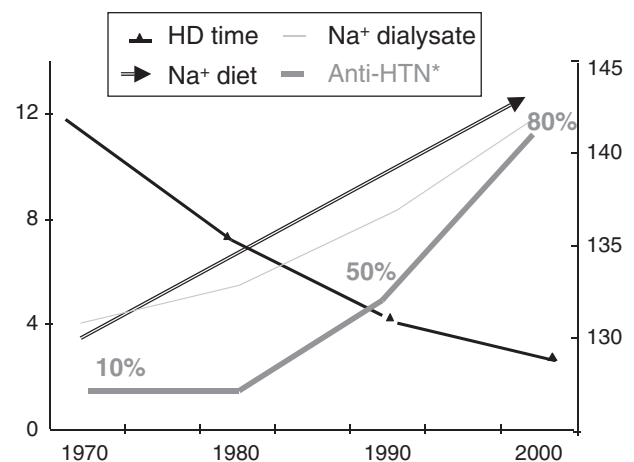
The volume changes occurring in the usual thrice-weekly HD set up are displayed in Figure 4. Owing to the intermittent nature of HD, the patient oscillates between a high-weight “wet” state, just before the session, and a low-weight “dry” state just at the end of the session.

Table 2 Hypertension control by hemodialysis alone

First author	Year	Number of patients	% control
Comty et al. ²⁶	1964	9	100
Comty et al. ²⁷	1966	25	100
Blumberg et al. ²⁸	1967	6	84
Thomson et al. ²⁹	1967	21	100
Schupak et al. ³⁰	1967	26	69
de Planque et al. ³¹	1969	10	100
Vertes et al. ¹⁰	1969	40	88
Curtis et al. ³²	1969	25	92
Traeger et al. ³³	1969	68	94
Total		230	91

% control=% of normotensive patients without antihypertensive medication.

Before dialysis treatment is started, as shown in the lower part of Figure 4, the ECV is increased homogeneously in plasma and interstitial spaces. During the few hours of the session, the plasma compartment is ultra filtered down to a nadir. Refilling from the interstitial space occurs, but it lags some hours behind, and it does not reach a new state of equilibrium between interstitial and plasma spaces before some hours. This explains that just at the end of the session, the patient is normally, plasma volume-wise, really “dry,” displaying some signs of hypovolemia (orthostatic BP drop with or without symptoms) that will disappear within a few hours. This also means that evaluating ECV from plasma volume



* Anti-HTN= % of patients using antihypertensive medications

Figure 3 Chronological trends of dialysis session time reduction, dialysate and diet sodium, and antihypertensive medication use (1960–2000).

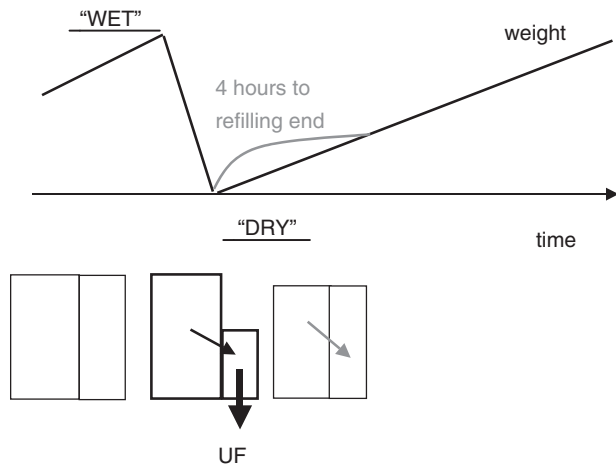


Figure 4 Hemodialysis patient’s oscillations between “wet” and “dry” state just before and just after the session. The refilling of plasma volume from interstitial space takes a few hours after the disconnection.

measured just at the end of the session (e.g., atrial natriuretic peptide [ANP], inferior vena cava [IVC] measurement) leads to a systematic overestimation of UF and underestimation of the actual ECV.

What dialysis basically does in terms of volume is to replace the native pressure—natriuresis closed-loop system schematized on the right-hand side of Figure 5. The physician or person in charge of the dialysis uses the same basic information as the native kidney (i.e., BP and ECV) to prescribe an ideal postdialysis weight, the DW. This target weight is converted into an UF rate sufficient to bring back the ECV (and BP) back to normal.

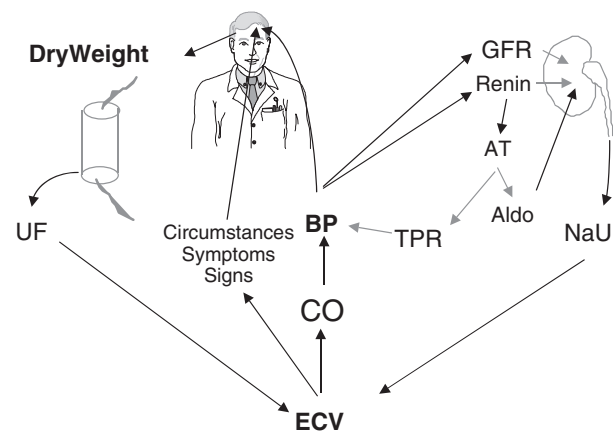


Figure 5 Dry weight prescription mimicks the native kidney closed-loop extracellular volume (ECV) and blood pressure-regulating system.

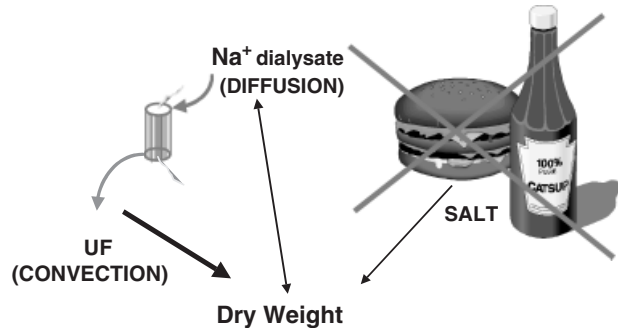


Figure 6 The 3 extracellular volume regulating methods in hemodialysis patients: reduced salt intake, reasonably low dialysate sodium concentration, and adequate ultrafiltration.

In fact, Figure 5 displays the most common situation, i.e., ECV correction is performed on the sole (or almost) basis of the UF rate. This is far from the ideal situation, which should include 2 other powerful tools in achieving the DW. Figure 6 displays the situation as it should be. Three simultaneous ways of controlling the excessive ECV variation should be used in HD: reducing the interdialytic weight gain by a moderate salt restriction (5–6 g NaCl/day) without the need for fluid restriction; using a reasonable dialysate sodium (135–138 mmol/L) in order to achieve a nil or slight diffusive drag of sodium out of the body; and dialysis UF (convection). The importance of reducing the salt intake must be underlined. The data reported in Table 3 demonstrate clearly that interdialytic weight gain and prevalence of hypertension are strongly related.^{36–41}

Ideally, the convective UF should just be the “fine tuning button” to adjust the ECV on dialysis. Unfortunately, dialysate sodium over 140 mmol/L is often used and salt restriction omitted, so that UF becomes the unique means to achieve the adequate postdialysis weight.

The time-dependent relationship between the ECV control by HD and the normalization of BP can be illustrated by the first year of dialysis of 712 patients started on HD in Tassin, France (Figure 7). During the first month, ECV expressed by the postdialysis weight declines sharply by 2 to 3 kg. Predialysis means arterial pressure also decreases rapidly. At 2 months, the postdialysis weight is stable, but BP continues to decrease. At that stage, antihypertensive medications have already been stopped in almost all patients. Between 3 and 12 months, the curves cross over, BP continues to decrease gently but weight increases by several kilograms. This gain in weight after 2 months does not reflect an ECV increase but the anabolic gain in lean and fat body mass following the start of dialysis. The lag time between change in ECV and BP

Table 3 Respective effects of dialysate Na⁺ concentration and dietary Na⁺ intake on interdialytic weight gain and on hypertension prevalence

Dialysis unit	Reference	Dialysate sodium (mmol/L)	Sodium diet (mmol/day)	Interdialytic weight gain (kg)	Percentage of patients using antihypertensive (%)
Manchester	Goldsmith et al. ³⁶	134	50	NA	9
Christchurch	Lynn et al. ³⁷	138	70	2.6	5
Tassin	Charra ³⁸	138	50	1.8	<5
Stockholm	Katzarski et al. ³⁹	142	100	2.4	50
Maastricht	Luik ⁴⁰	140	100	3.2	73
Izmir ^a	Özkahya ⁴¹	138	100	2.9	100
Izmir ^b	Özkahya ⁴¹	138	50	1.8	4

^aIzmir data before intervention (low salt diet+strict ultrafiltration).

^bIzmir data after intervention.

NA=not available.

response is an important practical point we shall discuss later. It has 2 possible and probably additive explanations. One is the vascular remodeling,⁴² followed by a progressive reduction of peripheral resistances; the other is the very slow removal of vasoactive middle molecular substances such as ADMA or Na-K-ATPase.⁴³

DRY WEIGHT USING THE CLINICAL METHOD

How is the DW assessed? In everyday practice in almost all dialysis units worldwide, DW is assessed using the clinical method. As displayed in Table 4, this implies 4 categories of information:

Case history: The case history reveals the circumstances of ECV excess—almost always due to salt excess (e.g.,

patient's dietary indiscretion or ingestion of unrecognized circumstances high sodium content medication, mineral water, etc.)—with/without symptoms of volume overload (dyspnea, headache). In case of ECV depletion, suspicion arises by circumstances of salt depletion through diarrhea, use or abuse of diuretics or laxative, and eventual symptoms of volume depletion (postural dizziness, fatigue, cramps). Such symptoms are unspecific, poorly sensitive, often discordant, and show a large inter and intraindividual variability.⁴⁴ A patient can be overtly volume overloaded but show symptoms of volume depletion during and after dialysis. In contrast, a volume-depleted patient may complain of shortness of breath or headache. Symptoms are only confirmative clues of a volume diagnosis built on more solid data.

Clinical signs: Blood pressure must be measured lying, sitting, and standing, as the diagnostic value of orthostatic change is essential. Sodium or ECV-overloaded patients have a normal or high blood pressure; they do not show any orthostatic drop of BP when standing. Extracellular volume depletion is expressed by orthostatic hypotension persisting over the few hours following the end of the dialysis session, and sometimes by permanent hypotension. This may/may not be accompanied by symptoms such as dizziness, cramps, or vomiting.

The measurement of weight is primary. One must insist on the importance of weighing the patient on the same scales that are rigorously and meticulously calibrated on a regular basis and under the same conditions (hours, clothing). Errors in weighing are frequent and may adversely impact the dialysis tolerance and the estimation of DW. The acute change in weight between 2 sessions may be due to changes in body water content (rather unusual in anephric dialysis patients). More often, the change in

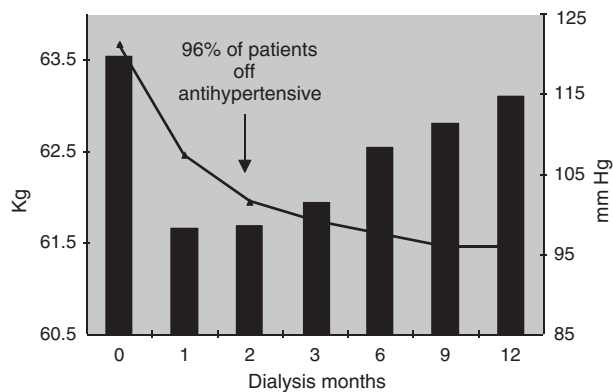


Figure 7 Evolution of postdialysis weight and predialysis mean arterial pressure of 712 Tassin hemodialysis patients during their first treatment year.

Table 4 Dry weight clinical assessment data

	ECV overload	ECV depletion
(1) Case history	Excessive salt intake Dyspnea, headache	Diarrhea, vomiting, diuretics Postural dizziness, cramps
(2) Signs	No BP postural drop Increased BP Weight increase Full neck veins Edema	BP postural drop Hypotension Decreased weight Flat neck veins No edema
(3) X-Ray	Increased cardio-thoracic index	Normal cardio-thoracic index
(4) Lab data	Decreased hematocrit, total proteins and serum albumin	Increased hematocrit, total proteins and serum albumin

BP=blood pressure; ECV=extracellular volume.

ECV is due to the interdialytic weight gain (IDWG, or loss) of salt and water. A moderately restricted diet usually allows for IDWG of less than 2 kg (or less than 3% of estimated DW). A very liberal diet (as often used in United States, Europe, or Japan) of 10 to 15 g of sodium per day causes the IDWG to increase to 4 kg or more (more than 6% of estimated DW).

The measurement of central venous pressure when the patient is using a central venous catheter gives direct information on the plasma volume and ECV. When it is not available, reading the external jugular vein on the patient lying flat is a good substitute. It is easy to perform, fast, and very informative.

Looking for edema should complete the examination. But one must point out the fact that if the presence of edema is a strong indicator of ECV overload (taking into account cardiac function and serum albumin), the absence of edema in no way implies that the patient is not overloaded. Actually, a large majority of ECV-overloaded patients show no edema at all.

Chest X-ray: This allows for calculation of the cardio-thoracic index (normally <0.50). Other radiological features of pulmonary congestion may be present. A normal chest X-ray in no way eliminates a diagnosis of ECV overload.

Lab data: These are less reliable in the diagnosis of ECV overload. The hemoconcentration or hemodilution value is relative; it must be compared with the previous values in the patient.

In short, among all these elements, the 2 essential clues are the BP which indicates the direction of the ECV change, and the weight, which not only gives the direction of the change but also a quantitative indication of the importance of the change.

In everyday practice, it is of utmost importance that the physician has access to a dialysis summary of the last few sessions as shown in Table 5. This log chart summarizes the last few weeks predialysis and postdialysis session weight and blood pressure values. It includes for each session the interdialytic weight gain, the intradialytic

Table 5 Tassin dialysis log chart

HD #	Date	Weight		BP		2W	Observations	Validation
		In	Out	In	Out			
1097	5/05/94	65.9	64.5	145/82	128/77	1.4	—	N.C.
1098	7/05/94	65.5	64.3	128/80	110/70	1.2	Cramp	-•? N.C.
1099	9/05/94	66.9	65.1	145/82	130/80	1.8	+500	N.C.
1101	14/05/94	66.2	64.5	134/72	111/70	1.7	—	N.C.
1102	16/05/94	65.9	64.5	126/67	104/72	1.4	—	N.C.
1103	19/05/94	66.9	64	135/82	90/67	2.9	NS 250 mL	- 500 B.C.
1104	21/05/94	65.2	64.2	100/50	95/60	1	NS 500 vomitus	- 300 JCT
1105	23/05/94	65.5	64.5	125/65	92/65	1	—	- 500 JCT
1106	26/05/94	65.9	64.5	125/60	108/67	1.4	—	JCT
1107	28/05/94	65.9	64.8	122/70	110/75	1.1	—	+300 CC
1108	30/05/04	65.9	64.5	145/82	128/77	1.4	—	OK CC

events, and therapeutic steps taken (e.g., stopping UF, saline perfusion, etc.). Browsing through these lines gives a one-glance dynamic image of the weight/blood pressure relationship. In Tassin, one column (Table 5, extreme right column) is reserved for the physician in charge of the ward who validates the data after each dialysis session. This includes comments, prescribed correction of target weight, and physician's initials. If this is not done the computer will refuse to edit a new dialysis sheet at the start of next dialysis. This in a way obligates the physicians to re-evaluate the DW after each session. This summary easily allows the physicians to fine tune the dialysis prescription on an ongoing basis.

Probing for DW

In the usual state of long-term dialysis, volume indicators and blood pressure data allow for a reasonably accurate guess of the DW prescription, thus allowing to achieve a normal BP. But changes in weight may be due to lean and fat body mass change rather than changes in ECV. This is encountered in almost all patients during the initial period of their dialysis treatment, which almost always improves appetite while the ECV excess is being progressively corrected.⁴⁵ It may also be the case during the maintenance phase of dialysis during or after an intercurrent event or disease that induces a nutritional change. Under these conditions, one must "probe" for DW.

Probing for DW is the opposite of Guyton's salt loading maneuver in partially nephrectomized dogs. It consists of a systematic step-by-step lowering of post-HD weight down to the point of hypovolemia. That is when hypotension occurs regularly at the end of the session. When this has been achieved, the target postdialysis weight may be increased by a few hundred grams to improve the patient's comfort.

This dynamic test is the most definitive way to assess DW clinically.

Limitations of clinical DW

Assessing the ideal DW on pure clinical grounds is not very easy and several factors may confound the issue.

There is a lag time of a few weeks to months between a modification of ECV and the resulting BP response.⁴⁶ This absence of immediate blood pressure response to a modification of ECV was been recognized early.^{27,47} It is usually explained by the cardiovascular remodeling and the delay needed to clean out middle molecular vasoactive substances accumulating in ESRD. It should be well known to the physician, staff, and patient, and not be

considered as an argument against the ECV-BP relationship.

The occurrence of hypotension on dialysis does not necessarily mean that the patient's ECV has been normalized. A short or very short thrice-weekly dialysis often leads to hypotension just because the session time is too short to allow for an adequate intravascular space refilling by the interstitial space. Besides, if the patient is receiving a BP-lowering medication (whether it is prescribed specifically as an antihypertensive agent or for cardiac reasons), a change in BP is not the sole criterion for reassessing DW. A large proportion of dialysis patients indeed use antihypertensive medications that not only are very poor in controlling BP in the presence of ECV overload but are also a considerable hindrance in assessing and achieving DW.⁴⁸

The DW in a given patient also varies in the long term when lean and fat body mass change. Evaluating the respective components of ECV and body mass modifications in a patient is often difficult. While it is possible and reasonable to infer that a weight change over a few hours or days is due to the fluid change, it is impossible to guess whether the weight has changed over several weeks or months.

It is fair to admit that the clinical assessment of DW, whereby hypotension is deliberately sought for and achieved, is somewhat uncomfortable (dizziness, fatigue) and even sometimes painful (cramps, vomiting) for the patient.

To overcome the difficulties and discomfort of clinical DW assessment, several methods have been proposed: natriuretic peptide measurement, IVC measurement, blood volume measurement and bioimpedance, etc.

NON-CLINICAL DW ASSESSMENT

The dilution methods measure the distribution spaces accurately. They are indeed the gold standard, but due to handling errors in practice they are not very reproducible. Besides, there is no specific tracer strictly confined to ECV space. The method is not very accessible to clinicians, is relatively invasive, expensive, and measurements are not easy to repeat.

Natriuretic peptides

Atrial natriuretic peptide, brain natriuretic peptide (BNP), and their messenger cyclic guanosine monophosphate (cGMP) are essentially produced by stretched atrial and ventricular cardiomyocytes. Their blood level increases in CRF and in dialysis. Although they reflect the intravascular

volume overload, accurate estimation of ECV is difficult. They are noninvasive but are poorly specific and widely variable. They are also not widely available.

Inferior vena cava diameter

Inferior vena cava diameter and collapsibility on deep inspiration also allow evaluation of the intravascular volume. It correlates well with central venous pressure, and it can detect intravascular overload and depletion in HD patients. Non-invasive and fast, it reflects well the plasma but not the interstitial volume, and it varies widely as a function of heart function. On dialysis, the refilling lags a few hours behind UFUF, so that measuring it just at the end of the session systematically over-estimates the UF and under-estimates the ECV. At least 2 hr are necessary to reach stabilization after the end of the session. This limits the clinical application of the method. Besides, it is operator dependent, not widely available, and expensive.

Continuous blood volume measurement

Based on relative hemoconcentration/dilution during UF on dialysis, it was first measured using dilution techniques (labeled red blood cells or albumin) and then by photonic or infrared densitometry and by electric or ultrasonic conductivity. It is noninvasive. Rather than evaluating the DW, this method was devised and is used to predict and avoid intradialytic morbidity (critical patient hematocrit threshold). It measures the intravascular volume changes which depends on UF and refilling rates. Not very specific or sensitive, it needs training and multiple interventions of nurses during the session, which makes it rather expensive.

Bioimpedance analysis (BIA)

Low-amperage high-frequency alternating electric current flows through intracellular and extracellular compart-

ments and allows for total body water evaluation. A low-frequency current due to cell membranes resistance flows almost exclusively through the ECV and allows to measure the ECV. Multifrequency BIA (spectroscopy) allows to measure both intracellular volume and ECV.

Global BIA measures the resistance of the whole body, which is likened to a homogeneous cylinder, an obvious oversimplification. The segmental method is more accurate, but one single segment is not very representative of the whole body. Summing up 5 segments gives a better representation⁴⁹ but is more time consuming. The electric data must be converted in volume using one of several mathematical models whose respective values are open to discussion. BIA is sensitive to changes in position, temperature, and body composition. It postulates that ECV is stable, a rare situation in dialysis.

Noninvasive and sensitive, its reproducibility is good but needs strictly identical operational conditions, which is not easy to achieve in practice. It is also expensive.

In view of the weakness of the conventional methods, several BIA modalities have been designed to improve its accuracy. A vectorial representation (phase angle) allows to overcome the bias of constant hydration postulated by the classical method.⁵⁰ But it is rather complex and not widely used. Others have proposed an analysis based on the intersection of the BIA curves in normohydration and in hypervolemia.⁵¹ This method has not yet been validated. Lastly, sequential measurements of segmental BIA during the session (while reducing deliberately the post-dialysis weight over several subsequent HD sessions) has been proposed more recently.⁵² Owing to its “dynamic” nature it in some ways resembles the clinical probe for DW.

A summary of the different methods described is displayed in Table 6. None of them is perfect; even BIA, the one which performs the best, is not validated on dialysis. Their respective inadequacies have led to a proposal of combining several methods,⁵³ but this makes it even

Table 6 Summary of nonclinical ECV measurement methods

Method	ANP/BNP/cGMP	IVC Echo	Blood volume	Bioimpedance
ECV overload detection capacity	+	+	++	+++
ECV depletion detection capacity	0	+	+	+++
Plasma volume measuring capacity	+	++	+++	0
Interstitial space measuring capacity	0	0	0	++
Accuracy	±	±	±	±
Reproducibility	0	+	+	+++
Cost	±	++	++	++

ANP, atrial natriuretic peptide; BNP, brain natriuretic peptide; cGMP, cyclic guanosine monophosphate; ECV, extracellular volume; IVC=inferior vena cava. 0=nil; ± =very low; +=low; ++=medium; +++=high.

more cumbersome and expensive. The great number of publications of non-clinical methods contrasts with the paucity of those analyzing the clinical assessment of DW.

In fact, from a clinical standpoint what do we need for a satisfactory ECV management on dialysis? A precise absolute value of ECV is of no practical interest and it is very unstable all along the dialysis saw tooth variations. What we need is a relative value of the observed actual ECV in relation to the ideal ECV (DW), in order to avoid constantly ECV excess and HTN on the one hand, ECV depletion and discomfort and morbidity on the other hand. Of note, although long standing hypotension is a marker of frailty, severe progressive disease or congestive heart failure and is considered as a marker of short-term mortality risk.^{54–57} There is no evidence that hypotensive episodes during the session are causing an increased mortality on dialysis.⁵⁸

Given some time and effort, the clinical DW method is very simple and cheap, objective, non-invasive, universally available, and suffices in a large majority of cases. In case of doubt one must turn to the probe for DW. The non-clinical tools may be very useful for studies in a limited number of patients and for a limited time, as a complement to assess DW. However, they cannot be considered as superior to a well implemented clinical method.

CONCLUSION

The late 1970s saw, while HD session duration was reduced, an abandonment of the low salt diet, and the use of progressively higher dialysate sodium concentrations to compensate for the increasing morbidity of shortened dialysis sessions. This was followed by a loss of control of ECV and BP.³⁴ At the same time the incidence of intradialytic hypotensive episodes increased, due to the high UF rates, and too short refilling time.⁵⁹

The control of body sodium content (or ECV) allows for normalizing BP in over 90% of cases. This applies regularly to long dialysis and daily dialysis, but it may also apply (although it may require more effort) to standard short thrice-weekly dialysis.^{41,60} A longer or more frequent dialysis than usual is therefore not the mandatory excipient. In HD^{61–64} as in peritoneal dialysis^{65,66} sodium/ECV control is the first condition to achieve BP normalization and reduce the cardiovascular mortality.

The effect of dialysate sodium modeling on intradialytic morbidity is well established but it is at the cost of volume and BP control.⁶⁷ How new feed-back devices combining conductivity and UF modeling will allow for ECV and BP balance is yet an unsolved question. In the

mean time, returning to a moderate dietary salt restriction and reasonably low dialysate sodium concentration is simple, and universally available method to address this problem.

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