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Efficacy of Automatic Dynamic Ultrafiltration Compared to Constant Ultrafiltration Methods on Hypovolemic Intradialytic Symptoms: A Single-center Experience

Articoli originali

Maria Rita Stancanelli[1], Giuseppe Restivo[1], Maria Eva Sberna[1], Veronica Cucci[2], Veronica Santina Fortunato[2], Salvatore Gianna[2], Francesco Scofano[2], Vincenzo Calabrese[2]

1 Unit of Nephrology and Dialysis, Department of Medicine and Surgery, Hospital of Enna “Umberto I”, 94100 Enna, Italy
2 Unit of Nephrology and Dialysis, Department of Medicine and Surgery, University of Enna "Kore", 94100 Enna, Italy.

Vincenzo Calabrese

Corresponding author:
Vincenzo Calabrese,
University of Enna “Kore”, Enna, 94100, Italy
E-mail: v.calabrese@outlook.it,
Tel: +39-3208736905

ABSTRACT

Background. Hypovolemic intradialytic complications, including cramps, fatigue, and hypotension, are common in hemodialysis patients. Bioimpedance spectroscopy is the gold standard for fluid assessment, but it is not available in all dialysis centers. Ultrasound techniques can help clinicians, but they are operator-dependent and time-consuming. Ultrafiltration control (UF-control), a newer technology, allows for continuous monitoring of real-time blood volume changes (RBV%) and it adjusts ultrafiltration rates optimizing plasma refilling. This study aims to evaluate UF-control’s effectiveness in reducing hypovolemia-related events and post-dialysis weight adjustments in chronic dialysis patients.

Methods. We enrolled 21 chronic hemodialysis patients, each undergoing 3 treatments with standard constant UF and 3 treatments with UF-control modalities. Hypovolemia-related events were recorded both individually and as a composite outcome. An individualized “critical RBV%” was determined for each patient, with UF-control programmed to avoid dropping below this threshold. Data were analyzed using the Wilcoxon signed-rank test and generalized linear mixed models (GLMM), adjusted for interdialytic weight gain (IDWG) and the difference between prescribed and effective ultrafiltration.

Results. Hypovolemia-related symptoms were reduced from 32% in the constant UF setting to 7% in UF-control setting ($p = 0.007$). Similarly, intradialytic hypotension decreased from 18% to 4% ($p = 0.022$). GLMM analysis confirmed UF-control’s significant effect (adj-OR: 0.12, 95% CI: 0.06–0.26, $p = 0.004$). UF-control also enabled dynamic adjustments to post-HD weight in most patients, with no signs of fluid overload observed.

Conclusions. UF-control seems to actually reduce hypovolemic events in dialysis patients and provides a valuable tool for personalized fluid management. This technology can optimize patient tolerance and facilitate precise, session-by-session, dry weight adjustments.

KEYWORDS: Dry weight, Hemodialysis, Water control, UF-control

Introduction

Intradialytic cramps, fatigue, and hypotension are common clinical manifestations in patients experiencing hypovolemia. These symptoms may manifest in the context of absolute or effective hypovolemia, the latter occurring when plasma refilling is slower than the ultrafiltration rate. Accurate assessment and management of volume status is crucial for the safety and quality of dialysis treatments [1].

Bioimpedance spectroscopy represents the gold standard for assessing fluid status in dialysis patients, but it is not available in all dialysis centers. Some ultrasound-based techniques, such as the detection of B-lines, lung comet-tail artefacts, or the more recently introduced Venous Excess Ultrasound Score (VExUS score), can help clinicians. However, they are operator-dependent and entail a considerable expenditure of clinical time and professional resources, limiting their practical use in daily clinical workflows. Furthermore, these tools are likewise not available across all dialysis centers [2].

Recent advances in dialysis technology introduced Ultrafiltration control (UF-control), which operates by continuously monitoring the real-time change in blood volume, computing the relative blood volume percentage (RBV%), and instantaneously regulating the ultrafiltration (UF) rates based on this feedback [3]. By adjusting ultrafiltration in response to hemoconcentration changes, UF-control aims to optimize plasma refilling and reduce hypovolemia-related symptoms.

The objective of our study was to evaluate the clinical effectiveness of UF-control in reducing hypovolemia-related events in a sample of chronic dialysis patients in a real-world clinical setting, where Bioimpedance spectroscopy is not available. In addition, we aimed to assess how UF-control may facilitate adjustments to a patient's post-HD weight and to analyze the discrepancies between prescribed and actual fluid removal.

Methods

We conducted a prospective observational study involving 21 chronic hemodialysis patients, for a total of 126 dialyses. Each patient underwent dialysis sessions of 4 hours using two modalities: initially with standard constant UF settings, in which the post-HD weight was detected through classical methods, and subsequently with the UF-control module activated. Each patient underwent 3 treatments with constant UF setting and 3 treatments with UF-control. This study was approved by the government direction of our institution with protocol number I0049080 of April 28, 2025. All patients signed written informed consent.

Intradialytic hypotension, muscle cramps, and post-dialysis fatigue were systematically recorded as hypovolemic signs. Intradialytic hypotension was defined as systolic blood pressure <90 mmHg or a difference of more than 30 mmHg from baseline, while muscle cramps and post-dialysis fatigue were reported subjectively by patients. These were clustered into a composite outcome representing hypovolemia-related events.

UF-control works by decreasing ultrafiltration when hemoconcentration increases, which suggests inadequate refilling. Instead, low hemoconcentration reduction increases the UF when there is a sign of insufficient fluid removal. These adjustments are made automatically and instantaneously, optimizing the plasma refilling process and reducing hypovolemia-related manifestations. Furthermore, UF-control allows for small variations in dry weight that can be clinically imperceptible during individual treatments, enabling the dynamic modulation of a patient's post-HD weight on a session-by-session basis.

Before implementing UF-control, we determined an individualized "critical RBV%" for each patient over three dialysis sessions, used as a washout period. It is defined as the lowest RBV% reached

without the onset of hypovolemia-related symptoms. Once established, UF-control was programmed to avoid dropping below this critical RBV%, dynamically adjusting UF in real-time.
Data were collected on each session, both before and after the implementation of UF-control, recording if the composite outcome occurred and calculating the percentage of sessions affected by hypovolemia for each patient. The number of dialyses with UF-control was 50% of the total dialysis included in the analysis, with a temporal line of one month to reduce time-dependent bias. The Fresenius 5008S or Nipro monitor was used for the dialysis treatment. The first works with a variation of 500 g up or down the estimated UF, while Nipro works with an ultrafiltration up to 1.5 times the desired UF, as measured by various dialysis monitors.

Demographic and clinical variables, including age, sex, comorbidities, and interdialytic weight gain (IDWG), were also recorded. Data distribution was evaluated through the Kolmogorov-Smirnov test and graphical evaluation. The Wilcoxon signed-rank test for paired samples was used to compare the proportion of sessions with hypovolemia-related events before and after UF-control. The generalized linear mixed model (GLMM) was employed to assess the effect of UF-control on the composite outcome, with the patient ID as a random effect. Each GLM model was adjusted for IDWG and the difference between prescribed and effective ultrafiltration.

Overload was monthly detected through echographic VCI evaluation and pulmonary B-lines.

Results

A total of 21 patients were included in the analysis, with a median age of 73 [69-77] years. Thirteen were male (62%), and all had a history of hypertension pharmacologically treated, while heart failure was diagnosed in only one patient. In total, 126 dialysis sessions were analyzed (Table 1).

Implementation of UF-control resulted in a median increase in effective UF volume of 100 g for the session (interquartile range: –100 to +400 g). In detail, effective UF increased in 39 sessions and decreased in 22 sessions, compared to the corresponding prescribed UF.

Variable	
Age, year, median [IQR]	73 [69-77]
Sex, male n (%)	13 (62%)
BMI (kg/m^2), median [IQR]	25 [22-28.5]
Type 2 DM, n (%)	11 (52%)
Hypertension, n (%)	21 (100%)
Heart failure, n (%)	1 (5%)
IDWG, median [IQR]	2400 [1700-3000]

Table 1. Baseline features. DM: diabetes mellitus; IDWG: interdialytic weight gain.

During the four-month follow-up after UF-control implementation, post-dialysis weight adjustments were made in nearly all patients. In 11 patients, post-HD weight was reduced (range: –600 g to –2300 g), while in 6 patients it was increased (range: +600 g to +3000 g). In four patients, the weight remained unchanged.

The percentage of dialysis sessions manifesting hypovolemia-related symptoms declined from 32% during standard UF sessions to 7% with UF-control (p = 0.007) (Figure 1). Similarly, the incidence of intradialytic hypotension decreased from 18% to 4% (p = 0.022).

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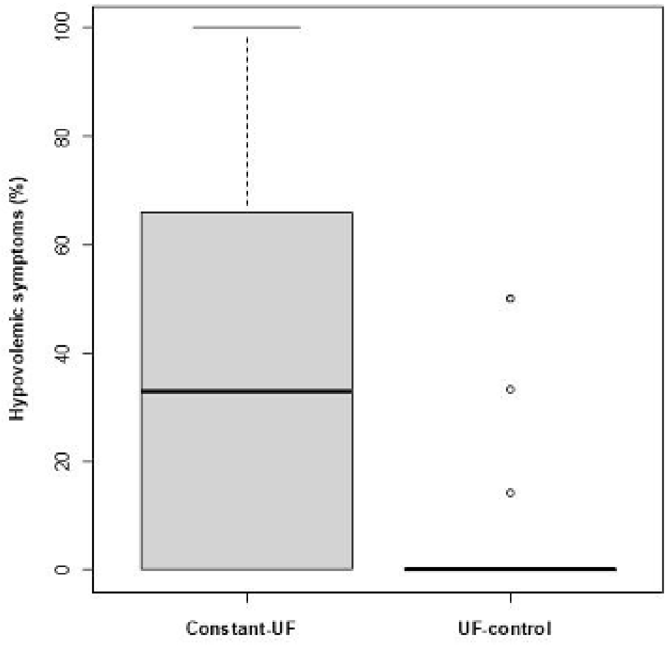

Figure 1. Comparison between Constant-UF and UF-control.

GLMM analysis confirmed a statistically significant effect of UF-control in reducing the risk of hypovolemia-related events (OR: 0.13, 95% CI: 0.07–0.24, p = 0.004). This association remained significant after adjusting for IDWG and the difference between prescribed and effective UF (adjusted OR: 0.12, 95% CI: 0.06–0.26, p = 0.004). Neither IDWG nor the difference between prescribed and effective UF had a statistically significant effect on outcomes (p = 0.53 and p = 0.58, respectively).

No signs of fluid overload were observed during the four-month follow-up, except one peritibial monolateral edema without echographic signs of hypervolemia. Indeed, Inferior Vena Cava collapsibility was higher than 30% and no B-lines were detected.

Discussion

Our study supports the clinical utility of UF-control modules in hemodialysis machines. UF-control seems to reduce hypovolemia-related symptoms, including fatigue, cramping, and intradialytic hypotension, by adapting the ultrafiltration rate based on real-time changes in blood volume. Furthermore, UF-control provides a novel and automated indicator to fine-tune a patient's post-HD weight, detecting subtle imbalances that may otherwise go unnoticed session-by-session.

This is particularly valuable considering that even minor discrepancies in dry weight estimation can accumulate over time, leading to chronic fluid imbalance or progressive cardiovascular strain. As fluid tolerance varies day-by-day, session-level optimization may prevent long-term complications [4].

Maintaining euvolemia is one of the greatest clinical challenges, both in elderly and comorbid patients, i.e. diabetes, heart failure, and autonomic dysfunction. Indeed, these conditions can exacerbate the difficulties in volume homeostasis and may increase the risk of intradialytic symptoms. In this setting, UF-control provides a practical tool for real-time and individualized fluid management based on intravascular dynamics and allows clinicians to identify early trends of fluid mismanagement [5].

The observed discrepancies between prescribed and actual fluid removal highlight the challenge of

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accurately predicting fluid needs based on static clinical assessments. UF-control seems to minimize this gap, ensuring more precise volume management [6]. In this line, our analysis showed that UF-control is able to modulate the effective UF, either increasing or decreasing it. This demonstrates the UF-control's ability to personalize fluid removal to each session's intravascular response.

This is of particular importance, given that small fluctuations in fluid status are often undetectable by conventional clinical assessment but may significantly impact patient well-being [7]. These micro-adjustments are frequently influenced by external factors such as dietary salt intake, interdialytic weight gain, and vascular refill rates, which are not captured through conventional assessments. Therefore, automated volume-guided systems may act as a bridge between clinical observation and physiological variability [8].
In this light, UF-control supports a more personalized dialysis, reducing long-term cardiovascular events.

Potential limit of UF-control includes the determination of the individualized "critical RBV%". Indeed, incorrect critical RBV could cause fluid overload. Furthermore, a deep staff training is needed to correctly interact with the monitor's advice about the continuous changes in the intradialytic concentration.
Furthermore, intradialytic hypotension is strongly related to Cardiovascular events [9]. In detail, dialysis patients are characterised by high vascular stiffness with reduced ability of adapting to difference in arterial pressure. For this, intradialytic hypotension seems to be associated with impaired coronary perfusion [10, 11].
Although few small observational studies evaluated the efficacy of the UF-control on the hypovolemic manifestation [12], our analysis highlighted this effect, adjusting for the intrasubject variability with a model for repeated measures, UF targets and IDWG, enhancing internal validity. Furthermore, no other study enrolled patients without frequent hypotension. A key strength of our study, distinguishing it from previous observational data, is the inclusion of patients across a spectrum of intradialytic hypotension risk, including those at low risk. This strategy was employed to minimize selection bias and ensure that the observed effects of the UF-control module were not solely exaggerated by an enrollment limited to highly unstable individuals. Enrolling all patients, the external validity is increased due to the general hemodialysis population has been included in the analysis. A limitation of our study is the small and non-randomised sample. Indeed, as a pivotal study, we enrolled patients who perform dialysis in a single center. Furthermore, only Caucasian patients were included, and this reduced the generalizability of our results.

Conclusion

Our findings suggest that the implementation of UF-control in dialysis practice appears to improve patient tolerance and suggest that it could reduce the intradialytic complications. It can be useful mostly in the absence of advanced monitoring tools like bioimpedance or ultrasound. Future perspectives should be based on patient-reported outcomes (PROs), such as post-HD symptoms and the quality of recovery. Furthermore, larger and longitudinal studies, including bioimpedance as a comparator, with diversified populations will be performed to confirm the UF-control efficacy in a longer follow-up and advanced artificial intelligence can be implemented for better weight control.

Data availability statement

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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