SIMULATION OF PLASMA SODIUM KINETICS DURING HEMODIALYSIS SESSIONS: VALIDATION AND COMPARISON OF SINGLE- AND DOUBLE-POOL MODELS

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INTRODUCTION

Changes in the body sodium (Na^+) pool play a pivotal role in the genesis of dialysis related complications: serum Na^+ decrease can cause intradialytic cardiovascular instability and hypotension, while a higher interdialytic weight gain can be related to serum Na^+ increase with risk of hypertension[1].

Dialysate fluid sodium concentration is one of the main factors responsible for the optimal sodium balance achievement.

Mathematical models can be used to describe the evolution of plasma sodium concentrations ([Na]pl) allowing to investigate its kinetics and elucidate the effect of dialysis prescription.

AIM OF THE STUDY

The aim of the study was to assess and compare the accuracy of single- and double- pool mathematical models in predicting intradialytic plasma sodium concentration.

METHODS

Single-pool model (Fig.1A): the Na^+ distribution volume equals the total body water based on the assumption that the equilibrium between intra- and extra-cellular pools, in response to an osmotic variation in the extracellular space, is almost instantaneous. So, a single pool kinetics is assumed for Na^+[2].

Double-pool model (Fig.1B), mainly derived from[3]: the concept of the intra- and the extra-cellular volumes is introduced, modeling the fluid exchange across the cellular membrane caused by the osmotic concentration gradient. The amount of solute exchanged at the cellular membrane depends on the intra- and extra-cellular concentration and takes into account the mass transfer coefficient, proportional to the velocity of the exchange process, and the ratio between intra- and extra-cellular solute concentration at equilibrium.

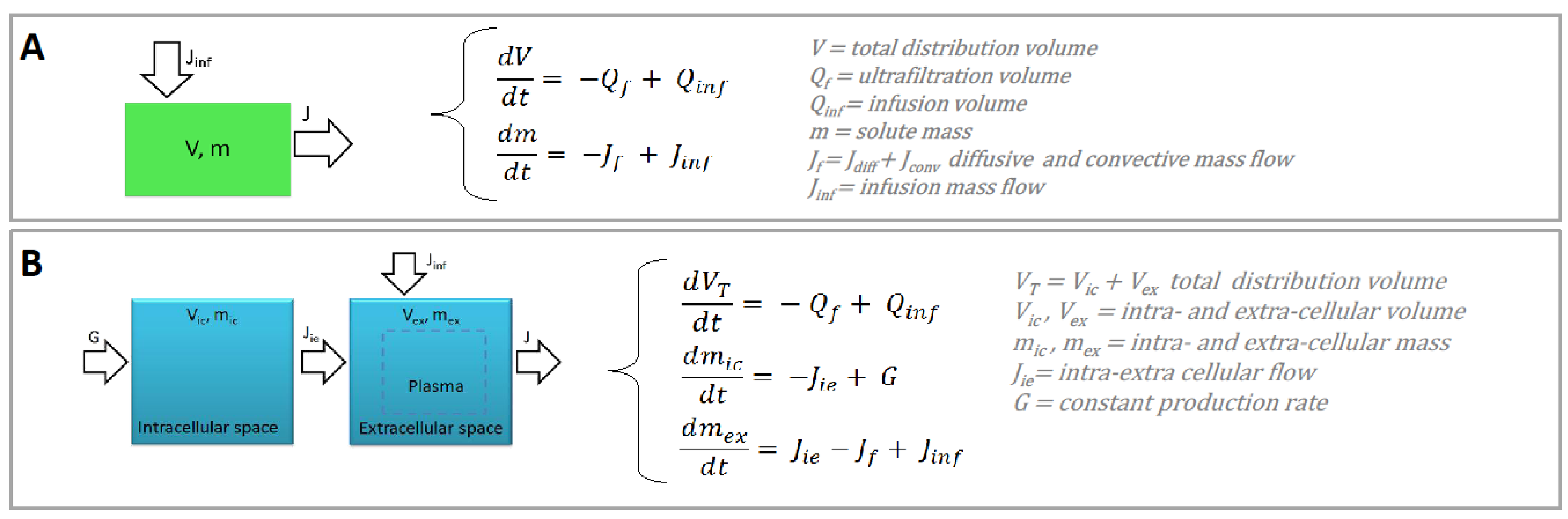

***Fig. 1** – Schematic representation of single- (A) and double-pool models (B) based on solute mass balance and distribution volume conservation equations*

Single- and double-pool models have some common features: 1) ignoring the presence of a residual renal function; 2) describing solute removal through diffusion and convection; 3) taking into account the possible presence of infusion fluid.

Both the models were validated using data collected in a Clinical Study, during which the HemoControl (HC, Gambro biofeedback system) was used in combination with standard hemodialysis (HD) and on-line hemodiafiltration (OL-HDF). Models' performances were assessed by comparing the predicted [Na]pl (Na_{SIM}) with the experimental data (Na_{LAB}), measured by an ion-selective electrode.

RESULTS

144 sessions with 6 patients were considered (12 HD and 12 OL-HDF per patient).

Comparing the two models we found:

- more pronounced fluctuations in the single-pool [Na]pl than in the double-pool one, in response to the prescription imposed by Hemocontrol system (Fig.2-3)
- higher correlation between simulated [Na]pl (Na_{SIM}) and experimental Na (Na_{LAB}) in the double-pool model: R=0.83 vs 0.62 (Fig.4 A,B)
- lower average deviation of the difference between Na_{LAB} and Na_{SIM} for the double-pool model: 1.83 mmol/L vs 3.37mmol/L (Fig.4 C,D)
- the double-pool model is almost unbiased (mean error=0.04 mmol/L Fig.4D)
- a negative bias (-1.33 mmol/L) in the single-pool model, meaning the average overestimation of the experimental [Na]pl (Fig.4C)
- more accurate ($p<0.05$) end-dialysis (ED) [Na]pl predicted by the double-pool model (Fig.4E)

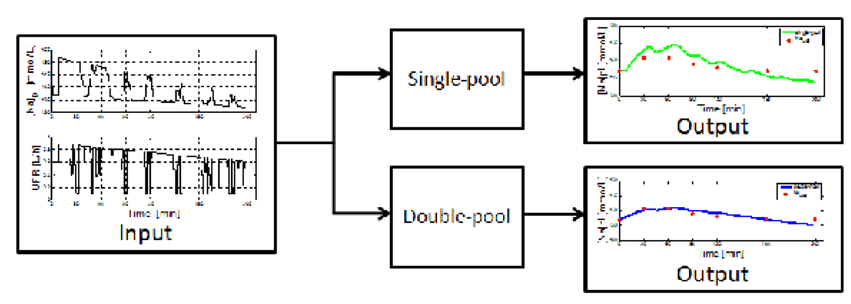

***Fig.2** - Scheme of input (sodium concentration in the dialysate, $[Na]_D$, and ultrafiltration rate, UFR) and output variables ([Na]pl) of the models*

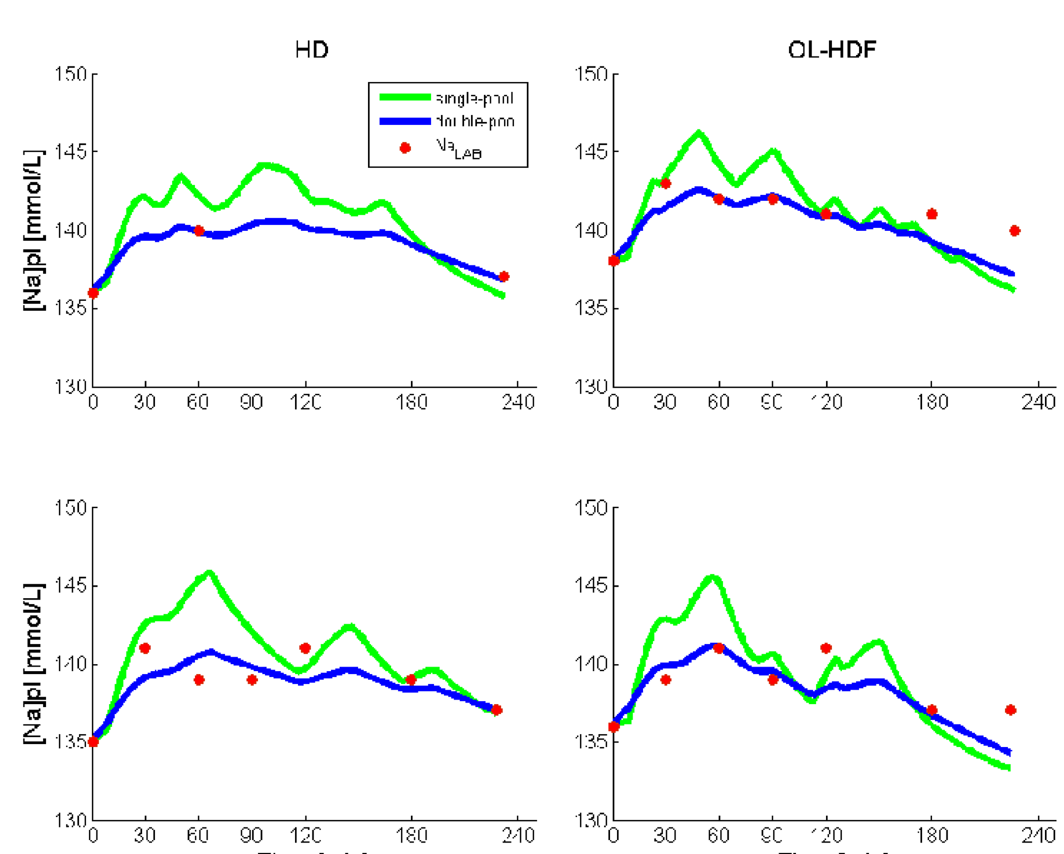

***Fig.3** - Examples of intradialytic kinetics of [Na]pl in HD and OL-HDF (both with Hemocontrol) simulated by single- (green) and double-pool (blue) model. The red circles are the experimental [Na]pl (Na_{LAB})*

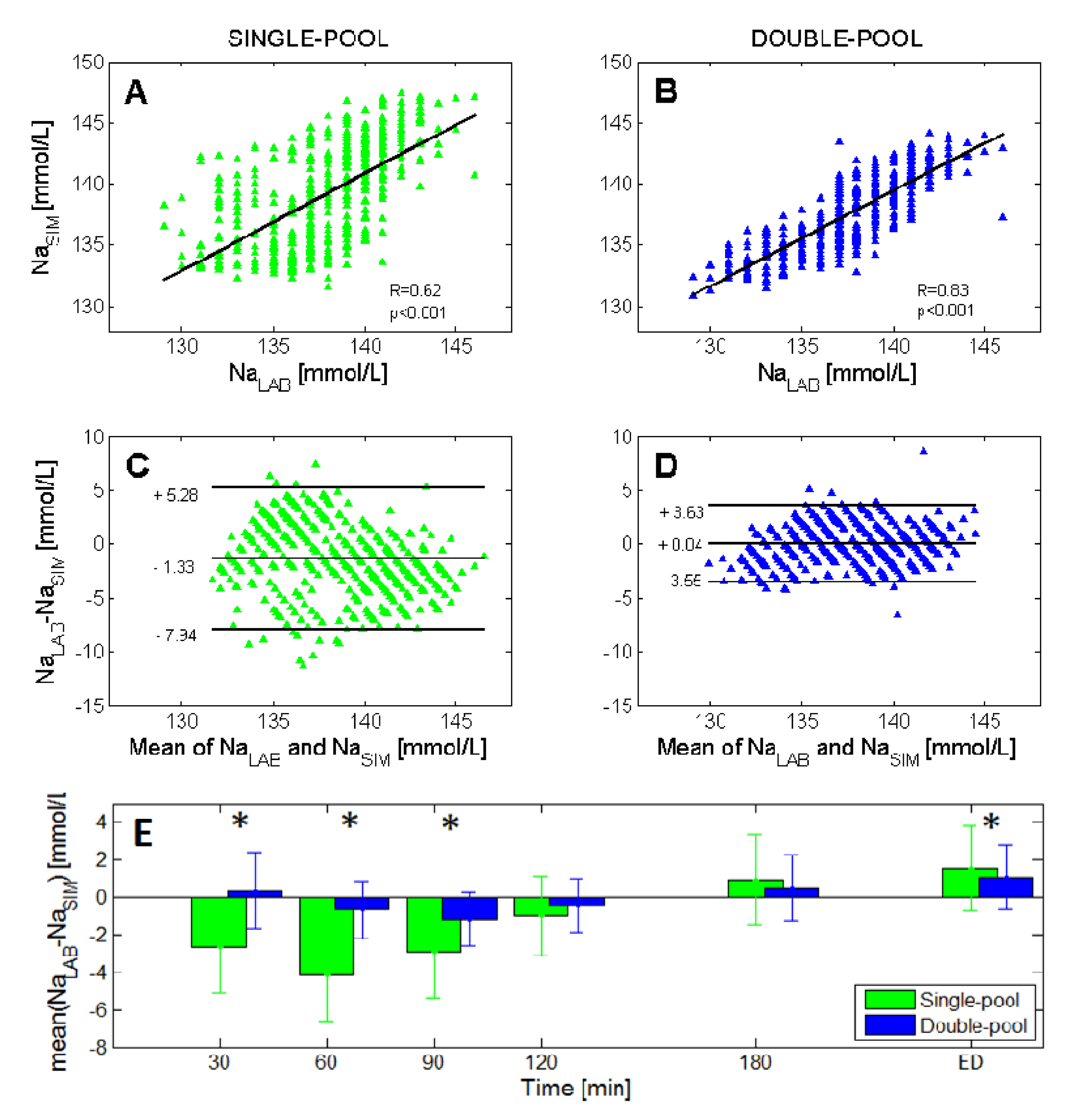

***Fig.4** - A, B: Correlation between Na_{SIM} and Na_{LAB} in single- and double-pool models. C,D: Bland-Altman plot comparing plasma Na measured by laboratory (Na_{LAB}) and simulated by the models (Na_{SIM}). E: mean and SD of the difference between Na_{LAB} and Na_{SIM} in the intradialytic and end-dialysis (ED) time instants (* p<0.05).*

CONCLUSIONS

Due to its more accurate description of solute fluxes between body compartments, the double-pool model better reproduces plasma sodium kinetics during sessions than the single-pool model does.

Moreover, the double-pool model's 95% confidence interval is comparable to the accuracy of the instrument used as benchmark (± 3 mmol/l). Hence, the double-pool model is better suited to be integrated into control systems and used as a tool to adapt dialysis prescription to patient status.

References

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