Online HD monitoring (BVM, OCM, BTM, etc.): Useful tools or fancy toys?

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Basics in Nephrology
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Therapeutical dilemma

- **High interdialytic volume increase**
  - Ultrafiltration $\uparrow$
  - Volume reduction $\uparrow$

- **Mortality $\uparrow$**
  - Intradialytic Hypotension

- Ultrafiltration $\uparrow$
  - Volume reduction $\uparrow$

- Mortality $\uparrow$
  - Intradialytic Hypotension
Technical solution?

High interdialytic volume increase → Mortality ↑ → Ultrafiltration ↑ → Volume reduction ↑ → Biofeedback Monitoring → Intradialytic Hypotension
Pathomechanism of intradialytic hypotension

- Ultrafiltration induces blood pressure instability, usually hypotension
"The true miracle is that these very primitive devices are able to provide several decades of survival time for the patients..."

Claude Jacobs  *NDT*  1999
What is actually „intradialytic hypotension?“...

- A critical threshold of blood volume decrease below which a relevant drop in blood pressure predictably occurs can not be defined.

- *Symptomatic* intradialytic hypotension occurs *individually* and is multifactorial in nature, and *not* simply dependent of blood volume reduction.
Intradialytic Hypotension

- Buffer
- Bio-compatibility
- Temperature
- Electrolytes
- Water Quality
- Blood Volume
- Medication

- Vascular Compliance
- Volume Status
- Heart
- Sympathetic Nerve System
ONLINE BIOFEEDBACK MONITORING
BLOOD VOLUME MONITORING
Gold standard of blood volume measurement

- $^{51}\text{Cr}$-labeled erythrocytes, or $^{131}\text{I}$-labeled human albumin
  - Expensive
  - Cumbersome
  - Not feasible in daily practice
Non-invasive continuous blood volume determination

- Measurement of **relative** blood volume (RBV) in *real-time*
- Principle: Preservation of mass (erythrocytes/Hk, protein)
- RBV change (in %) = \(((C_0/C_t) - 1) \times 100\)
  - \(C_0\) and \(C_t\): concentration of measured blood parameters at start and during HD
Physical methods to measure density of blood

Pros: Simple calibration  
Temperature sensitive

Cons: Sensitive to changes in osmolarity
Precision?
Additional module in blood lines required

Pros: Very precise  
Unsensitive to changes in osmolarity

Cons: Cumbersome calibration  
Temperature compensation
Additional module in blood lines required

Light beam

Ultrasound

Sender
Receiver

Sender
Receiver
Sonic velocity, temperature, hematocrit

- Sonic velocity in m/s
- Temperature °C
- Blood
  - HKT 50%
  - HKT 40%
  - HKT 30%
  - HKT 20%
  - HKT 10%
- NaCl 0.9%
- Water

Nephrology
Blood volume monitor display
Blood volume monitor: Display and graph

**Ultrafiltration**

Blood volume (%)

**Green area:**
UF starts with high rate, and is being reduced **continuously**

**Yellow area:**
UF rate is **reduced**

**Red area:**
Critical RBV is reached
UF is **stopped**
Conceputal limitations of non-invasive measurement of blood volume

- Measuring *relative* instead of *absolute* blood volume
Discrepancy between total (TBV) and relative blood volume (RBV)

N = 7 pts.

- For a “dry” patient: a bigger change (drop) in ΔRBV results
- Overestimation of ΔTBV

ΔRBV underestimates ΔTBV
ΔRBV overestimates ΔTBV
Factors affecting BVM

- **Volume and hydration status**

- **Blood homogeneity:**
  - Hematocrit is not the same in all vasculature compartments (arteries, veins, capillaries, venules, ...) → *Fahraeus effect/F cell ratio*
  
  - Relevant in case of a change in F ratio during dialysis:
    - Physical activity, temperature, upright position
      
      ➢ Results in a *volume shift* into the arterial compartment to maintain circulation
      
      ➢ **Underestimation of RBV reduction from volume removal** (= ultrafiltration) during dialysis
Change in F cell ratio during dialysis

Dasselaar JJ et al. CJASN 2007
Factors affecting BVM

- Volume and hydration status
- Blood homogeneity
- Eating
- Intradialytic physical activity or training
- Intravenous infusion of packed red cells or solutions containing albumin during HD
Not all systems/devices are equal... (in measuring \( \Delta \) RBV)

Comparison of measurement with BVM modul vs. measurement of Hb by laboratory method:
- ● after 2 hrs. HD; ○ after 4 hrs. HD
Blood volume monitoring

CLINICAL STUDIES
Warning!

- **No controlled studies exist** examining the correlation of *blood volume monitoring* with *intradialytic hypotension* → *clinical outcomes* (morbidity/mortality)!
Hematocrit as an indicator of blood volume and a predictor of intradialytic morbid events

- **Question**
  - Correlation of mean arterial blood pressure (MAP) with change in blood volume and hematocrit (Hk)?
  - Correlation between dialysis induced intravascular volume depletion and intradialytic complications (cramps, vertigo)?

- **Methodology**
  - Continuous optical measurement of hematocrit in 16 patients
Hematocrit as an indicator of blood volume and a predictor of intradialytic morbid events

• Results
  – MAP decrease correlates with increase in Hk in 10 of 16 patients (P < 0.05)
  – Low interindividual correlation between MAP and Hk
  – HD without complications was associated with lesser degree in blood volume changes (5.6 +/- 3.6 %/hr) versus treatments with consecutive complications (12.2 +/- 5.5 %/hr, P < 0.001)
  – Repeated complications occurred in 12 of 16 patients at a specific Hk (intraindividual correlation)
Hematocrit as an indicator of blood volume and a predictor of intradialytic morbid events

• Conclusion:
  ➢ An individual, patient specific Hk threshold *may be predictive* of critical blood pressure drop an associated complications
Blood pressure reduction during hemodialysis correlates to intradialytic changes in plasma volume

• Method:
  – Plasma volume measured by $^{125}$I-albumin and $^{51}$Cr-EDTA
Blood pressure reduction during hemodialysis correlates to intradialytic changes in plasma volume

- Results
  - \( \Delta \) blood pressure during HD correlates with \( \Delta \) body fluid
  - Drop in systolic BP correlates both with absolute \((r = 0.66, p < 0.05)\) and relative PV reduction \((r = 0.72, p < 0.02)\)
Blood pressure reduction during hemodialysis correlates to intradialytic changes in plasma volume

• Conclusion:
  - Plasma volume monitoring may be helpful for improvement of intradialytic hemodynamic control
Less symptomatic hypotension using blood volume controlled ultrafiltration

- **Methods**
  - Ultrafiltration rate based on predefined blood volume profil
  - Control conditions
    - Constant drop in relative blood volume (BV)
    - Faster decrease in BV during the first 60 minutes of dialysis
    - UF rate as high as possible
    - Reaching defined dry weight within (predefined) regular treatment time
    - 10 patients
Less symptomatic hypotension using blood volume controlled ultrafiltration

• **Results**
  – Significantly lesser hypotensive episodes and muscle cramps versus conventional/constant UFR

• **Conclusion**
  – BV controlled UF is an important step towards optimized dialysis therapy
Variability of relative blood volume during haemodialysis

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Department of Internal Medicine I, University Hospital Rotterdam–Dijkzigt, Rotterdam, The Netherlands

Table 1. Characteristics of the patients

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
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<tbody>
<tr>
<td>Age (years)</td>
<td>65.5 ± 11.9</td>
</tr>
<tr>
<td>Male/female</td>
<td>5/5</td>
</tr>
<tr>
<td>Dry weight (kg)</td>
<td>63.8 ± 11.8</td>
</tr>
<tr>
<td>Time on dialysis (years)</td>
<td>5.3 ± 2.5</td>
</tr>
<tr>
<td>Cardiac index (l/m²)</td>
<td>2.3 ± 1.1</td>
</tr>
</tbody>
</table>

• Only patients with > 1000 ml of volume removal were studied
Results

Table 2. Weight gain, ICV measurement, blood pressure, RBV, and ultrafiltration volume (mean of all sessions)

<table>
<thead>
<tr>
<th>Time (minutes)</th>
<th>Start</th>
<th>60</th>
<th>120</th>
<th>180</th>
<th>240</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>UV (ml/m²)</td>
<td>10.3 ± 1.7</td>
<td>386 ± 118</td>
<td>746 ± 184</td>
<td>1098 ± 254</td>
<td>1428 ± 311</td>
<td></td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>ICVD-exp. (mm²)</td>
<td>151.4 ± 20.6</td>
<td>151.1 ± 14.1</td>
<td>150.5 ± 18.6</td>
<td>148.1 ± 18.9</td>
<td>140.0 ± 17.3</td>
<td>7.3 ± 1.5</td>
<td>&lt;0.05</td>
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<tr>
<td>SAP (mmHg)</td>
<td>84.0 ± 7.1</td>
<td>82.7 ± 7.7</td>
<td>83.8 ± 6.5</td>
<td>83.6 ± 7.9</td>
<td>79.8 ± 7.7</td>
<td>6.2</td>
<td>&lt;0.001</td>
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<tr>
<td>DAP (mmHg)</td>
<td>73.9 ± 7.9</td>
<td>74.9 ± 10.1</td>
<td>76.9 ± 9.2</td>
<td>80.0 ± 9.2</td>
<td>81.3 ± 10.2</td>
<td>33.7</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>HR (b.p.m.)</td>
<td>-3.8 ± 2.5</td>
<td>-5.4 ± 2.8</td>
<td>-8.0 ± 3.2</td>
<td>-10.3 ± 3.6</td>
<td>314.5</td>
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<td>RBV (%)</td>
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ICV: Vena cava inferior
ICVD: V. cava inf. diameter
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Individual RBV patterns over time
Individual RBV patterns normalized for ultrafiltration volume („Entzug“)
Correlation with Δ relative blood volume

(a) Ultrafiltration volume (ml/m²) vs RBV (%): 
- r = -0.63 (p < 0.0001)

(b) Change in systolic blood pressure (%) vs RBV (%): 
- r = 0.16 (n.s.)
Correlation with $\Delta$ relative blood volume

V. cava inf. diameter
Incidence of hypotensive episodes

- Hypotension occurred in 7 HD treatments (2 patients)
- Intraindividual variability in ΔRBV during hypotensive episodes was high in both patients (patient 1: −9.2 to −16.0%; patient 7: −1.4 to −16.5%)
Conclusion

- RBV monitoring is *of limited use* in prevention of intradialytic hypotension
„Man versus machine“


→ **Versus:** UF modification by dialysis nurse based on observed changes in RBV via “manual” changes in UF rate and/or administration of volume

→ **Positive effect in preventing/reducing UF associated intradialytic hypotension...**
CONDUCTIVITY MEASUREMENT
Online conductivity measurement

• Multifunctional, measuring:
  – Dialysis dose (online-KtV)
  – Shunt volume (vascular access blood flow)
Concordance in electrolyte (Na⁺) and urea clearance

- **Diffusion coefficient at 37° C**

<table>
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<th>Na⁺</th>
<th>Urea</th>
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<td></td>
<td>1,94 × 10⁻⁵</td>
<td>2,20 × 10⁻⁵</td>
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</table>

- Babb AL, Maurer CJ, Fry DL, Popovich RP, McKee RE:
  The determination of membrane permeabilities and solute diffusivities with applications to hemodialysis
The basics of the OCM® measurement

- Dialysate outflow
- Conductivity detector “post”
- Dialysate inflow
- Blood inflow
- Blood pump
- Blood outflow
- Conductivity detector “pre”
- Rec. ?
- Fistula
- Dialyzer
The basics of the OCM® measurement

Dynamic conductivity pulse → measurement of Δ conductivity pre and post dialyzer. Ionic dialysance is translated into the resulting urea clearance by clinically validated algorithms.
Variables required to calculate urea clearance

- Inflow pulse area
- Outflow pulse area
- Dialysate flow
- Ultrafiltration rate
- Hematocrit
  - Precision of $k \sim \pm 5\%$

\[
\frac{k \times t}{V}
\]

→ Measurement of $\Delta$conductivity pre and post dialyzer
→ Translation into the resulting urea clearance by clinically validated algorithms
The OCM display
Limitations of OCM

• Affected by Na\(^+\) recirculation
  – Correction by integrated algorithm

• Ignores **urea rebound** after HD
  (\(\leftrightarrow\) actually making a correction by an arbitrary algorithm)

• Requires input of urea distribution volume (V)
  – „Default“ or estimation (anthropometric: i.e. Watson) or measurement (i.e. bioimpedance)
Validation of OCM based KtV determination

→ Underestimation of real KtV

Bioimpedance spectroscopy
Class. urea kinetic modelling
Simplified urea kinetic modelling
Validation of OCM based KtV determination

High interindividual variability
Benefits of online conductivity measurements (i.e. OCM FMC)

- Simple, free, non-invasive
- Helpful in determining the quantity/quality of the individual treatment session as well as changes over time

⇒ Helpful in monitoring intraindividual changes
Circulatory stability
Shunt recirculation

BLOOD TEMPERATURE MONITORING
BTM module Fresenius

- BTM inside
- BTM outside
- Heater
- Blood lines
- Temperature sensor
Recirculation measurement

- Dialysate
- Venous blood
- Arterial blood

T: Temperature
C°: Celsius

Graph showing temperature changes over time with recirculation start and result points.

Time (t/min): 0, 2, 4, 6, 8, 10, 12
Use of BTM module

• Lowering body temperature improves blood pressure stability mainly in *hypothermic* patients
  – Dialysate temperature should be tailored to the predialysis body temperature

• Measurement of shunt recirculation
CONCLUSIONS:
These results suggest that both *actively controlled body temperature* and UF profiled by online monitoring systems have **no significant impact on the incidence of intradialytic hypotension** in the ICU setting. Further research is needed before the use of these new sophisticated automatic methods can be applied routinely to the ICU setting.
SUMMARY & RECOMMENDATIONS
Personal recommendations

- **Conductivity measurement:** helpful to monitor dialysis quality and quantity (Kt/V) individually and over time
- **Blood temperature measurement:** helpful for timely detection of shunt recirculation
- Altogether probably not very helpful to reduce clinical endpoints (cardiovascular stability)
- No clinical outcome data available
EISERNER WILLE. DAS EINZIGE WERKZEUG, DAS MAN NICHT KAUFEN KANN.

HORBACH
Es gibt immer was zu tun.
“Nephrologists have an ethical responsibility not to lose interest in developing new technology”...

*James Tattersal, 2001*
Thank you for your attention!