Describing Cardiac ICU Patients' Fluid Transfer Characteristics Using System Analysis – a Proof of Concept

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Background

- Especially in an intensive care setting, the cumulative fluid balance (CFB) provides easy-to-assess and valuable information on the patient's current health status[1].
- A fluid overload of 10% of the baseline body weight is associated with an increased mortality[2-4] and should therefore be avoided.
- Modeling an individual patient's fluid transfer characteristics by considering as many relevant patient parameters as possible can be challenging and easily results in high dimensional and complex models, whose introduction into clinical practice can be difficult.
- Control system analysis is commonly used in technical fields for system description purposes and has already been applied in other areas aiming to model physiological systems[5-9].

Materials and Methods

- The CFB course of critically ill patients recovering from trauma has already been described qualitatively in literature[10-13]. Malbrain et al. suggested the ROSE model, which divides the recovery process into four subsequent stages: Resuscitation, Optimization, Stabilization and Evacuation. Figure 1 shows the CFB course to be targeted in intensive care.

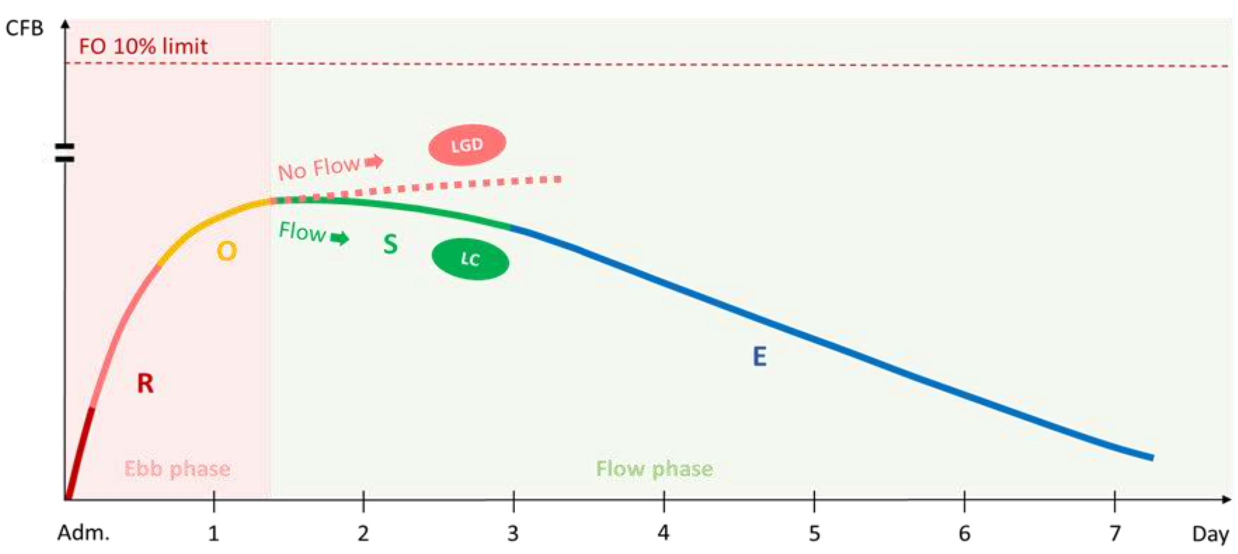

Figure 1: The constructed cumulative fluid balance course to be targeted in a postoperative patient staying at the intensive care unit for seven days based on recommendations from literature[10]. Cumulative fluid balance (CFB), Fluid overload (FO), Resuscitation phase (R), Optimization phase (O), Stabilization phase (S), Evacuation phase (E), Admission to ICU (Adm.), Late conservative fluid therapy (LC), Late goal-directed fluid therapy (LGD).

- A second order discrete-time transfer function (TF) was identified using a selected cardiac patient's individual cumulative fluid intake (CFI) and CFB as input series and output series respectively (Figure 2).

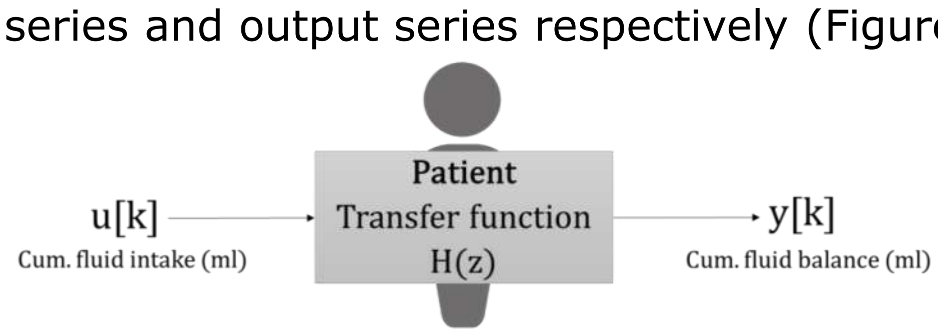

Figure 2: Cumulative fluid intake and cumulative balance series were used for identification of a transfer function H(z) describing the patient's fluid transfer characteristics.

- The patient's TF was estimated using the MATLAB System Identification Toolbox. Model verification was performed using MATLAB Simulink, whereby an approximated intake function fitted to the patient's CFI was used as input series.

Results

- The identified TF comprises a holistic description of the patient's characteristics influencing the individual reaction to administered fluids without necessity for measuring multiple and/or complex vital parameters.
- The model output of the estimated TF for a selected patient after application of the approximated CFI compared to the patient's actual CFB versus the averaged CFBs including four patients with similar lengths of stay are shown in Figure 3.

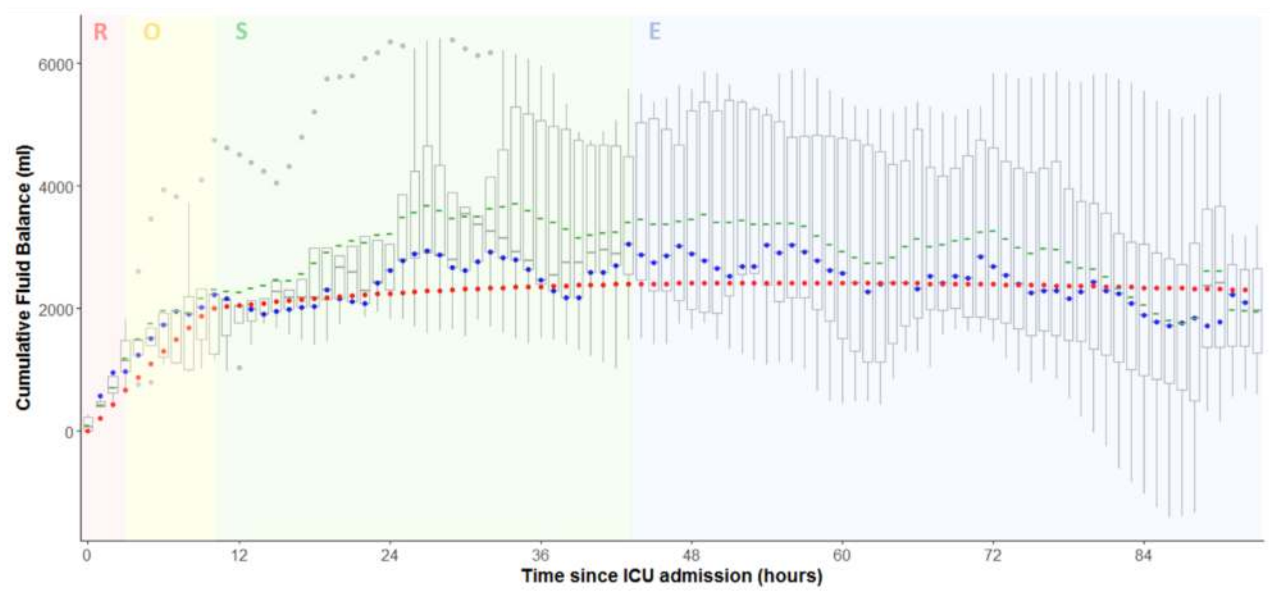

Figure 3: The output of the transfer function model (red) as response to the fitted cumulative intake matches the actual cumulative fluid balance (blue) of a selected patient which is compared to the overall mean cumulative fluid balance (green) including four patients having a similar length of stay. Resuscitation phase (R), Optimization phase (O), Stabilization phase (S), Evacuation phase (E).

Discussion

- In general, the lengths of the four subsequent recovery phases depend on the clinical course of the respective patient.
- Insensible fluid losses and orally or pulmonally administered medications were not considered in fluid balance calculation.
- A second order model is sufficient for describing a patient's CFB course and shows a good congruence with the documented patient data. A TF of higher order does not result in a justifying increase of goodness of fit.

Conclusion

- Individual TFs may help in detecting patients being non-responsive to late conservative fluid therapy at an early stage of postoperative fluid therapy.
- Estimating a patient's response to different fluid application regimes may be difficult.
- Transfer function models provide a valuable option for describing fluid transfer characteristics of ICU patients.
- Clustering the individual patients' TFs within a large patient population with respect to diagnosis or other patient features might allow the definition of cohort-specific model parameters.
- Patient-specific TFs might act as a key tool reflecting the actual patient within control loops being an essential base for providing decision support in fluid administration.

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B|BRAUN SHARING EXPERTISE

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