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Blood volume changes and measurement during hemodialysis. Dry weight estimation

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Presentation for LSD Forum on technology application in hemodialysis. Tripoli 28/12/2021

Do we use technology properly?

1991 **2021**

Introduction

- One of the main goals of hemodialysis is the excess fluid removal in people with renal failure and the achievement of dry weight.
- On the other hand, the fast reduction of blood water volume due to ultrafiltration via hemodialysis machine can result in clinical complications such as dizziness, nausea, vomiting, hypotension, and muscle cramp.
- Continuous and accurate monitoring of body fluid removal during dialysis is significantly important.

Optimal fluid volume and hemodynamic management in hemodialysis patients is considered an essential component of dialysis adequacy.

- In hemodialysis the excess fluid (water and small solutes) is removed from the blood flowing through the dialyzer in the process called ultrafiltration.

- The resulting blood volume reduction is compensated by the so called vascular refilling , which consists in the absorption of fluid from the tissues in the capillary beds

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- The reduction of the total blood volume cannot be excessively large or abrupt, otherwise the cardiovascular regulatory mechanisms may not be able to maintain sufficient blood pressure leading to intradialytic hypotension.
- Intradialytic hypotension (IDH) is still the most frequent complication during the dialysis treatment with a frequency of about 15–30% (and perhaps higher) of all maintenance hemodialysis sessions

IDH problems

- Mesenteric hypoperfusion with subsequent translocation of endotoxin into the bloodstream,
- cerebral damage,
- accelerated loss of residual renal function
- cardiac damage.
- Frequent IDH may well aggravate chronic fluid overload due to saline infusions and failure to achieve the prescribed post-dialysis target weight. 30% of patients remain fluid overloaded at DW.
- mortality.

Fluid management

- Two main aspects:
- The short-term (intradialytic) preservation of blood volume to avoid hypotensive episodes.
- The long-term maintenance of fluid status below a critical level beyond which cardiovascular damage may occur.

✓ BVM assesses the balance between refilling and UFR in respect to the absolute blood volume.

Challenge and Technology in RRT

- Despite many technological advances in hemodialysis therapy, the management and optimization of fluid status remains a major challenge in the field of renal replacement therapy.

Absolute or Relative Blood Volume Change – Which Is More Relevant?

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- Relative blood volume refers to the ratio of the current blood volume to the initial blood volume at the start of the treatment, typically expressed as a percentage.
- Absolute blood volume can easily be converted to relative blood volume.
- Relative blood volume is inferior to knowledge of absolute blood volume in several ways.
  - Pre-dialysis blood volume varies between patients depending on body size, body composition and fluid status.
  - The relative blood volume change during dialysis contains no information regarding the actual absolute post-dialysis blood volume.

- ✓ RBV is the ratio of current blood water volume to the initial blood water volume at the start of dialysis.

- $RBV(t) = BV(t) BV(0) \times 100\%$ (1)

In this formula, BV(t) and BV(0) represent blood water volume at time t and at the start of HD, respectively.

- the RBV changes can be calculated from HCT variation using the following equation:

- $\Delta BVHCT(t)=(HCT0HCTt-1)\times 100[\%]$

Can Technology Aid the Clinical Decision Process?

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- In 1987, Schallenberg et al. proposed a mathematical method to derive absolute blood volume from measurements of relative blood volume around an abrupt change in ultrafiltration rate, and others have subsequently applied and aimed to validate the concept.

Relative blood volume monitoring

- Relative blood volume (RBV) monitoring is frequently used in haemodialysis patients to help guide fluid management and improve cardiovascular stability.

- RBV changes are typically estimated based on online measurements of certain hemoconcentration markers, such as hematocrit (HCT), hemoglobin (HGB) or total blood protein concentration (TBP).

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On-line monitoring devices and bio-feedback systems have evolved from toys for research use to tools for routine clinical application, particularly in patients with clinical complications.

Haemodialysis with on-line monitoring equipment: tools or toys?

Francesco Locatelli 2005

Can Technology Aid the Clinical Decision Process?

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- The added value of technology assistance should be regarded in terms of its contribution to the clinical decision process.
- Easily applicable technology like bioimpedance spectroscopy may aid in identifying patients with extracellular FO at risk for adverse outcomes.
- Measurements of absolute BV may predict the tolerance to dialysis treatment.

Recommendations

- Routine RBV monitoring in clinical practice should be used with caution until the major methodological and conceptual problems inherent to indirect blood volume estimation are clarified.
- The limitations of the use of these devices should be known to the complete dialysis staff.
- In addition, practical guidelines should be developed on how to interpret and use the RBV results generated by these devices in the individual patient.

A Simple and Feasible Method to Determine ABV in HD Patients in Clinical Practice

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- Absolute blood volume can be easily measured at the beginning of the dialysis session using the current dialysis technology.
- A technique should be completely automated without altering the hardware of currently available online dialysis devices.
- Noninvasive RBV devices provide information on relative blood volume changes, but give no information on the actual absolute blood volume.
- The absolute blood volume increases as the extracellular fluid volume increases both in healthy people and in HD patients.
- The absolute blood volume at the start of HD is extremely variable depending on the hydration status of the patient.
- In the same patient, identical RBV decreases may result in very different postdialysis absolute blood volumes.

RBV sensors

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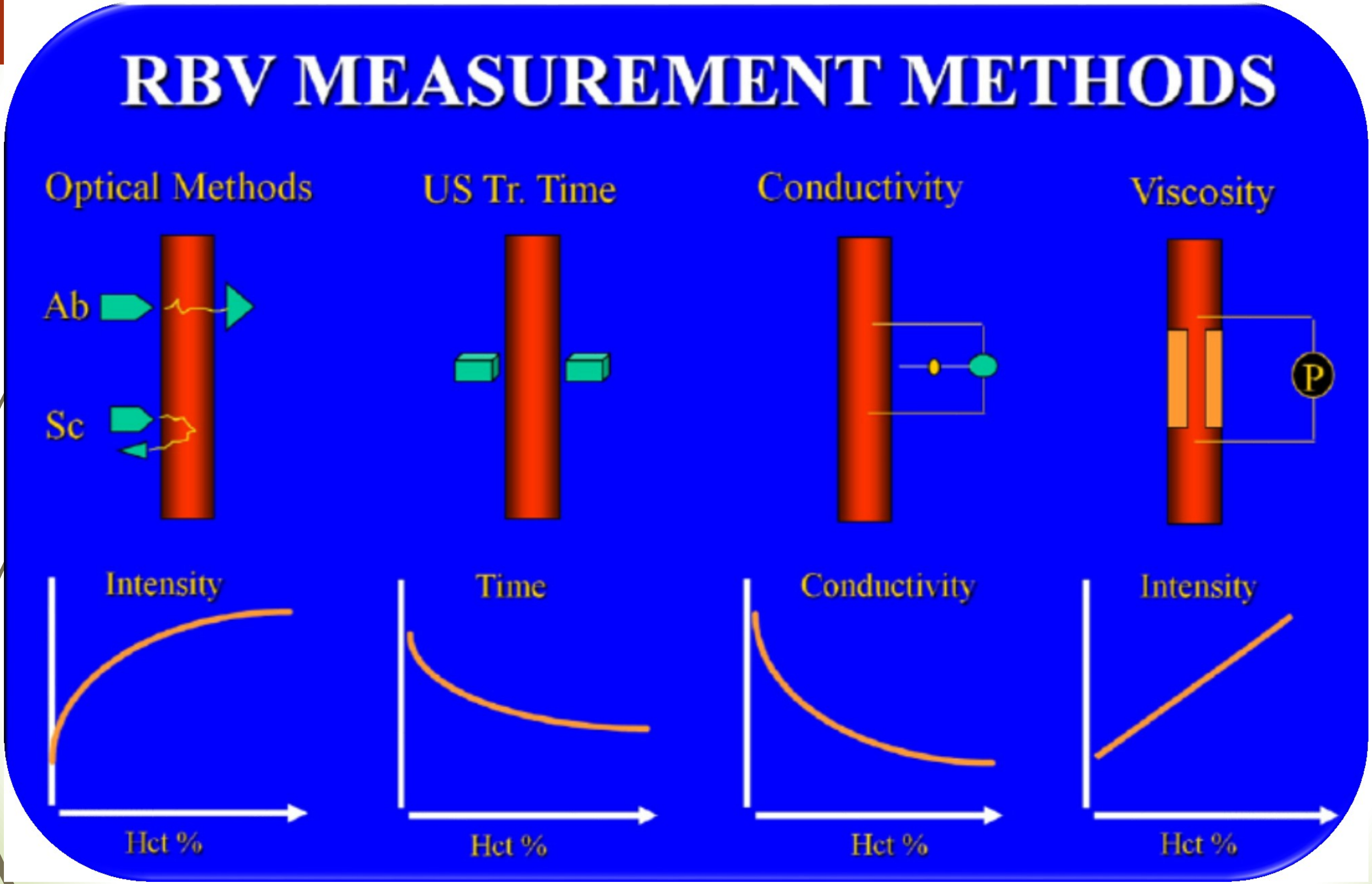
- The most common RBV sensors for HD are optical .
- Some ultrasound-based sensors also exist.

- Optical sensor is based on using a LED /photodiode system to measure hemoglobin (Hb) absorbance.

- Hb and Ht are measured by quantifying the absorption of monochromatic light in blood.

- Protein concentration is estimated from the velocity of sound waves in blood


RBV MEASUREMENT METHODS
Optical Methods
US Tr. Time
Conductivity
Viscosity
Ab
Sc
P
Intensity
Time
Conductivity
Intensity
Hct %
Hct %
Hct %
Hct %

BVM : Noninvasive devices

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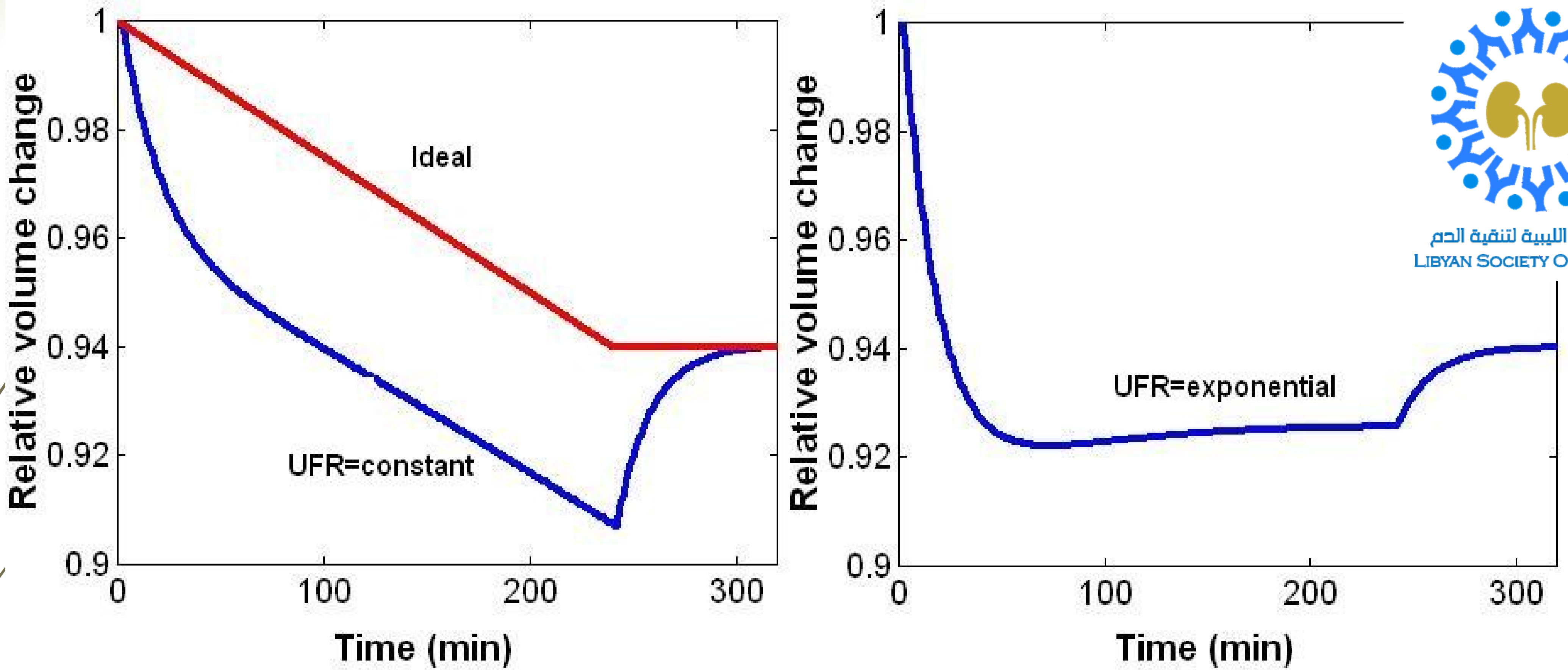
- **Stand-alone devices**
  - **(Crit-Line):** is made by Hema Metrics as an independent machine. This system uses a noninvasive optical method and measures the absolute value of Ht and oxygen saturation and through this, calculates the RBV changes, during the hemodialysis process.
- **Devices incorporated into the HD apparatus**
  - **BVM** (Blood volume monitor) Fresenius
  - **Hemoscan:** developed by Gambro-Hospal, uses another method and is installed on the dialysis machine, to function as a single device. This system measures the amount of Hb and calculates the changes of the RBV, according to the blood optical absorption
  - **Ultrasound techniques**
  - **Optical device (Nikkiso)**
  - **BVA-100 calculates BV using radiolabeled albumin (Iodine-131) followed by serial measures of the radioisotope.**

RBV devices differences

- RBV results differed systematically from those calculated from laboratory-derived hemoglobin changes.
- substantial differences observed in the RBV change between the different devices.
- the results from these devices should be considered as an estimate of ‘real’ RBV changes and that results of different devices are not interchangeable.



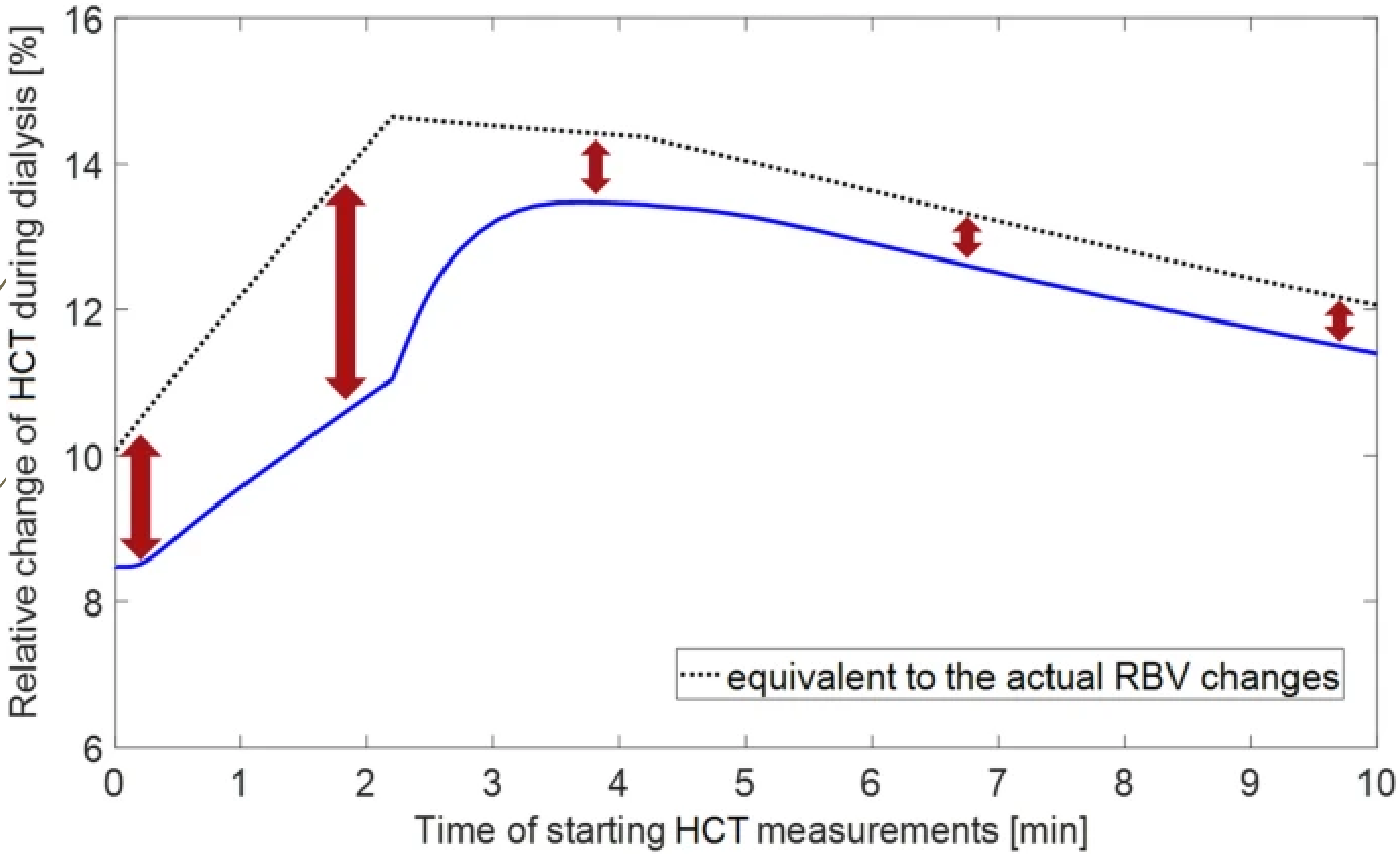
Volume trajectories.

Left panel: Ideal volume change (red line) and expected volume change with constant UFR producing an excessive drop in blood volume and a rebound after the end of ultrafiltration (blue line).

Right panel: Volume change with exponential decline in UFR with high UFR at the beginning and low UFR at the end of the ultrafiltration phase (notice the reduction in blood volume rebound).

Timing

The exact moment of starting the measurements of HCT changes in the arterial blood line has a significant impact on the obtained estimates of RBV changes during HD.



Relative change of HCT during dialysis [%]
16
14
12
10
8
6
0
1
2
3
4
5
6
7
8
9
10
Time of starting HCT measurements [min]
equivalent to the actual RBV changes

Sensitivity of RBV Monitoring for Fluid Status Assessment in Hemodialysis Patients

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- RBV significantly underestimates TBV during HD.
- The rise in F cell ratio strongly suggests that blood translocates from the microcirculation to the macrocirculation during HD, probably as a cardiovascular compensatory mechanism in response to intravascular volume depletion

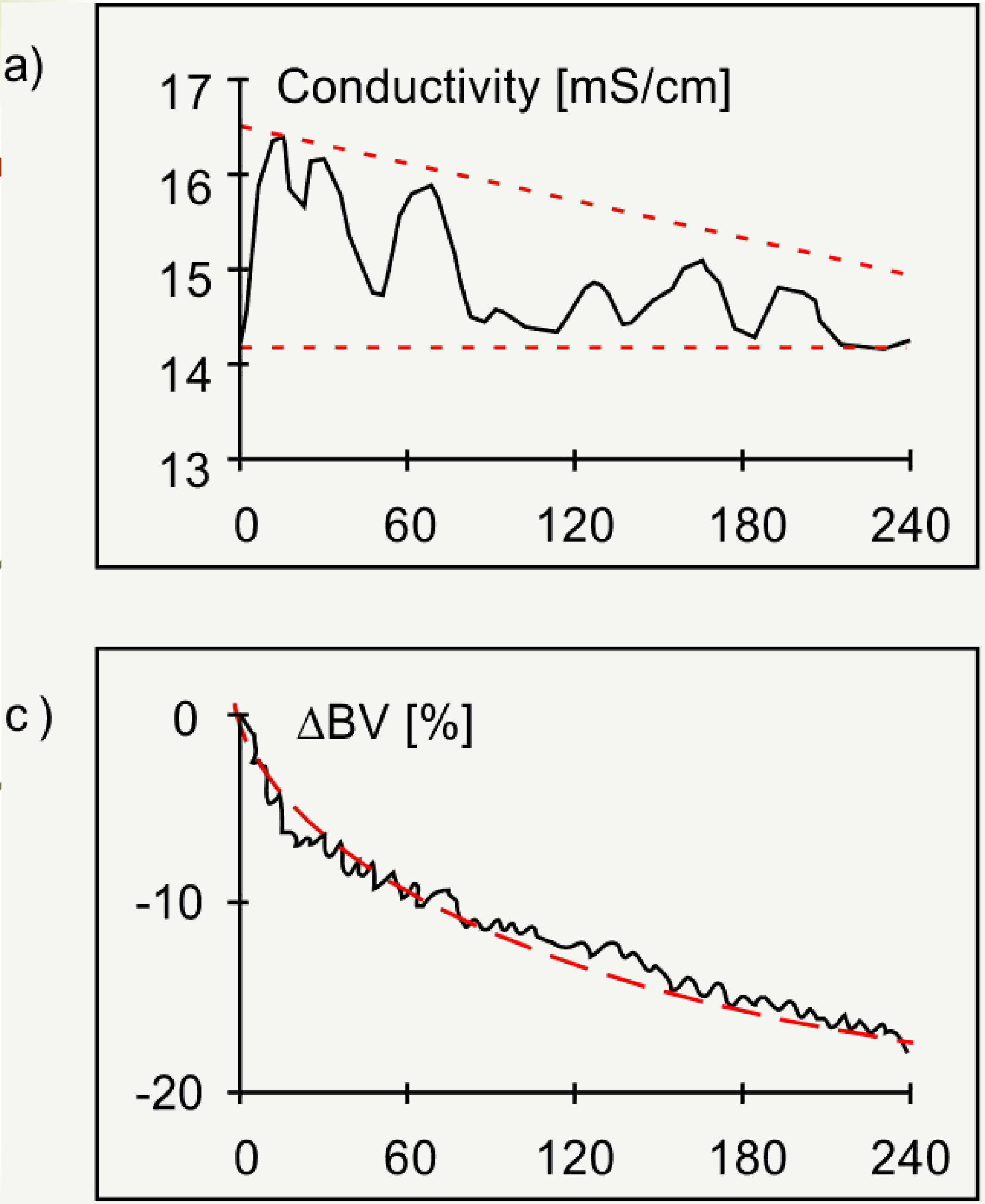
Problems with RBV measurements

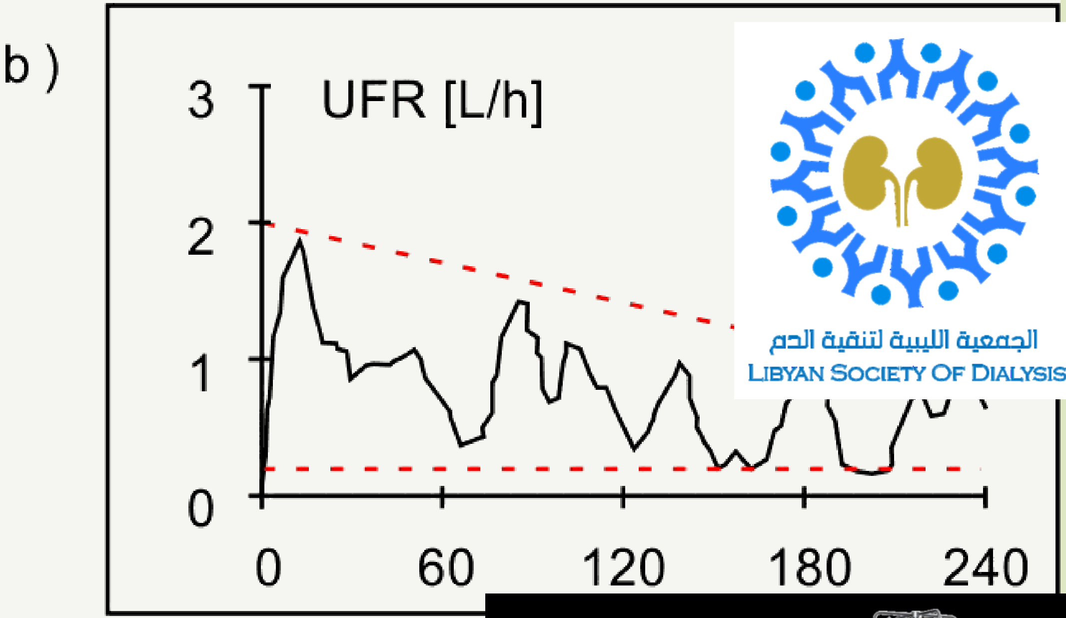
- Postural changes during first 30 mints of HD.
- Observed decrease in RBV underestimates changes in total blood volume.
- ?? Not as good in preventing hypotension.
- ?? Better at managing fluid overload.

- Another important limitation of relative blood volume measurements to bear in mind is that, as part of the intradialytic counter-regulation, blood shifts from the micro- to the macrocirculation.

- ✓ *Two patients with the same drop in relative blood volume can have very different absolute blood volumes at the end of the treatment.*

Can Technology Aid the Clinical Decision Process?





Hospal Hemoco

The concept of dry weight

DW definition over time

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Author	Year	Definition of dry weight
Thomson et al.55	1967	The body weight at which blood pressure is reduced to hypotensive levels, associated with no obvious causes other than ultrafiltration.
Henderson54	1980	The weight obtained at the conclusion of a regular dialysis treatment, below which the patient more often than not will become symptomatic and go into shock.
Charra53	1996	The body weight at the end of dialysis at which the patient can remain normotensive until the next dialysis despite the retention of saltwater (saline).
Sinha and Agarwall57	2009	The lowest tolerated post-dialysis weight achieved via gradual change in post-dialysis weight at which there are minimal signs or symptoms of either hypovolemia or hypervolemia.
van der Sande et al.59	2020	The body weight at which the patient is normotensive and has no clinical signs of fluid overload. In the presence of significant RRF, accept some degree of (BIS-defined) fluid overload.

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Dry weight issues:

- sodium balance
- fluid overload

Q &A

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- There are 3 major questions that must be answered if overhydration and its widespread prevalence in dialysis populations are to be improved:
- (1) What are the reasons for accumulation of salt and water?
- (2) What are the problems in removing this excess fluid load?
- (3) How can a dialysis prescription be constructed to calculate the appropriate ultrafiltration total volume and rate?

Dw assessment

- **Clinical assessments**

(Does not reflect the patient’s underlying illnesses and decreases in muscle mass)

  - Odema
  - Assessing congested neck veins.
  - Respiratory distress
  - BNP as a marker of fluid overload in hemodialysis.
- Ultrasound assessment of IVC diameter
- Lung ultrasound (LUS)
- BIS before and after hemodialysis
- BVA-100 device
- Sparse Laplacian regularized Random Vector Functional Link (SLapRVFL) !!

Fluid status groups based on symptoms and bioimpedance measurement.

	A	B	C	D
Clinically assessed fluid status	Overload	Overload	Depletion	Depletion
OH post (BIS measured)	≤ 0	> 0	> 0	≤ 0
Suggested clinical response	Decrease DW 0.5–1 kg/week	Decrease DW 0.5–1 kg/week	First treat malnutrition and inflammation.	Increase DW 0.5–1 kg/week
Plausible OH post target (L)	-2–0	±1	0–2	±1

Suggested clinical response, and over-hydration target, as defined by Recova®

Symptom scoring system

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1. Symptom Score

	Symptoms of fluid depletion (0-8 points)				Symptoms of fluid overload (0-8 points)		
	3	2	1	0	1	2	3
Dyspnoea at rest				Absence of symptoms	Recumbent	Two cushions	Sitting
Pretibial oedema					Weak	Severe	
Symptoms of FO between HD sessions					Unexpectedly low weight gain	Chronic coughing (new)	
Blood pressure increase					BP increase after UF		
Muscle cramps (calf)		Severe	Moderate				
Symptomatic IDH and ≥ 20 mmHg sBP decrease	Vomiting or unconscious-ness	Requiring saline infusion or stopped UF	Requiring position change				
Symptoms of FD between HD sessions	Dizziness, symptomatic hypotension	Limpness /tiredness	Thirst directly after HD				

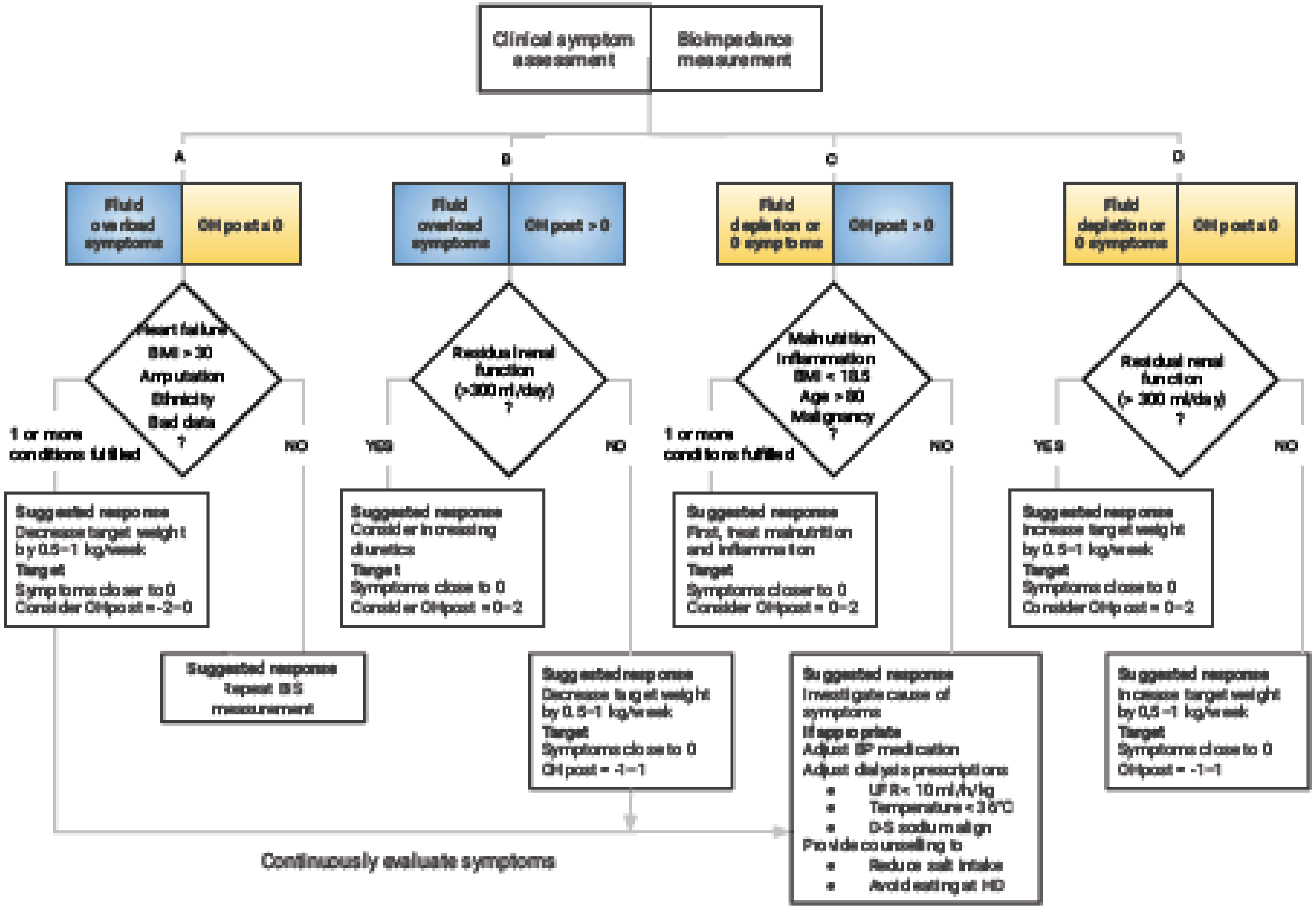
FO: fluid overload; HD: haemodialysis; IDH: intradialytic hypotension, sBP: systolic blood pressure; FD: fluid depletion

Recova® thresholds and triggers for action

2. Thresholds and triggers

SVS Score	Response	Action
0	Evaluation of target weight (DW) every second week	Bioimpedance measurement 2 – 4 times/year for assessment of hydration status and nutritional status
1 – 4	Target weight should be questioned	Inform registered nurse, who must assess the patient, and decide whether initiation of DW change is required or if symptoms may be explained by other known conditions (such as heart failure or advanced chronic obstructive pulmonary disease). Perform Bioimpedance measurement and evaluate according to decision aid. Repeat measurement at three occasions or until target weight is achieved.
5-6 or 3 in a single parameter	Target weight should be adjusted	Inform clinician for assessment. Perform Bioimpedance measurement without delay and evaluate according to decision aid. Repeat on three occasions or until achievement of target weight goal.
7 or more	Immediate need for evaluation of hydration status and target weight adjustment	Registered nurse to immediately inform the clinician

Recova flow chart algorithm.



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Fluid management: Conclusions

- Salt and water accumulation remain a **major problem** for dialys patients.
- It is important to define ways to minimize intra- and interdialytic salt and water accumulation to prevent excessive cardiovascular morbidity and mortality.
- Physicians must define effective ways to evaluate volume frequently and to **change the target weight prescription as needed**.
- Dry weight is the sine qua non of **adequate dialysis**, and patient outcomes should be better once these principles can be achieved.
- **A multidisciplinary approach**, dialysis facility practices, and frequency of dry weight adjustments have been shown to have positive implications for fluid status in hemodialysis patients

Machine-learning

Machine-learning-based artificial intelligence has been successfully applied in the medical field and has shown promising results in predicting complications.

- end

Thank you all for joining us

Tripoli
last
night