Clinical Application of Bioelectrical Impedance Analysis for Fluid Assessment in Hemodialysis Patients

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Abstract

Background: Fluid overload is common in maintenance hemodialysis (MHD) patients and is associated with adverse cardiovascular events and mortality. Conventional clinical methods for fluid assessment have limited accuracy. This study evaluated the effectiveness of bioelectrical impedance analysis (BIA) for the fluid evaluation in MHD patients.

Methods: A prospective interventional study was conducted in 34 clinically stable MHD patients at Ranong Hospital from June to August 2025. Fluid status was assessed monthly using BIA, combined with standard of care, and dry body weight was adjusted accordingly. The outcomes were the change in fluid status, expressed as target average fluid overload (TAFO), dialysis-related complications, and blood pressure control before and after BIA-guided management.

Results: At baseline, 67.6% of patients were fluid overloaded, 20.6% were normovolemic, and 11.8% were dehydrated. In the overloaded group, mean TAFO significantly decreased from 3.4 ± 2.8 L to 2.1 ± 2.8 L at 3 months ($p = 0.001$). Dehydrated patients shifted toward normovolemia, while normovolemic patients remained stable. Dialysis-related complications, including intradialytic hypotension and hypertension, symptoms of cramps and fatigue, improved significantly in the overload group. The mean number of antihypertensive drug classes was also substantially reduced.

Conclusions: BIA-guided fluid management improved fluid control in MHD patients, resulting in reduced dialysis-related complications and fewer anti-hypertensive drug classes. These findings support integrating BIA into standard clinical practice for individualized volume management, particularly in patients with fluid overload.

Keywords: volume overload; CHF; dialysis; kidney failure; ESKD; ESRD; heart failure

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การประยุกต์ใช้ทางคลินิกของการวิเคราะห์องค์ประกอบร่างกายด้วยไฟฟ้าเพื่อประเมินภาวะสารน้ำในผู้ป่วยฟอกเลือดด้วยเครื่องไตเทียม

นิชนันท์ กาญจนสุภัค

หน่วยไต แผนกอายุรกรรม โรงพยาบาลระนอง

บทคัดย่อ

บทนำ: ภาวะน้ำเกินเป็นปัญหาที่พบบ่อยในผู้ป่วยโรคไตเรื้อรังระยะสุดท้ายที่ได้รับการฟอกเลือดด้วยเครื่องไตเทียม ซึ่งสัมพันธ์กับภาวะแทรกซ้อนด้านหัวใจและหลอดเลือดและเพิ่มอัตราการเสียชีวิต การประเมินสารน้ำด้วยวิธีทางคลินิกมีความแม่นยำจำกัด เครื่องวิเคราะห์องค์ประกอบร่างกายด้วยไฟฟ้า (Bioelectrical Impedance Analysis; BIA) จึงถูกนำมาใช้เป็นเครื่องมือเสริมเพื่อประเมินภาวะสารน้ำและปรับน้ำหนักแห้ง งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาประสิทธิผลของการใช้ BIA ในการควบคุมสมดุลสารน้ำในผู้ป่วยฟอกเลือด

ระเบียบวิธีวิจัย: การศึกษาเชิงทดลองไปข้างหน้าในผู้ป่วยโรคไตเรื้อรังระยะสุดท้ายที่ได้รับการฟอกเลือดที่มีอาการคงที่จำนวน 34 ราย ณ โรงพยาบาลระนอง ตั้งแต่เดือนมิถุนายนถึงสิงหาคม พ.ศ. 2568 โดยทำการประเมินสารน้ำด้วย BIA เดือนละ 1 ครั้ง ควบคู่กับแนวทางปฏิบัติในการปรับสมดุลสารน้ำให้อยู่ในเกณฑ์มาตรฐาน เพื่อศึกษาการเปลี่ยนแปลงของสมดุลสารน้ำ ภาวะแทรกซ้อนระหว่างการฟอกเลือดและความดันโลหิตก่อนและหลังการใช้เครื่อง BIA

ผลการวิจัย: การศึกษานี้รวบรวมผู้ป่วย 34 ราย กลุ่มน้ำเกินร้อยละ 67.6, กลุ่มสมดุลสารน้ำปกติร้อยละ 20.6 และกลุ่มขาดน้ำร้อยละ 11.8 ปริมาณสารน้ำเฉลี่ยในร่างกายของผู้ป่วยกลุ่มน้ำเกินลดลงอย่างมีนัยสำคัญจาก 3.4±2.8 ลิตร เหลือ 2.1±2.8 ลิตร ที่ 3 เดือน ($p = 0.001$) ปริมาณสารน้ำเฉลี่ยในร่างกายในกลุ่มขาดน้ำมีการปรับเข้าสู่ภาวะปกติ และกลุ่มสารน้ำปกติมีความคงที่ ภาวะแทรกซ้อนระหว่างฟอกเลือดลดลง เช่น ความดันต่ำ ความดันสูง และอาการตะคริวดีขึ้น จำนวนชนิดยาลดความดันที่ใช้ลดลงอย่างมีนัยสำคัญ (2.7±1.6 เหลือ 2.1±1.7; $p = 0.036$)

สรุป: การใช้ BIA ช่วยปรับสมดุลสารน้ำในผู้ป่วยฟอกเลือดด้วยเครื่องไตเทียมได้อย่างมีประสิทธิภาพ พร้อมทั้งลดภาวะแทรกซ้อนและชนิดของยาลดความดันโลหิต ผลการศึกษานี้สนับสนุนการนำเครื่อง BIA มาบูรณาการในเวชปฏิบัติมาตรฐาน เพื่อการจัดการปริมาณน้ำแบบเฉพาะราย โดยเฉพาะในผู้ป่วยที่มีภาวะน้ำเกิน

คำสำคัญ: น้ำท่วมปอด; หัวใจวาย; ฟอกไต; ล้างไต; ไตวาย; ไตวายระยะสุดท้าย

Introduction

Fluid overload is common, occurring in 30–43% [1,2] of patients with end-stage kidney disease (ESKD) undergoing hemodialysis (HD), and is associated with adverse health outcomes such as hypertension, left ventricular hypertrophy, malnutrition, systemic inflammation, and increased mortality.[3,4] Conversely, hypovolemia in hemodialysis patients may result in complications including intradialytic hypotension, vascular access thrombosis, muscle cramps, fatigue, reduced urine output, and increased mortality.[5] Therefore, the assessment and control of fluid balance are important in this patient group.

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Currently, most dialysis centers evaluate fluid status based on clinical symptoms, physical signs, and blood pressure measurements. However, these methods have low sensitivity and specificity, leading to limited accuracy. Thus, tools that accurately measure body fluid volume are necessary.

According to the Kidney Disease: Improving Global Outcomes (KDIGO) 2020 guidelines,[5] the evaluation of fluid status should be based on history taking, physical examination, and blood pressure measurement. However, more precise tools such as Bioimpedance Analysis (BIA) and extracellular volume measurement (NaBr) can be used as adjuncts. Among these, BIA offers advantages in convenience, rapidity, and accuracy.[6,7] Nevertheless, BIA is not yet widely used in clinical practice due to its high cost and limited accessibility. The 2022 Thai Hemodialysis Clinical Practice Guidelines recommend regular reassessment of dry weight accuracy, suggesting clinical evaluation along with adjunctive tools such as BIA or lung ultrasound in patients with hypertension, and BIA or inferior vena cava diameter measurement in patients with intradialytic hypotension.[8]

Therefore, this study aims to compare the outcomes of fluid assessment using standard methods (history taking, physical examination, and blood pressure measurement) alone versus standard methods combined with BIA in hemodialysis patients at Ranong Hospital Dialysis Center, to evaluate the effectiveness of BIA as an adjunct tool for fluid balance management in HD patients.

Materials and methods

Study Design and Population

This prospective study was conducted at the HD center of Ranong Hospital, Thailand, between June and August 2025. Thirty-four adult (age > 18 years) ESKD patients undergoing maintenance HD for at least 3 months were enrolled. Exclusion criteria included: (1) severe intradialytic blood pressure instability, defined as intradialytic hypotension requiring any inotropic drug or hypertension with target organ damage within the preceding month; (2) major limb amputation; (3) pregnancy or breastfeeding; (4) the presence of a pacemaker or metallic device within the body. Ethical approval was obtained from the local ethics committee, and all participants provided written informed consent.

All patients underwent a standard 4-hour HD session. The patients received dialysis twice or three times weekly, depending on their residual kidney function, dialysis adequacy, and clinical symptoms. Pre- and post-dialysis body weight and blood pressure were recorded at each session. Standard laboratory parameters were obtained monthly. Intradialytic symptoms (e.g., hypotension, cramps, fatigue) were documented.

Outcomes

The primary outcome is the change in the proportion of HD patients with fluid overload who achieve normal fluid status before and after the use of BIA. Secondary outcomes include changes in blood pressure control, the number of antihypertensive medications, and dialysis-related complications. These complications include intradialytic hypotension, defined as a decrease in systolic blood pressure of ≥20 mmHg or a decrease in mean arterial pressure of ≥10 mmHg accompanied by symptoms or requiring intervention,[5] intradialytic hypertension,[5] defined as an increase in systolic blood pressure of >10 mmHg from pre- to post-dialysis, as well as symptoms of muscle cramps and fatigue, assessed before and after the use of BIA.[5]

BIA and adjustment of dry body weight

Fluid status was assessed monthly using a bioimpedance spectroscopy device (Body Composition Monitor [BCM]; Fresenius Medical Care, Germany). Measurements were performed pre-dialysis with the patient in a supine position. Data quality was verified using the Cole plot; results were recorded only if the curve was continuous and symmetric, and the quality factor (Q) was> 85%.

In BIA, targeted absolute fluid overload (TAFO) represents the absolute difference (in liters) between a patient's measured extracellular fluid volume and the predicted "normal" fluid volume for that individual (based on body composition). Positive values indicate fluid excess, and negative values indicate fluid deficit. Because fluid accumulation varies across interdialytic intervals, weekly TAFO [1] was used to standardize the assessment. TAFO was calculated as the mean of pre- and post-dialysis fluid overload values measured within a week. For the thrice-weekly schedule, TAFO was the average of three pre-dialysis and three post-dialysis values. For the twice-weekly schedule, TAFO was calculated as the average of two pre-dialysis and two post-dialysis values. The target TAFO in this study was 0.5 L, based on large-scale data from Fresenius NephroCare centers,[7] with an acceptable tolerance range of±0.75 L.

Two approaches for calculation have been described:

Thrice-weekly schedule: The average of three predialysis (FOpre) and three postdialysis (FOpost) values measured within the same week:

$$\text{Average weekly TAFO} = \frac{F0pre1 + F0pre2 + F0pre3 + F0post1 + F0post2 + F0post3}{6}$$

Twice-weekly schedule: The average of two predialysis and two postdialysis values:

$$\text{Average weekly TAFO} = \frac{F0pre1 + F0pre2 + F0post1 + F0post2}{4}$$

The dry body weight was reassessed monthly. Adjustments were made by modifying ultrafiltration targets, with changes of approximately 0.5 kg per week. Patients were categorized as fluid overload (TAFO >+1.25 L), normovolemia (TAFO between –0.25 L and +1.25 L), and dehydration (TAFO < –0.25 L)

Statistical Analysis

Data were analyzed using STATA version 14.2 (StataCorp, TX, USA). Continuous variables were summarized as the mean ± standard deviation (SD) or median (range) as appropriate. Categorical variables were expressed as frequencies and percentages. Changes in TAFO over time were analyzed using paired t-tests. Correlations between TAFO and clinical parameters were assessed using mixed-effects regression models. A p-value <0.05 was considered statistically significant.

Results

Baseline characteristics of all patients

The study flow diagram is shown in **Figure 1**. Of 39 patients screened, 5 were excluded: two with limb amputation, one with a pacemaker, one with unstable blood pressure, and one planning transfer to another dialysis center. A total of 34 patients were included in the final analysis.

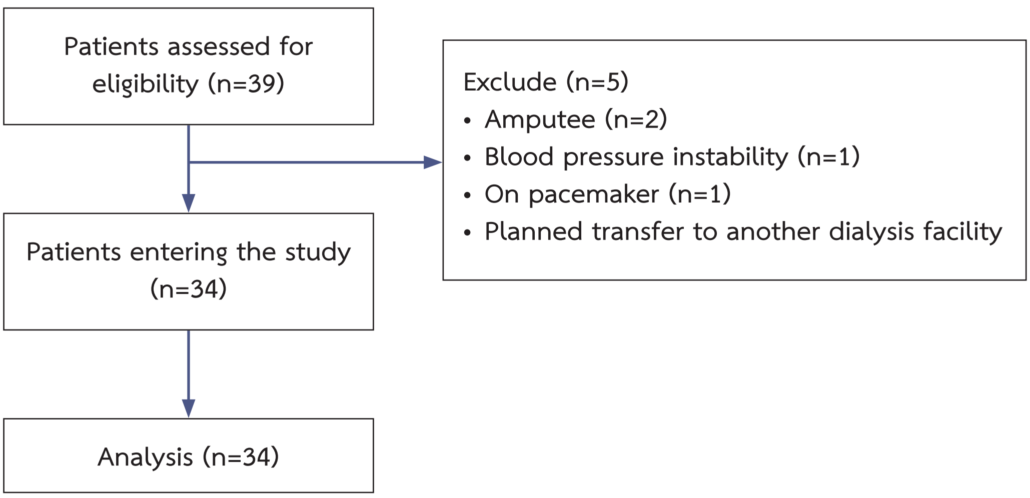

Figure 1 Study Flow Diagram

Baseline characteristics and laboratory data of all patients are shown in **Table 1**. Hemodialysis frequency was evenly distributed between 2 and 3 sessions per week. The average estimated dry weight at baseline was 57.2±11.5 kg, compared with 56.0±12.6 kg after BIA, yielding a mean difference of 1.2±3.6 kg. At baseline, 23 (67.6%) patients had fluid overload, 7 (20.6%) patients were normovolemic, and 4 (11.8%) patients had dehydration.

Table 1 Baseline characteristics, laboratory data, and fluid status of all patients

Parameters	Statistics
Age (years); median (min, max)	65 (22, 89)
Gender; n (%)	
Male	18 (52.9)
Female	16 (47.1)
Body Weight (kg); mean±SD	59.1±12.2
Height (cm); mean±SD	159.5±9.3
Body Mass Index (kg/m^2); mean±SD	23.2±4.3
Underlying diseases; n (%)	
Diabetes mellitus	19 (55.9)
Hypertension	32 (94.1)
Coronary artery disease	7 (20.6)
Stroke	4 (11.8)
Dialysis vintage (months); median (min, max)	36 (7, 294)
Residual kidney function (ml); mean ± SD	448.3±305.2
Types of vascular access; n (%)	
Tunnel cuffed catheter	4 (11.8)
Arteriovenous fistula	27 (79.4)
Arteriovenous Graft	2 (5.9)
Double-lumen catheter	1 (2.9)
Dialysis frequency; n (%)	
Twice weekly	17 (50.0)
Thrice weekly	17 (50.0)
Medications	
Antihypertensive drugs	30 (88.2)
Erythropoietin dose (unit/week); median (min, max)	5878 (1000, 36000)

Table 1 Baseline characteristics, laboratory data, and fluid status of all patients (continued)

Parameters	Statistics
Laboratory data	
Hematocrit (%); mean ± SD	30.2±3.9
Albumin (g/dl); mean ± SD	3.3±0.4
Blood pressure (mmHg); mean±SD	
Systolic blood pressure	145.1±23.0
Diastolic blood pressure	75.6±14.9
Home blood pressure monitoring (mmHg); mean±SD	
Systolic blood pressure	147.6±15.5
Diastolic blood pressure	77.1±10.9
Estimated dry weight before BIA (Kg); mean±SD	57.2±11.5
Initial dry weight by BIA (Kg); mean ± SD	56.0±12.6
Difference in dry weight (Kg); mean ± SD	1.2±3.6
Pre-dialytic weight (kg); mean±SD	59.5±12.3
Fluid status defined by TAFO (kg); median (min, max)	3.2 (-0.3, 14.6)
Initial TAFO group; n (%)	
Dehydrated status (< -0.25 L)	4 (11.8)
Nomovolemic status (-0.25 to 1.25 L)	7 (20.6)
Overloaded status (> 1.25 L)	23 (67.6)

BIA, bioimpedance analysis; TAFO, targeted absolute fluid overload

Changes in TAFO fluid status

Changes in TAFO from baseline during the study period are summarized in **Tables 2, Figure 2,** and **Figure 3**. In the overload group, TAFO significantly decreased from 3.4±2.8 L at baseline to 2.4±2.3 L at 1 month (p = 0.001), 2.1±2.4 L at 2 months (p = 0.002), and 2.1±2.8 L at 3 months (p = 0.001). The downward trend demonstrated effective reduction of fluid overload, with a marked decline during the first two months and stabilization thereafter. The box plot confirmed not only a reduction in median TAFO but also a narrower interquartile range and fewer extreme outliers, indicating more uniform fluid control.

In the dehydration group, TAFO increased from −1.5±0.6 L at baseline to 1.0±1.3 L at 1 month (p = 0.052), 0.3±0.4 L at 2 months (p = 0.008), and 0.5±1.1 L at 3 months (p = 0.030). These findings suggest that BIA-guided adjustment improved hypovolemia towards normovolemia, with variability decreasing over time. In the normovolemia group, TAFO remained stable throughout follow-up (0.4±0.3 L at baseline, 1.0±0.7 L at 1 month, 0.8±0.5 L at 2 months, and 0.7±0.9 L at 3 months; all p > 0.05). Both line and box plots showed consistently narrow interquartile ranges within the normal zone, confirming that BIA-guided management maintained fluid stability.

Table 2 Changes in TAFO status from baseline

TAFO group	Time						
	Baseline	1 month	p-value	2 months	p-value	3 months	p-value
Dehydration	-1.5±0.6	1.0±1.3	0.052	0.3±0.4	**0.008**	0.5±1.1	**0.030**
Normovolemia	0.4±0.3	1.0±0.7	**0.059**	0.8±0.5	0.124	0.7±0.9	0.441
Overload	3.4±2.8	2.4±2.3	**0.001**	2.1±2.4	**0.002**	2.1±2.8	**0.001**

TAFO, targeted absolute fluid overload

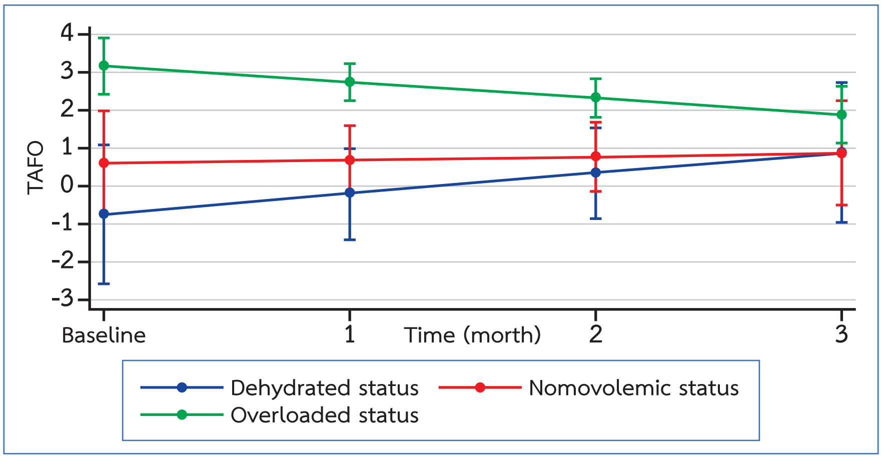

Figure 2 Changes in TAFO status from baseline during the study period

TAFO, targeted absolute fluid overload

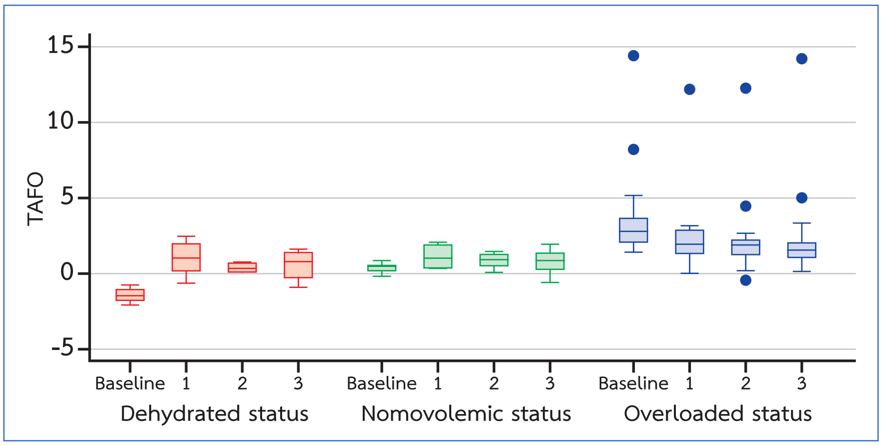

Figure 3 Box plot graphs of the changes in TAFO status from baseline

TAFO, targeted absolute fluid overload

Dialysis-related complications

Table 3 presents dialysis-related complications in the overload group during the study period. Intradialytic hypotension occurred in 21.7% of patients, with the mean number of episodes decreasing from 10.2±9.3 to 4.2±4.5. Intradialytic hypertension was reported in 34.8%, with a reduction in mean episodes from 8.1±6.6 to 3.6±5.1. Other complications included cramp (21.7%), fatigue (17.4%), and volume overload (13.0%, all of which showed improvement after BIA-guided management. Hospitalization occurred in 21.7% of patients due to other conditions such as gastrointestinal bleeding, ischemic heart disease, cellulitis, diabetic foot, and septic arthritis.

Table 3 Dialysis-related adverse events in the overload group (N=23)

Events	
Intradialytic hypotension; n (%)	5 (21.7)
Before the study (episodes); mean ± SD	10.2±9.3
End of the study (episodes); mean ± SD	4.2±4.5
Intradialytic hypertension; n (%)	8 (34.8)
Before the study (episodes); mean ± SD	8.1±6.6
End of the study (episodes); mean ± SD	3.6±5.1
Cramps; n (%)	5 (21.7)
Before the study (episodes); mean ± SD	2.2±1.8
End of the study (episodes); mean ± SD	1.6±0.5
Fatigue; n (%)	4 (17.4)
Before the study (episodes); mean ± SD	2.0±1.8
End of the study (episodes); mean ± SD	1.0±0.0
Volume overload; n (%)	3 (13.0)
Before the study (episodes); mean ± SD	1.7 (0.6)
End of the study (episodes); mean ± SD	1.3 (0.6)
Hospitalization; n (%)	5 (21.7)
Residual kidney function (ml); mean ± SD	
Before the study (n = 15); mean ± SD	313.3±233.4
End of the study (n = 12); mean ± SD	331.67±257.5
Other complications; n (%)	
Arteriovenous fistula malfunction	1 (4.4)

The average number of antihypertensive drug classes was significantly reduced after BIA (2.7±1.6 vs. 2.1±1.7; p = 0.036). A decline in the number of pills from baseline was also observed, but the difference did not reach statistical significance (4.7±4.0 vs. 4.0±4.8; p = 0.127) **(Table 4)**. There was no significant association between TAFO with systolic blood pressure (P=0.87), while a positive correlation was observed with diastolic blood pressure (Coefficient 0.03; 95% CI, 0.001 to 0.05; p = 0.004). **(Figure 4)**.

Table 4 Antihypertensive drugs in the overload group (n = 23)

Antihypertensive drugs	Before	After	p-value
Number of drug classes; mean ± SD	2.7±1.6	2.1±1.7	**0.036**
Number of pills (tablets or capsules); mean ± SD	4.7±4.0	4.0±4.8	0.127

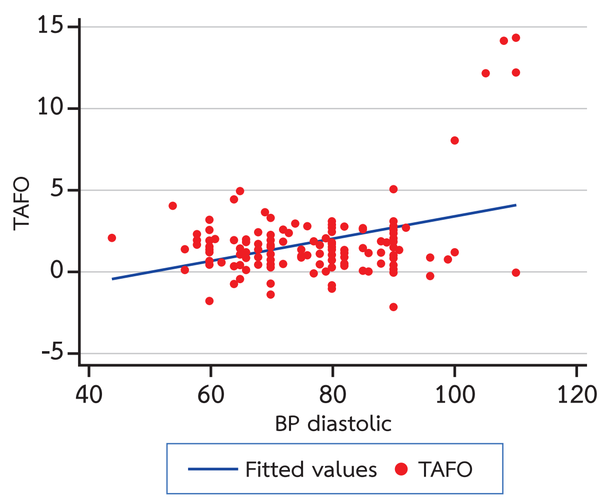

Figure 4 Correlation between targeted absolute fluid overload (TAFO) and diastolic blood pressure

Discussion

This prospective interventional study evaluated the effectiveness of BIA in combination with standard clinical practice for fluid management in maintenance HD patients. The main findings were that BIA improved fluid balance by reducing overload, correcting hypovolemia, and maintaining normovolemia; reduced dialysis-related complications; and decreased the number of antihypertensive drug classes.

The present study shows that TAFO decreased in the overload group, decreased in the dehydration group, and remained stable in the normovolemia group. These findings are consistent with previous reports supporting the role of BIA in guiding dry weight assessment and fluid management in HD patients. The previous study demonstrated that BIA-guided management led to a reduction in TAFO by −1.20 ± 1.32 L ($p < 0.01$) in fluid-overloaded patients, stability in normovolemic patients ($p = 0.59$), and an increase of 0.59±0.76 L ($p = 0.02$) in dehydrated patients.[1]

In addition, BIA was associated with reductions in dialysis-related complications in the overloaded group. Regarding blood pressure, we found that diastolic blood pressure was positively correlated with TAFO, although a similar association was not observed with systolic blood pressure. Notably, the mean number of antihypertensive drug classes was significantly reduced after BIA implementation. Our findings differ from previous studies that showed significant correlations between changes in fluid status and blood pressure.[1 9-10] Every 1 L change in TAFO resulted in a 9.9 mmHg change in systolic blood pressure,[1] while the DRIP trial found a −6.6 mmHg reduction in systolic pressure per kg of post-dialysis weight reduction.[9] While the present study did not assess left ventricular mass index (LVMI), due to the relatively short follow-up duration, another study demonstrated an improvement in LVMI with BIA-guided fluid management.[11]

The findings support recommendations from KDIGO (2020)[5] and the Thai Hemodialysis Clinical Practice Guideline (2022).[8] Both of which advocate the integration of adjunctive tools such as BIA for reassessment of dry weight, particularly in patients with uncontrolled hypertension or intradialytic blood pressure instability. While BIA is not yet widely used due to financial and logistical constraints, this study adds local evidence that its use is feasible and clinically beneficial in an HD unit.

The strengths of this study included its prospective design, systematic evaluation across different volume status groups, and integration of both clinical and pharmacological outcomes. Limitations include the lack of a control group, a relatively small sample size, a single-center design, and a short follow-up period, which precluded evaluation of long-term outcomes. The absence of a control group also limits causal inference, though withholding intervention in fluid-overloaded patients would have been questionable on ethical grounds. Future research should involve larger, multicenter randomized controlled trials with longer follow-up periods to confirm the benefits of BIA-guided fluid management.

In conclusion, BIA-guided fluid management improved fluid balance, reduced dialysis-related complications, and decreased the need for antihypertensive drug classes in maintenance HD patients. These findings support integrating BIA into standard clinical practice for individualized volume management, particularly in patients with fluid overload. Future large-scale, multicenter trials with longer follow-up are warranted to confirm these findings and explore long-term clinical outcomes.

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