Survey of U.S. Critical Care Practitioners on Net Ultrafiltration Prescription and Practice Among Critically Ill Patients Receiving Kidney Replacement Therapy

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Abstract

Introduction: The current prescription and practice of net ultrafiltration among critically ill patients receiving kidney replacement therapy in the U.S. are unclear. **Aim of the study**: To assess the attitudes of U.S. critical care practitioners on net ultrafiltration (UF_{NET}) prescription and practice among critically ill patients with acute kidney injury treated with kidney replacement therapy. **Methods**: A secondary analysis was conducted of a multinational survey of intensivists, nephrologists, advanced practice providers, and ICU and dialysis nurses practising in the U.S. **Results**: Of 1,569 respondents, 465 (29.6%) practitioners were from the U.S. Mainly were nurses and advanced practice providers (58%) and intensivists (38.2%). The median duration of practice was 8.7 (IQR, 4.2-19.4) years. Practitioners reported using continuous kidney replacement therapy (as the first modality in 60% (IQR 20%-90%) for UF_{NET}. It was found that there was a significant variation in assessment of prescribed-to-delivered dose of UF_{NET}, use of continuous kidney replacement therapy for UF_{NET}, methods used to achieve UF_{NET}, and assessment of net fluid balance during continuous kidney replacement therapy. There was also variation in interventions performed for managing hemodynamic instability, perceived barriers to UF_{NET}, belief that early and protocol-based fluid removal is beneficial, and willingness to enroll patients in a clinical trial. **Conclusions**: There was considerable practice variation in UF_{NET} among critical care practitioners in the U.S., reflecting the need to generate evidence-based practice guidelines for UF_{NET}.

Keywords: net ultrafiltration, critical care practitioners, renal replacement therapy, web-based survey

◼ Introduction

Fluid overload is prevalent in two-thirds of critically ill patients with acute kidney injury when kidney replacement therapy is initiated in an intensive care unit and is independently associated with morbidity and mortality and impaired recovery of kidney function among survivors [1-3]. Net ultrafiltration (UF_{NET}), also known as net fluid removal during kidney replacement therapy, is frequently used by clinicians to treat fluid overload for more than seven decades and is currently recommended by several international clinical practice guidelines [4-6]. This recommendation is based on several observational studies suggesting that fluid removal is associated with a lower risk of death [1, 7, 8]. However, several aspects of UF_{NET} among acutely ill patients, including optimal timing of initiation, specific indications, rate, barriers, and management of complications, remain uncertain. In addition, several quality metrics have also been developed for fluid removal based on observational studies without solid evidence for practice from randomised clinical trials [9, 10].

Current observational studies suggest a "J" shaped relationship between the rate of UF_{NET} (*i.e.*, the net fluid removal rate) and mortality. Specifically, both slower and faster rates of UF_{NET} are associated with an increased risk of death compared to moderate UF_{NET} rates [11-15]. However, data on net ultrafiltration practice patterns in the intensive care unit (ICU) and clinician perspectives on fluid removal are scarce.

In the U.S., intensivists, nephrologists, and advanced practice providers typically prescribe fluid removal; intensive care unit and dialysis nurses perform UF_{NET} and manage hemodynamics following a provided prescription.

Thus, it would be essential to understand perspectives towards UF_{NET} and the barriers and challenges related to fluid removal among physicians and nurses. For example, a previous study by Murugan et al. (2020) using a multinational survey of critical care practitioners revealed wide regional variations in dosing of diuretics, criteria used for initiation and prescription of UF_{NET}, modality of kidney replacement therapy used for UF_{NET}, the assessment of prescription dose of UF_{NET}, the monitoring of fluid balance, management of complications and perceived barriers to UF_{NET} [16]. Among critical care practitioners in Europe, there was also variation noted in attitudes toward UF_{NET} prescription and processes of care between physicians and nurses [17].

In the present study, a secondary analysis was conducted using data from a multinational survey [16] to understand attitudes of U.S. critical care practitioners regarding the prescription and practice of UF_{NET}.

Specifically, the criteria for initiation and prescription of UF_{NET}, monitoring fluid balance, managing complications, and perceived barriers to successful fluid removal were examined. Additionally, the attitudes of U.S. practitioners toward protocol-based management and willingness to enrol patients in clinical trials comparing protocol-based ultrafiltration versus usual care was explored.

◼ METHODS

Survey Development and Administration

A worldwide, self-administered, cross-sectional, internet-assisted, open survey of adult intensivists and nephrologists including trainees, advanced practice providers (*i.e.,* nurse practitioners), intensive care unit and dialysis nurses, involving fourteen critical care and nephrology societies in 80 countries was undertaken. (Supplementary online material - Appendix Methods A.1)

The survey instrument development and methodology and survey administration are described in detail elsewhere [16]. The final survey instrument was approved by the University of Pittsburgh's Human Research Protection Office (Supplementary online material - Appendix Methods A.2).

In this secondary analysis, only responses from the U.S. critical care practitioners, including physicians, nurses, and advanced practice providers, were examined.

The survey was prefaced by an invitation letter administered using an online software platform (Qualtrics, Provo, UT, USA) and was disseminated between January 6th, 2018 and January 10th, 2019, via email to members of international societies. The survey was administered anonymously, and the I.P. addresses of individuals and information related to identity were not collected. The survey was voluntary, and consent was implied if the participants responded; no incentives were offered for survey completion. The survey was adhered to the checklist for Reporting Results of Internet E-Surveys (CHERRIES) to report the data [18].

Statistical Analysis

Only fully completed questionnaires were included in the final analysis. For the analyses, intensivists, nephrologists, and those who are both intensivists and nephrologists under the category of physicians were grouped. In addition, the intensive care unit and dialysis nurses and advanced practice providers were grouped under the category of nurses.

The descriptive statistics were presented as proportions or median with interquartile range (IQR). In assessing proportions, responses such as "*I do not prescribe/make a decision,*" "*other,*" "*I do not know,*" "*not applicable*" were excluded in the analysis.

For survey items with continuous variables, the median and IQR and performed a statistical comparison of physician and non-physician subgroups using Student's T-test were assessed.

For survey items involving two or more categorical variables in which only one choice could be made, we measured proportions for each choice and assessed the difference between the above subgroups using the Chi-squared test of homogeneity for each item.

For items that allowed for more than one categorical variable to be chosen, proportions for each choice were measured and compared with the above subgroups using the Z-test difference of proportions.

The significance level was set at $\alpha = 0.05$.

All analyses were performed using Microsoft Excel 2019 version 16.0.

■ RESULTS

Practitioner characteristics, Diuretic Use and Criteria Used for Initiation and Prescription of UF$_{NET}$.

Of the 1,569 international survey respondents, 465 (29.6%) were U.S. practitioners. Of the U.S. practitioners, 177 (38.2%) respondents were self-identified as intensivists, 11 (2.4%) as nephrologists, 8 (1.7%) as nephrologists and intensivists, 239 (51.6%) as ICU nurses caring for patients receiving kidney replacement therapy, and 30 (6%) as advanced practice providers. The mean duration of clinical practice was 8.8 years (IQR, 4.4 - 16.7) for physicians and 8.7 years (IQR, 4.1 – 21.0) for nurses and advanced practice providers. Approximately two thirds (66.3%) of the physicians and (63.7%) of nurses and advanced practice providers practised in a University-based hospital in the U.S. (Table 1).

More than half of the practitioners (63.0%) stated that they prescribed a maximum of 100-250 milligrams of loop diuretics per day before determining diuretic resistance and proceeding ahead with extracorporeal UF$_{NET}$. The reasons for initiation of UF$_{NET}$ included severe hypoxemia (33.7%), oliguria or anuria (28.9%), or pulmonary oedema with or without hypoxemia (14.7%) (Figure 1). In addition, more than two-thirds of practitioners considered hemodynamic status (71.2%) followed by cumulative fluid balance (12.1%) of the patients for prescribing UF$_{NET}$.

Kidney replacement therapy modality, UF$_{NET}$ Prescription, Assessment of Prescribed-to-Delivered UF$_{NET}$ Dose, and Evaluation of Net Fluid Balance

Intermittent hemodialysis (IHD)

In the month before completing the survey, practitioners reported that they treated a median of 10.0% (IQR, 2.2%- 30.0%) of patients with IHD and 1.0% (IQR, 1.0% - 15.0%) of patients with slow forms of IHD such as Sustained low-efficiency Dialysis (SLED), Prolonged Intermittent Renal Replacement Therapy (PIRRT), or Extended Daily Dialysis (EDD). The typical median UF$_{NET}$ volume was 2.0 litres (IQR, 2.0-3.0) per session during IHD and 2.0 litres (1.0 -2.5) per session during slow forms of IHD.

Compared to nurses and advanced practise providers, a higher percentage of physicians reported assessing the prescribed-vs-delivery dose of UF$_{NET}$ (Physician vs nurses: 90.0% vs 72.5%; p=0.02).

Continuous Kidney Replacement Therapy (CKRT)

More than half (60%, IQR, 10%-90%) of the practitioners indicated that they used continuous kidney replacement therapy as the first modality for UF$_{NET}$ within the previous month of practice. However, more physicians reported using CKRT than nurses (physician vs nurses, 80% vs 50%; P<0.001). Practitioners reported that they initiated UF$_{NET}$ at a rate of 100 mL/h (IQR, 79.0 – 200.0) and increased to a maximum rate of 285.0 mL/h (IQR, 200.0 – 341.0) for hemodynamically stable
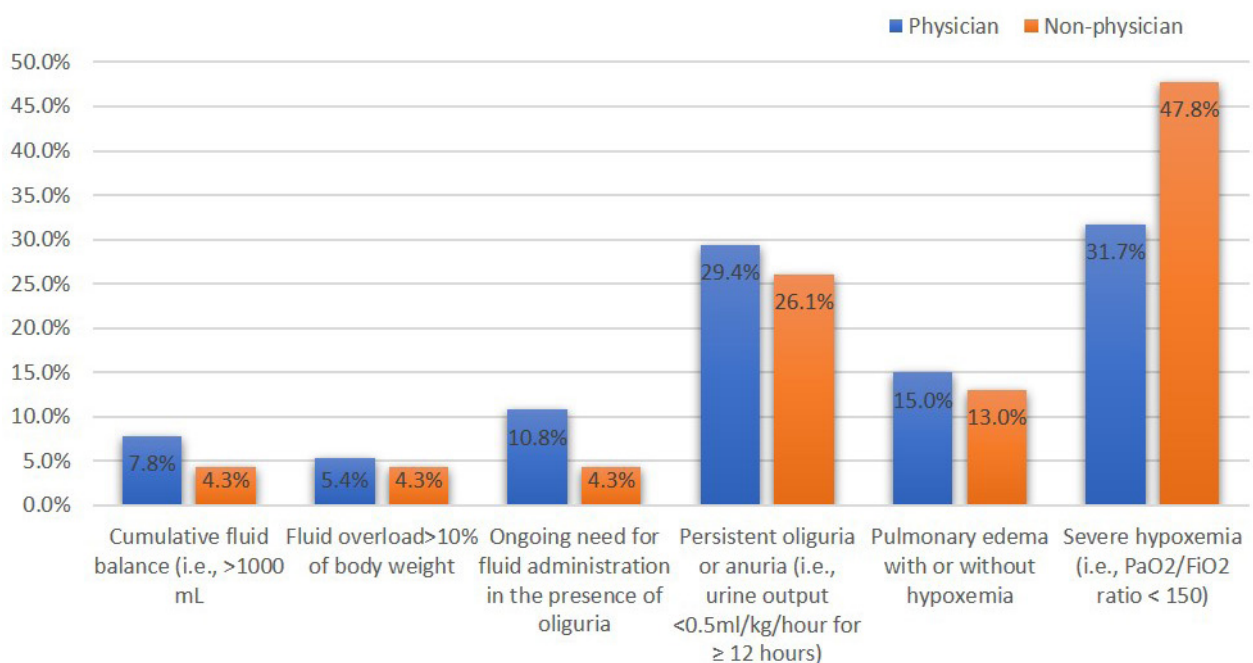

Fig.1. Reported Criteria Used for Initiating Fluid Removal

Table 1. Characteristics of U.S. Survey Respondents and Practice of Net Ultrafiltration

Characteristic	No. (%)			P value
	All (n=465)	Physician (n=196)	Nurse & Nurse Practitioner (n=269)	
Years of practice, median (IQR)	8.7 (4.2 - 19.4)	8.8 (4.4 - 16.7)	8.7 (4.1 - 21.0)	0.41
Hospital type[a]				
University-based	295 (64.8)	128 (66.3)	167 (63.7)	0.003
Community-based	140 (30.8)	50 (25.9)	90 (34.4)	
Government	20 (4.4)	15 (7.7)	5 (1.5)	
Maximum dose of loop diuretic in milligrams equivalent to furosemide dosing before determining diuretic resistance, mgs/day[b]				
<100	10 (4.8)	8 (4.4)	2 (8)	
100-250	131 (63.0)	114 (62.3)	17 (68)	0.30
251-500	53 (25.5)	50 (27.3)	3 (12)	
501-750	4 (1.9)	4 (2.2)	0	
751-1000	9 (4.3)	6 (3.3)	3 (12)	
>1000	1 (0.5)	1 (0.55)	0	
Criteria for initiating fluid removal[b,c]				
Cumulative fluid balance (*i.e.,* >1000 mL)	14 (7.4)	13 (7.8)	1 (4.3)	
Fluid overload>10% of body weight	10 (5.3)	9 (5.4)	1 (4.3)	
Ongoing need for fluid administration in the presence of oliguria	19 (10.0)	18 (10.8)	1 (4.3)	0.72
Persistent oliguria or anuria (*i.e.,* urine output <0.5ml/kg/h for ≥12 hours)	55 (28.9)	49 (29.4)	6 (26.1)	
Pulmonary edema with or without hypoxemia	28 (14.7)	25 (15.0)	3 (13.0)	
Severe hypoxemia (*i.e.,* PaO2/FiO2 ratio < 150)	64 (33.7)	53 (31.7)	11 (47.8)	
Criteria used for prescribing UF_{NET}[b,c]				
24-hour fluid balance	21 (10.6)	20 (11.5)	1 (4.2)	
Cumulative fluid balance since ICU admission	24 (12.1)	23 (13.2)	1 (4.2)	
Hemodynamic status (*i.e,* HR, BP, CVP, PPV, dose of vasopressors)	141 (71.2)	121 (69.5)	20 (83.3)	0.61
Radiographic features suggestive of fluid overload	6 (3.0)	5 (2.9)	1 (4.2)	
Volume of anticipated fluid administration in the next 24 hours	1 (0.5)	1 (0.6)	0	
Weight gain since ICU admission	5 (2.5)	4 (2.3)	1 (4.2)	

Table 1 (continued from page 275)

Characteristic	No. (%)			P value
	All (n=465)	Physician (n=196)	Nurse & Nurse Practitioner (n=269)	
Intermittent hemodialysis, median (IQR)				
Percent use last month	10.0 (2.2 – 30.0)	10.0 (5.0-30.0)	10.0 (2.0-30.0)	0.29
Typical prescription, liters per session	2.0 (2.0-3.0)	2.0 (2.0-3.0)	2.0 (1.6-2.4)	0.07
Slow forms of IHD, median (IQR)				
Percent use last month	1.0 (1.0- 15.0)	2.0 (0-23.0)	1.0 (0-10.5)	0.08
Typical prescription, liters per session	2.0 (1.0-2.5)	2.0 (1.0-2.5)	2.0 (1.2-2.4)	0.17
Percent of assessment of prescribed- delivered dose, median (IQR)	90.0 (20.0-100.0)	90.0 (50.0-100.0)	72.5 (2.7-100.0)	0.02
CKRT, median (IQR)				
Percent use last month	60.0 (20.0-90.0)	80.0 (50.0-90.0)	50.0 (10.0-80.0)	<0.001
Initial UF$_{NET}$ rate for hemodynamically stable patient, mL per hour	100.0 (79.0-200.0)	100.0 (100.0-197.0)	100.0 (52.0-200.0)	0.96
Maximal UF$_{NET}$ rate for hemodynamically stable patient, ml per hour	285.0 (200.0-341.0)	298.0 (200.0-351.0)	253.5 (200.0-310.5)	0.22
UF$_{NET}$ rate for hemodynamically unstable patient, mL per hour	51.0 (25.0-100.0)	52.0 (49.0-100.0)	51.0 (10.0-100.0)	0.91
Method used to achieve UF$_{NET}$ [d]				
By varying ultrafiltration rate only	205 (61.9)	75 (54.3)	130 (67.4)	0.04
By varying replacement fluid rate only	13 (3.9)	8 (5.8)	5 (2.6)	
By varying both ultrafiltration and replacement fluid rate	113 (34.1)	55(39.9)	58 (30.1)	
How frequently did you check net fluid balance[e]				
1 hour	211 (58.2)	43 (28.7)	168 (79.2)	<0.001
2 hours	19 (5.2)	10 (6.7)	9 (4.2)	
4 hours	34 (9.4)	24 (16.0)	10 (4.7)	
6 hours	13 (3.6)	11 (7.3)	2 (0.9)	
8 hours	16 (4.4)	9 (6.0)	7 (3.3)	
12 hours	34 (9.4)	24 (16.0)	10 (4.7)	
24 hours	35 (9.7)	29 (19.3)	6 (2.8)	

IQR, interquartile range; HR, heart rate; BP, blood pressure; CVP, central venous pressure; PPV, pulse pressure variation; IHD, intermittent hemodialysis; CKRT, continuous kidney replacement therapy

[a] Ten practitioners answered other hospitals which included private and mixed community and academic centers

[b] Only the physicians and advanced practice provider were asked these questions and nurses were excluded.

[c] These data were analyzed from clinicians who have active role in initiating dialysis; other answers such as I do not make decision to initiate dialysis were excluded in the analysis

[d] These data were analyzed from answers of one of the three options; other answers such as I do not know or not applicable were excluded in the data analysis

[e] These data were analyzed from answers of one of the seven listed options; other answers were excluded in the analysis

patients. For hemodynamically unstable patients, the median UF_{NET} rate reported by practitioners was 51.0 mL/h (IQR, 25.0 – 100.00) with no reported variation in prescribed UF_{NET} rates between clinicians.

Most clinicians varied the ultrafiltration rate to achieve desired UF_{NET} rate. However, there was a significant variation between practitioners. Most nurses (67.4%) reported that they achieved UF_{NET} by varying ultrafiltration rate, whereas only a smaller proportion of physicians (39.9%) reported that they achieved UF_{NET} by varying both U.F. rate and replacement fluid. In addition, only one half (58.2%) of the practitioners monitored net fluid balance on an hourly basis during treatment with CKRT. While 79.2% of nurses checked the hourly net fluid balance, only 28.7% of physicians reported evaluating hourly net fluid balance (Table 1).

Hemodynamic Management and Perceived Barriers to UF_{NET}

Practitioners reported new hemodynamic instability characterised by onset or worsening of tachycardia, hypotension, or a need to start or increase the dose of vasopressors in 25.0% (IQR,10.0-100.0) of patients. When hemodynamic instability occurred, 71.2% of the practitioners reported that they decreased the rate of fluid removal, 56.6% reported starting or increasing the dose vasopressor, and 44.3% reported completely stopping UF_{NET} (Table 2; Figure 2). Compared with physicians, a higher percentage of nurses and advanced practice providers reported decreasing rate of fluid re-

moval (physician vs nurse: 65.3% vs 75.5%; p=0.02) starting or increasing the dose of vasopressors (47.4% vs 63.2%; p<0.001) and administering albumin or mannitol bolus (28.6% vs 37.5%; p=0.04). Patient intolerance was the most common barrier (79.8%) reported by U.S. practitioners (Figure 3). The second most common perceived barrier to UF_{NET} was frequent interruptions (50.1%), followed by under prescription (17.8%) and unavailability of adequately trained nursing staff (17%). Finally, physicians reported the unavailability of dialysis machines as a barrier for volume removal compared with non-physician clinicians (13.8% vs 4.8%; p<0.01; Table 2).

Perception Toward Timing, Use of a Protocol, and Enrolling Patients in a Clinical Trial of Protocol-Based UF_{NET}

More than two-thirds of practitioners agreed that early (89%) and a protocol-based UF_{NET} outlining the rate, volume, and duration of UF_{NET} (82.3%) would be beneficial with variation between physicians and nurses. Two-thirds of practitioners (70.5%) were also willing to enrol patients in a clinical trial of protocol-based UF_{NET} versus usual care, with more physicians willing to enrol than nurses (Table 3).

Thematic Comments

Survey respondents were given opportunities to give suggestions about information that was not provided in the survey, and many of them provided perceptive
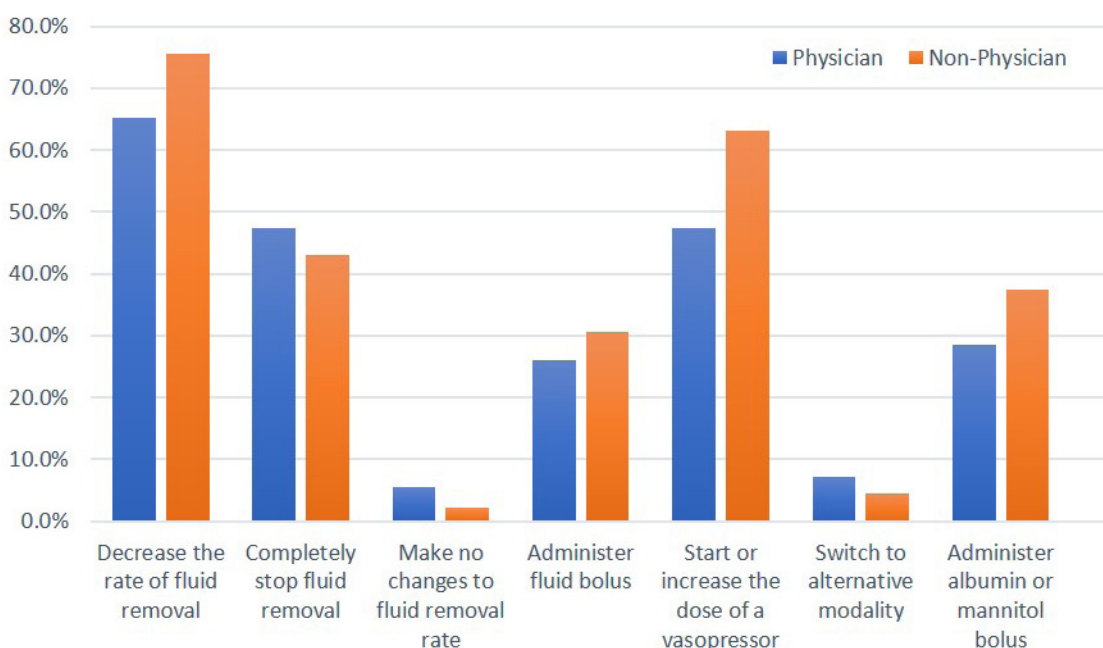

Fig.2. Reported Interventions Performed for Hemodynamic Instability During Net Ultrafiltration

Table 2. Hemodynamic Management and Perceived Barriers to Net Ultrafiltration

Characteristic	No. (%)			P value
	All (n=465)	Physician (n=196)	Nurse & Nurse Practitioners (n=269)	
Percentage of patients developing new hemodynamic instability during UF^{NET} median (IQR)	25.0 (10.0-100.0)	25.0 (13.2-35.0)	20.5 (10.0-50.0)	0.79
Interventions performed for hemodynamic instability[a]				
Decrease the rate of fluid removal	331 (71.2)	128 (65.3)	203 (75.5)	0.02
Completely stop fluid removal	206 (44.3)	93 (47.4)	113 (43)	0.24
Make no changes to fluid removal rate	17 (3.7)	11 (5.6)	6 (2.2)	0.05
Administer fluid bolus	133 (28.6)	51 (26)	82 (30.5)	0.29
Start or increase the dose of a vasopressor	263 (56.6)	93 (47.4)	170 (63.2)	<0.001
Switch to alternative modality	26 (5.6)	14 (7.1)	12 (4.5)	0.21
Administer albumin or mannitol bolus	157 (33.8)	56 (28.6)	101 (37.5)	0.04
Perceived barriers[a]				
Patient intolerance (*e.g.,* hypotension)	371 (79.8)	156 (80.0)	215 (79.9)	0.93
Under prescription	83 (17.8)	32(16.3)	51 (19.0)	0.47
Frequent interruptions (*e.g.,* trip to CT scan, operating room, filter clotting, catheter malfunction)	233 (50.1)	96 (49.0)	137 (50.9)	0.67
Inability to titrate fluid removal	47 (10.1)	24 (12.2)	23 (8.6)	0.19
Unavailability of adequately trained nursing staff	79 (17.0)	28 (14.3)	51 (19.0)	0.18
Unavailability of dialysis machines	40 (8.6)	27 (13.8)	13 (4.8)	0.001
Cost associated with treatment	11 (2.0)	5 (2.5)	6 (3.1)	0.83

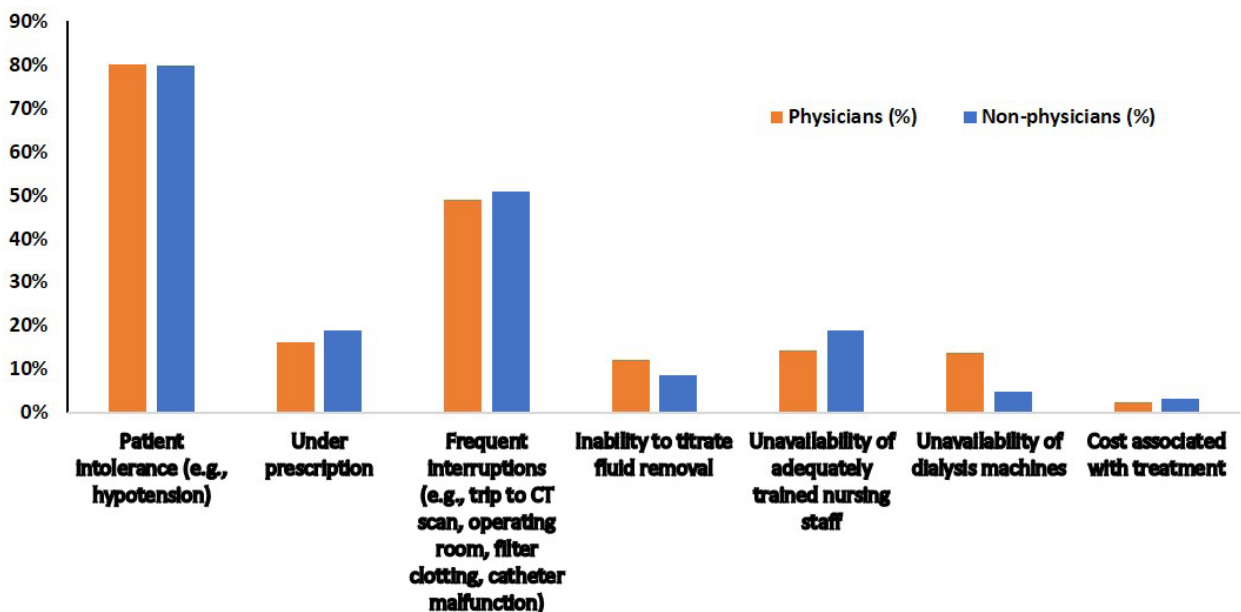[a] Multiple option can be chosen for these questions

Fig.3. Perceived Barriers to Net Ultrafiltration

Table 3. Attitudes Toward Timing, Use of a Protocol and Willingness to Enroll Patients in a Clinical Trial of Protocol-based Net Ultrafiltration

Characteristic	No. (%)			P value
	All (N=465)	Physician (N=196)	Nurse & Nurse Practitioners (N=269)	
I believe early fluid removal is beneficial				
Strongly agree	148 (31.8)	56 (28.6)	92 (34.2)	
Agree	195 (41.9)	68 (34.7)	127 (47.2)	
Somewhat agree	71 (15.3)	42 (21.4)	29 (10.8)	
Neither agree nor disagree	37 (8.0)	19 (9.7)	18 (6.7)	<0.001
Somewhat disagree	7 (1.5)	6 (3.1)	1 (0.4)	
Disagree	3 (0.6)	2 (1.0)	1 (0.4)	
Strongly disagree	4 (0.9)	3 (1.5)	1(0.4)	
I believe a protocol-based fluid removal strategy would be beneficial				
Strongly agree	113 (24.4)	28 (14.3)	85 (31.5)	
Agree	160 (34.6)	60 (30.6)	100 (37.2)	
Somewhat agree	108 (23.3)	57(29.1)	51 (20.0)	<0.001
Neither agree nor disagree	52 (11.2)	33 (16.8)	19 (7.1)	
Somewhat disagree	18 (3.9)	9 (4.6)	9 (3.3)	
Disagree	11 (2.4)	7 (3.6)	4 (1.5)	
Strongly disagree	3 (0.6)	2 (1.0)	1 (0.4)	
I would enroll my patient in a clinical trial comparing protocol-based versus usual care				
Strongly agree	108 (23.2)	46 (23.5)	62 (23.0)	0.001
Agree	168 (36.1)	84 (42.9)	84 (31.2)	
Somewhat agree	52 (11.2)	24 (12.2)	28 (10.4)	
Neither agree nor disagree	107 (23.0)	26 (13.3)	81 (30.1)	
Somewhat disagree	4 (0.9)	3 (1.5)	1 (0.4)	
Disagree	15 (3.2)	9 (4.6)	6 (2.2)	
Strongly disagree	9 (1.9)	4 (2.0)	5 (1.9)	

comments about UF_{NET} practice. The themes of the comments ranged from individualising UF_{NET} in special patient populations, factors guiding UF_{NET} rate, timing of initiation, communication, staffing, cost, barriers, education, leadership, and use of protocol (Supplementary online material - Appendix Table .1).

■ Discussion

In this survey of U.S. physicians, nurses, and advanced practice providers, significant variation in attitudes toward the practice of UF_{NET} was found. Most practitioners were ICU nurses, had an average of 8.7 years of experience, and were from university-based hospitals. Although this survey predominantly reflects nurses attitudes towards the practice of UF_{NET}, variations were noted in the assessment of prescribed-to-delivered dose of UF_{NET}, the use of continuous kidney replace-

ment therapy for UF_{NET}, the methods used to achieve UF_{NET}, and assessment of net fluid balance during CKRT. There was also variation in interventions performed for hemodynamic instability such as decreasing or stopping UF_{NET} and increasing or starting a new vasopressor, administration of albumin and mannitol bolus, as well as barriers to UF_{NET} such as unavailability of machines, belief that early and protocol-based fluid removal is beneficial, and willingness to enrol patients in a clinical trial.

The survey findings of U.S. practitioners were similar to findings in a global survey and Europe in that there is important practice variation in several care processes for UF_{NET} [16, 17]. This is partly due to the lack of evidence-based guidelines for UF_{NET} prescription and practice in critically ill patients. Unlike solute clearance management, where there is strong evidence for dosing, timing, and modality of kidney replace-

ment therapy, no such evidence exists for UF_{NET} prescription and practice in critically ill patients [19-21]. In addition, we found variation in the assessment of prescribed-to-delivered dose of UF_{NET} between physicians and nurses. This finding may either represent actual challenges to implementing UF_{NET} due to various reasons (e.g., hemodynamic instability) despite current quality guidelines to target >80% of prescribed dose [10].

As is the case in Europe, CKRT was the most frequent modality volume management in the U.S. However, while 90% of practitioners in Europe reported using CKRT for volume management, only 60% of the U.S. practitioners used CKRT, with physicians reporting higher use than nurses [17]. This difference in practice might be due to a lack of evidence from randomised clinical trials confirming the benefit of CKRT among patients treated with UF_{NET}. In addition, while CKRT is superior for volume control in critically ill patients, no randomised control trials have been conducted comparing CKRT with other modalities of kidney replacement therapy for fluid removal [22].

Although no reported variation was found between clinicians among the rate of UF_{NET} prescription for hemodynamically stable and unstable patients on CKRT, we found substantially lower reported UF_{NET} rates in the U.S. compared with practitioners in Europe and the global survey [16, 17]. Previous research showed that among patients with >5% fluid overload before initiation of kidney replacement therapy, a UF_{NET} intensity >25 mL/kg/day was associated with lower 1-year mortality [23]. In contrast, a secondary analysis of the Randomised Evaluation of Normal versus Augmented Level (RENAL) trial reported that a UF_{NET} rate >1.75mL/kg/h was associated with a higher risk of 90-day mortality [11].

Significantly, more negative daily fluid balance attenuated the harmful mortality effect of high UF_{NET} (>1.75 mL/kg/h) rate group compared with moderate (1.01-1.75 mL/kg/h) and low (<1.01 mL/kg/h) UF_{NET} rate groups. However, despite this attenuation, the high UF_{NET} rate group remained significantly and directly associated with higher mortality than the moderate UF_{NET} rate group and lower renal recovery [15, 24].

Similarly, a recent study supported that a UF_{NET} rate >1.75mL/kg/h in the first 48 h was associated with increased mortality, lower potassium, higher hypophosphatemia, longer duration of CKRT, and more extended ICU stay [12]. Observational studies in chronic hemodialysis patients showed similar results: high fluid removal rates were associated with increased cardiovascular mortality, possibly due to impaired plasma refilling rate and myocardial stunning independent of interdialytic fluid gain [25, 26].

There was also a variation between clinicians in the approach to performing UF_{NET} during CKRT. While most clinicians (62%) reported achieving UF_{NET} by varying ultrafiltration rate, nearly a third of clinicians reported achieving UF_{NET} by combining varying ultrafiltration and replacement fluid rates, which may reflect institutional practice patterns for achieving UF_{NET}. In addition, nurses and nurse practitioners evaluated fluid balance hourly, more frequently than physicians, which may be due to the continued presence of the nursing staff at the bedside while delivering UF_{NET} in an ICU.

There was also variation in approach to managing hemodynamic instability and perceived barriers. For example, nurses and advanced practice providers more likely reported to start or increase the vasopressor dose or administer albumin than physicians. This variation might be due to the lack of guidelines for hemodynamic management during kidney replacement therapy in critically ill patients, unlike clear guidelines for managing hemodynamic instability in the outpatient setting [27]. Additionally, U.S. physicians are more likely to report the unavailability of dialysis machines as a significant barrier for fluid removal than the nurses and advanced practice providers.

Despite lack of evidence, most practitioners believed in early initiation of UF_{NET} despite several trials showing no difference in patient outcomes among patients with early initiation of kidney replacement therapy, even though these trials did not evaluate the timing of volume management [20]. Thus, despite variation in attitudes toward the use of protocol and timing of initiation of UF_{NET}, U.S. critical care practitioners were willing to enrol patients in a protocol-based clinical trial of UF_{NET}.

Thematic analysis of practitioner comments revealed the need for precision medicine tools to assess intravascular volume to individualise and titrate UF_{NET}. Clinicians also focused on various challenges related to UF_{NET} in the U.S. population, including lack of training, uncertainty in the timing of volume removal, communication issues between clinicians, availability of kidney replacement therapy modality for volume removal, and educational issues. These findings outline the multifactorial challenges that underlie volume management in

critically ill patients and highlight the need to generate evidence-based treatment guidelines to reduce practice variation and improve patient outcomes.

The present study has several significant limitations. First, most practitioners were intensivists and ICU nurses; thus, a comparison could not be made between the responses of nephrologists and dialysis nurses. Across many hospitals in the U.S., nephrologists typically prescribe volume removal during intermittent hemodialysis in the ICU, whereas intensivists and ICU nurses typically manage volume removal during CKRT. Nevertheless, the current survey is the first to explore the clinician practice variation in UF_{NET} in the U.S. Second, we could not determine the actual response rate for U.S. practitioners since the survey was emailed via the society membership and one member may belong to multiple societies. Thus, there may be a selection bias by clinicians who were volunteering to complete the survey, and perspectives may not be representative of the entire range of U.S. practitioners.

Third, if multiple participants from the same institutions completed surveys, it could lead to similar practice patterns. Fourth, we did not assess clinician practice patterns across patient populations (e.g., medical versus surgical population), and thus the reported practise patterns may vary by patient subpopulation. Fifth, since most practitioners were from university-based hospitals, their perspectives may not reflect clinicians from community hospital settings. Despite these limitations, this survey provides insight into U.S. clinician practice variation in UF_{NET}, which may help plan future research and quality implementation initiatives.

■ CONCLUSION

In this secondary analysis of a multinational survey involving critical care practitioners in the U.S., a significant practice variation was found between physicians and nurses in methods used to achieve UF_{NET} during CKRT, the frequency in monitoring net fluid balance, the perceived barriers of UF_{NET}, and interventions performed for patients with hemodynamic instabilities during UF_{NET}. Nevertheless, there is a considerable willingness on the part of U.S. practitioners to enrol patients in clinical trials of UF_{NET}. These findings emphasise the need to generate

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