



HAL
open science

Diuretic dose is a strong prognostic factor in ambulatory patients awaiting heart transplantation

Guillaume Baudry, Guillaume Coutance, Richard Dorent, Fabrice Bauer, Katrien Blanchart, Aude Boignard, Céline Chabanne, Clément Delmas, Nicolas d'Ostrevy, Eric Epailly, et al.

► To cite this version:

Guillaume Baudry, Guillaume Coutance, Richard Dorent, Fabrice Bauer, Katrien Blanchart, et al.. Diuretic dose is a strong prognostic factor in ambulatory patients awaiting heart transplantation. ESC Heart Failure, 2023, 10 (5), pp.2843-2852. 10.1002/ehf2.14467 . hal-04154052

HAL Id: hal-04154052

<https://hal.univ-lorraine.fr/hal-04154052v1>

Submitted on 6 Jul 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial - NoDerivatives 4.0 International License

Diuretic dose is a strong prognostic factor in ambulatory patients awaiting heart transplantation

Guillaume Baudry¹ , Guillaume Coutance², Richard Dorent³, Fabrice Bauer⁴, Katrien Blanchart⁵, Aude Boignard⁶, Céline Chabanne⁷, Clément Delmas⁸, Nicolas D'Ostrevy⁹, Eric Epailly¹⁰, Vlad Gariboldi¹¹, Philippe Gaudard¹², Céline Goéminne¹³, Sandrine Grosjean¹⁴, Julien Guihaire¹⁵, Romain Guillemain¹⁶, Mathieu Mattei¹⁷, Karine Nubret¹⁸, Sabine Pattier¹⁹, Emmanuelle Vermes²⁰, Laurent Sebbag²¹, Kevin Duarte¹ and Nicolas Girerd^{1*}

¹Université de Lorraine, Centre d'Investigations Cliniques Plurithématique 1433, INSERM DCAC, CHRU de Nancy, F-CRIN INI-CRCT, Reicatra, Vandoeuvre-lès-Nancy, 54500, France; ²Department of Cardiac and Thoracic Surgery, Cardiology Institute, Pitié Salpêtrière Hospital, Assistance Publique-Hôpitaux de Paris (AP-HP), Sorbonne University Medical School, Paris, France; ³Department of Cardiac Surgery, CHU Bichat-Claude Bernard, AP-HP, Université Paris VII, Paris, France; ⁴Department of Cardiology and Cardiovascular Surgery, Hospital Charles Nicolle, Rouen, France; ⁵Department of Cardiology and Cardiac Surgery, University Hospital of Caen, University of Caen, Caen, France; ⁶Department of Cardiology and Cardiovascular Surgery, CHU Michallon, Grenoble, France; ⁷Department of Thoracic and Cardiovascular Surgery, CHU Pontchaillou, Inserm U1099, Rennes, France; ⁸Department of Cardiology, Centre Hospitalier Universitaire de Toulouse, Toulouse, France; ⁹Department of Cardiology and Cardiac Surgery, CHU Clermont-Ferrand, Clermont-Ferrand, France; ¹⁰Department of Cardiology and Cardiovascular Surgery, Hôpitaux Universitaires de Strasbourg, Strasbourg, France; ¹¹Department of Cardiac Surgery, La Timone Hospital, Marseille, France; ¹²Department of Cardiac Surgery, Anesthesiology and Critical Care Medicine, Arnaud de Villeneuve Hospital, CHRU Montpellier, Montpellier, France; ¹³Department of Cardiac Surgery, CHU Lille, Institut Coeur-Poumons, Lille, France; ¹⁴Department of Cardiology and Cardiac Surgery, Dijon University Hospital, Dijon, France; ¹⁵Department of Cardiothoracic Surgery, Marie Lannelongue Hospital, University of Paris Sud, Inserm U999 (Pulmonary Hypertension: Pathophysiology and Novel Therapies [PAH]), Le Plessis Robinson, France; ¹⁶Department of Cardiology and Cardiac Surgery, European Georges Pompidou Hospital, Paris, France; ¹⁷Department of Cardiology and Cardiac Surgery, CHU de Nancy, Hôpital de Brabois, Nancy, France; ¹⁸Department of Thoracic and Cardiovascular Surgery, Hôpital Cardiologique du Haut-Lévêque, Université Bordeaux II, Bordeaux, France; ¹⁹Department of Cardiology and Heart Transplantation Unit, CHU Nantes, Nantes, France; ²⁰Department of Cardiothoracic Surgery, Tours University Hospital, Tours, France; ²¹Department of Heart Failure and Transplantation, Hôpital Cardiovasculaire Louis Pradel, Hospices Civils de Lyon, Bron, France; and ²²Department of Cardiology, CHU de Besançon, EA 3920, Unité INSERM 942 CHU Lariboisière, Paris, France

Abstract

Aims The prognostic value of 'high dose' loop diuretics in advanced heart failure outpatients is unclear. We aimed to assess the prognosis associated with loop diuretic dose in ambulatory patients awaiting heart transplantation (HT).

Methods and results All ambulatory patients ($n = 700$, median age 55 years and 70% men) registered on the French national HT waiting list between 1 January 2013 and 31 December 2019 were included. Patients were divided into 'low dose', 'intermediate dose', and 'high dose' loop diuretics corresponding to furosemide equivalent doses of ≤ 40 , 40–250, and > 250 mg, respectively. The primary outcome was a combined criterion of waitlist death and urgent HT. N-terminal pro-B-type natriuretic peptide, creatinine levels, pulmonary capillary wedge pressure, and pulmonary pressures gradually increased with higher diuretic dose. At 12 months, the risk of waitlist death/urgent HT was 7.4%, 19.2%, and 25.6% ($P = 0.001$) for 'low dose', 'intermediate dose', and 'high dose' patients, respectively. When adjusting for confounders, including natriuretic peptides, hepatic, and renal function, the 'high dose' group was associated with increased waitlist mortality or urgent HT [adjusted hazard ratio (HR) 2.23, 1.33 to 3.73; $P = 0.002$] and a six-fold higher risk of waitlist death (adjusted HR 6.18, 2.16 to 17.72; $P < 0.001$) when compared with the 'low dose' group. 'Intermediate doses' were not significantly associated with these two outcomes in adjusted models ($P > 0.05$).

Conclusions A 'high dose' of loop diuretics is strongly associated with residual congestion and is a predictor of outcome in patients awaiting HT despite adjustment for classical cardiorenal risk factors. This routine variable may be helpful for risk stratification of pre-HT patients.

Keywords Advanced heart failure; Diuretic; Heart transplant; Congestion; Cardiorenal syndrome

Received: 31 May 2023; Accepted: 21 June 2023

*Correspondence to: Nicolas Girerd, Université de Lorraine, Centre d'Investigations Cliniques Plurithématique 1433, INSERM DCAC, CHRU de Nancy, F-CRIN INI-CRCT, Reicatra, 54500 Vandoeuvre-lès-Nancy, France. Email: n.girerd@chru-nancy.fr

Introduction

Loop diuretics are the only group of drugs with a class I recommendation in heart failure (HF), for alleviating HF symptoms, despite a level C recommendation.¹ As advanced HF is characterized by the presence of severe cardiac dysfunction resulting in recurrent hospitalizations for congestive episodes,² it could lead to a progressive increase in daily diuretics dose particularly in patients with cardiorenal syndrome. Persisting fluid overload or increased diuretic requirement are criteria requiring referral to an advanced HF centre according to HF guidelines.^{1,3} However, the dose of loop diuretic that should prompt a referral is not well defined according to the author of “‘I Need Help’—A Mnemonic to Aid Timely Referral in Advanced Heart Failure’.”³

Diuretic resistance has mainly been evaluated in acute settings and is dependent (albeit not exclusively) on transient phenomena such as impaired diuretic absorption, decreased renal blood flow, renal congestion, azotaemia, hypoalbuminaemia, and proteinuria.⁴ Diuretic dose has been shown to be a strong prognostic marker in ambulatory patients with HF (e.g. in the EMPHASIS trial⁵). Yet, the prognostic value of daily doses of diuretics has not been extensively studied in ambulatory advanced HF. Indeed, the Seattle Heart Failure Model,⁶ which incorporates the daily oral furosemide dose as a continuous variable, was developed based on the PRAISE study⁷ published in 1996. In that study, the patients had an average New York Heart Association class of 3.6 and were predominantly treated with digoxin and angiotensin-converting enzyme inhibitors (ACEis). Similarly, Eshaghian *et al.* reported a correlation between diuretic dose and mortality in advanced HF, but their study included patients referred in the 1990s, of whom only 40% were receiving beta-blockers (BBs) and 26% were on mineralocorticoid receptor antagonists (MRAs).⁸ Considering that pump dysfunction is a significant characteristic of advanced HF, the prognostic value of diuretic dose may be less significant in this specific patient population. Furthermore, the current era of life-saving HF treatments such as ACEis, BBs, MRAs, and, more recently, angiotensin receptor-neprilysin inhibitors may have diminished the predictive value of diuretic dose.

The aim of the present study was to assess the association between congestion and diuretic dose as well as the prognostic value of daily diuretic doses in contemporary ambulatory patients with advanced HF listed for heart transplantation (HT).

Methods

Study population

A total of 2089 patients (18 years or older) without previous solid organ transplants (heart, kidney, liver, or pancreas)

listed on the French national waiting list for HT between 1 January 2013 and 31 December 2019 were deemed eligible. Of the latter, 700 ambulatory patients without intravenous inotrope therapy, mechanical assistance, or dialysis at time of listing were included.

Furosemide equivalent dose

Only two loop diuretics are available in France, furosemide and bumetanide. A 1 mg dose of bumetanide was considered equivalent to 40 mg of furosemide. Three groups were created according to furosemide dose. Diuretic dosages were categorized based on previous reports⁵ and clinically relevant thresholds. A reference ‘low dose’ group was defined as patients with a daily furosemide dose of ≤ 40 mg, the ‘high dose’ furosemide group was defined as a daily dose of > 250 mg, and the ‘intermediate dose’ group corresponded to patients with a daily furosemide dose between 41 and 250 mg.

Follow-up and study outcomes

The primary outcome was the combined criteria of the occurrence of waitlist death or urgent HT. Secondary outcomes were components of waitlist mortality, delisting for aggravation, urgent HT, or left ventricular assist device (LVAD) implantation.

Urgent HT was defined by the presence of intravenous inotrope or extracorporeal mechanical assistance at time of transplant.

Follow-up of all study events was maintained up to 12 August 2021. Patients were censored at elective HT or delisting for medical improvement.

Data collection and variables

This national multicentre study was performed using the data from the French registry (CRISTAL). The registry is administered by the Ministry of Health (Agence de la Biomédecine), which prospectively collects data on all organ transplant candidates in France along with their outcomes. A description of the CRISTAL registry has previously been published.⁹ Data were registered in CRISTAL at the time of patient listing and during follow-up as part of routine care. The study was conducted according to French legislation stipulating that anonymized research studies based on the national CRISTAL registry do not require institutional review board or ethics approval.

Table 1 Patient characteristics, medication use, laboratory, and echocardiographic parameters at time of heart transplant listing according to quartile of furosemide dose

| At listing time | Missing (%) | Whole cohort n = 700 | Furosemide equivalent dose 0–40 mg (n = 202) | Furosemide equivalent dose 41–250 mg (n = 365) | Furosemide equivalent dose >250 mg (n = 133) | P-value |
|---------------------------------------|-------------|-------------------------|--|--|--|---------|
| Demographic data | | | | | | |
| Age, years | 0 (0) | 55 (47 to 61) | 54 (41 to 60) | 56 (47 to 61) | 56 (49 to 62) | 0.011 |
| Male sex, n (%) | 0 (0) | 491 (70) | 143 (71) | 253 (69) | 95 (71) | 0.876 |
| Medical history | | | | | | |
| Hypertension, n (%) | 19 (3) | 151 (22) | 38 (19) | 84 (23) | 29 (22) | 0.494 |
| Diabetes, n (%) | 0 (0) | 111 (16) | 17 (8) | 62 (17) | 32 (24) | <0.001 |
| Smoking history, n (%) | 16 (2) | 398 (55) | 104 (53) | 204 (57) | 70 (54) | 0.617 |
| Heart failure duration, days | 234 (33) | 3202 (688 to 6295) | 3543 (993 to 7175) | 3273 (650 to 6166) | 2386 (600 to 5520) | 0.350 |
| Heart failure aetiology, n (%) | | | | | | |
| Ischaemic, n (%) | 0 (0) | 214 (31) | 60 (30) | 114 (31) | 40 (30) | 0.969 |
| Dilated cardiomyopathy, n (%) | 0 (0) | 298 (43) | 86 (43) | 155 (42) | 57 (43) | |
| Hypertrophic cardiomyopathy | 0 (0) | 77 (11) | 24 (12) | 41 (11) | 12 (9) | |
| Furosemide equivalent dose, mg | 0 (0) | 100 (40 to 250) | 40 (20 to 40) | 120 (80 to 200) | 500 (375 to 750) | <0.001 |
| CRT, n (%) | 37 (5) | 237 (34) | 63 (32) | 125 (34) | 49 (39) | 0.468 |
| ICD, n (%) | 6 (1) | 596 (85) | 168 (83) | 320 (88) | 108 (82) | 0.058 |
| Biological, laboratory data | | | | | | |
| Creatinine, $\mu\text{mol/L}$ | 1 (0) | 106 (87 to 131) | 98 (83 to 120) | 109 (89 to 136) | 112 (89 to 137) | <0.001 |
| eGFR, mL/min/1.73 m^2 | 1 (0) | 62.2 (48.5 to 81.3) | 70.5 (54.1 to 85.3) | 60.4 (45.7 to 77.6) | 59.6 (46.3 to 79.4) | <0.001 |
| Naatraemia, mmol/L | 2 (0) | 138 (136 to 140) | 139 (137 to 140) | 137 (135 to 139) | 137 (133 to 138) | <0.001 |
| Total bilirubin, $\mu\text{mol/L}$ | 25 (4) | 13 (9 to 19) | 12 (8 to 17) | 13 (9 to 19) | 14 (10 to 22) | 0.002 |
| BNP, ng/L | 480 (69) | 574 (332 to 1002) | 513 (280 to 983) | 620 (353 to 1074) | 603 (368 to 1052) | 0.294 |
| NT-proBNP, ng/L | 264 (38) | 2290 (1297 to 4198) | 1703 (946 to 2577) | 2553 (1482 to 4734) | 2769 (1740 to 4993) | <0.001 |
| BNP/NT-proBNP Z-score | 59 (8) | -0.30 (-0.54 to 0.15) | -0.44 (-0.61 to -0.11) | -0.24 (-0.50 to 0.26) | -0.22 (-0.45 to 0.26) | <0.001 |
| Echocardiography | | | | | | |
| LVEF, % | 13 (2) | 25 (20 to 33) | 25 (20 to 35) | 25 (20 to 30) | 25 (20 to 37) | 0.633 |
| LVEDD, mm | 146 (21) | 64 (55 to 73) | 65 (56 to 75) | 64 (56 to 73) | 62 (53 to 70) | 0.129 |

BNP, B-type natriuretic peptide; CRT, cardiac resynchronization therapy; eGFR, estimated glomerular filtration rate; ICD, implantable cardioverter-defibrillator; LVEDD, left ventricular end-diastolic diameter; LVEF, left ventricular ejection fraction; NT-proBNP, N-terminal pro-B-type natriuretic peptide. Values are expressed as median (interquartile_{25–75%}) or n (%).

Statistical analysis

All results were first summarized overall and subsequently stratified according to the three groups of furosemide equivalent doses.

Baseline continuous variables are expressed as medians with interquartile 25–75% (I_Q_{25–75%}) range or as means (\pm standard deviation). Comparisons of continuous variables were carried out using the Kruskal–Wallis test and *t*-test as required. Categorical variables are expressed as frequencies (percentages) and compared using the χ^2 test. The two-tailed significance level was set at $P < 0.05$. Due to the use of B-type natriuretic peptide (BNP) or N-terminal pro-B-type natriuretic peptide (NT-proBNP) depending on the collection year and centres, a combined BNP or NT-proBNP Z-score value was created.

Survival probabilities are graphically represented as Kaplan–Meier curves. Cox proportional hazard regression was used to examine the association between furosemide equivalent dose groups and primary and secondary outcomes. Competing risk on HT waitlist (non-urgent HT, delisting for aggravation, urgent HT, or LVAD implantation, as appropriate) was taken into account by using cause-specific hazard function introduced by Fine and Gray.¹⁰ To further assess the added value of the diuretic dose on top of other congestion variables, we constructed a multivariable model adjusted for age, gender, estimated glomerular filtration rate (eGFR), bilirubin, and BNP/NT-proBNP Z-score.

All analyses were performed using SPSS Version 27.0.1.0 (IBM SPSS Statistics for Windows, NY: IBM Corp) and R software Version 4.1.2 (R Foundation for Statistical Computing).

Results

Baseline characteristics

Among the 700 studied patients, median age was 55 (47–61) years and 70% were men; 43% had dilated cardiomyopathy and 31% had ischaemic cardiomyopathy. The population presented a low level of comorbidities (22% hypertension and 16% diabetes). Median HF duration was 8.7 years, and ejection fraction was 25 (20–33)%. Median eGFR and NT-proBNP were 62.2 (48.5–81.3) mL/min/1.73 m² and 2290 (1297–4198) ng/L, respectively (Table 1). Overall diuretic dose was 100 (40–250) mg.

Association between diuretic dose and congestion variables

NT-proBNP ($P < 0.001$), creatinine ($P < 0.001$), total bilirubin levels ($P = 0.002$), pulmonary artery pressures ($P < 0.001$),

Table 2 Clinical, functional, and haemodynamic variables at time of heart transplant listing

| At listing time | Missing (%) | Whole cohort <i>n</i> = 700 | Furosemide equivalent dose 0–40 mg (<i>n</i> = 202) | Furosemide equivalent dose 41–250 mg (<i>n</i> = 365) | Furosemide equivalent dose >250 mg (<i>n</i> = 133) | <i>P</i> -value |
|---|-------------|--------------------------------|--|--|--|-----------------|
| Time from RHC to transplant listing, days | 25 (4) | 66 (28–124) | 66 (27–135) | 68 (28–124) | 67 (32–109) | 0.920 |
| Systolic PAP, mmHg | 29 (4) | 41 (33–52) | 36 (28–47) | 44 (35–54) | 45 (38–54) | <0.001 |
| Mean PAP, mmHg | 21 (3) | 28 (22–35) | 25 (18–33) | 29 (23–36) | 30 (25–37) | <0.001 |
| Diastolic PAP, mmHg | 32 (5) | 20 (15–25) | 17 (12–23) | 20 (15–26) | 22 (17–26) | <0.001 |
| PCWP, mmHg | 97 (14) | 20 (14–25) | 17 (11–24) | 21 (15–26) | 22 (17–26) | <0.001 |
| Cl, L/min/m ² | 41 (6) | 2.1 (1.7–2.5) | 2.1 (1.8–2.4) | 2.0 (1.7–2.5) | 2.1 (1.7–2.5) | 0.663 |
| PVR, Wood units | 34 (5) | 2.1 (1.5–3.0) | 2.0 (1.4–2.6) | 2.2 (1.5–3.0) | 2.0 (1.4–3.0) | 0.028 |
| Clinical and functional variables | | | | | | |
| Systolic blood pressure, mmHg | 66 (9) | 102 (94–112) | 104 (96–114) | 102 (94–112) | 102 (93–112) | 0.222 |
| Diastolic blood pressure, mmHg | 65 (9) | 67 (60–74) | 65 (60–74) | 67 (60–74) | 67 (60–74) | 0.778 |
| Heart rate, b.p.m. | 58 (8) | 70 (61–79) | 65 (60–74) | 70 (62–80) | 72 (65–81) | <0.001 |
| VO ₂ max | 185 (26) | 12.5 (10.2–15.0) | 13.3 (11.0–16.0) | 12.2 (10.2–14.8) | 11.4 (9.0–14.0) | <0.001 |
| NYHA I | 3 (0) | 3 (0) | 2 (1) | 1 (0) | 0 | 0.301 |
| NYHA II | 69 (10) | 69 (10) | 26 (13) | 28 (8) | 15 (11) | |
| NYHA III | 521 (75) | 521 (75) | 148 (73) | 275 (75) | 98 (74) | |
| NYHA IV | 104 (15) | 104 (15) | 26 (13) | 59 (16) | 19 (14) | |

b.p.m., beats per minute; Cl, cardiac index; NYHA, New York Heart Association; PAP, pulmonary artery pressure; PCWP, pulmonary capillary wedge pressure; PVR, pulmonary vascular resistance; RHC, right heart catheterization; VO₂ max, maximal oxygen uptake.

pulmonary capillary wedge pressure (PCWP) ($P < 0.001$), and heart rate ($P < 0.001$) gradually increased with diuretic dose (Table 2). Conversely, natraemia, eGFR, and peak VO_2 decreased with diuretic dose ($P < 0.001$ for all).

Outcomes on heart transplant waitlist

During a mean follow-up of 278 days, there were 158 composite outcomes of waitlist death or urgent HT: 47 waitlist deaths and 111 urgent HTs.

Overall, 'high dose' patients had the worst prognosis whereas 'low dose' patients experienced the best outcome. At 12 months, waitlist mortality occurred in 2 (1.0%), 19 (5.2%), and 13 (9.8%) patients for 'low dose', 'intermediate dose', and 'high dose' profiles, respectively (log-rank $P < 0.001$; Figure 1). At 12 months, waitlist death or urgent HT occurred in 15 (7.4%), 70 (19.2%), and 34 (25.6%) patients for 'low dose', 'intermediate dose', and 'high dose' patients, respectively (log-rank $P = 0.001$; Figure 1).

Predictors of primary outcome (waitlist mortality or urgent heart transplantation)

In raw analyses, significant associations with primary outcome were observed for 'intermediate dose' and 'high dose' patients (Table 3). These associations remained significant after adjustment only in 'high dose' patients with a 48% increase for the 'intermediate dose' group [hazard ratio (HR), 95% confidence interval (CI), 1.48, 0.95 to 2.31; $P = 0.081$]

whereas 'high dose' diuretics were associated with a two-fold increase in this outcome (HR 2.23, 1.33 to 3.73; $P = 0.002$).

Predictors of waitlist mortality

In crude analyses, significant associations with waitlist death were observed only for 'high dose' patients (Table 3). A 'high dose' was associated with a six-fold increase in this outcome (HR 5.61, 2.11 to 14.90; $P < 0.001$). In multivariable models adjusting for congestion variables (including total bilirubin and natriuretic peptides), association of 'high dose' with waitlist death was stronger (HR 6.18, 2.16 to 17.72; $P < 0.001$). The intermediate dose was not significantly associated with waitlist death after adjustment (Table 3).

Predictors of other outcomes on heart transplant waitlist

'High dose' profiles were also associated with the combined outcome of waitlist mortality, urgent HT, or LVAD implantation and with the combined outcome of waitlist mortality, delisting for aggravation, urgent HT, or LVAD implantation in crude analysis (HR 2.06, 1.36 to 3.11; $P < 0.001$ and HR 2.02, 1.39 to 2.93; $P < 0.001$, respectively) and after adjustment including congestion parameters (HR 1.97, 1.23 to 3.15; $P = 0.004$ and HR 1.99, 1.30 to 3.05; $P = 0.001$, respectively).

Figure 1 Likelihood of different outcomes according to quartiles of furosemide equivalent dose. LVAD, left ventricular assist device.

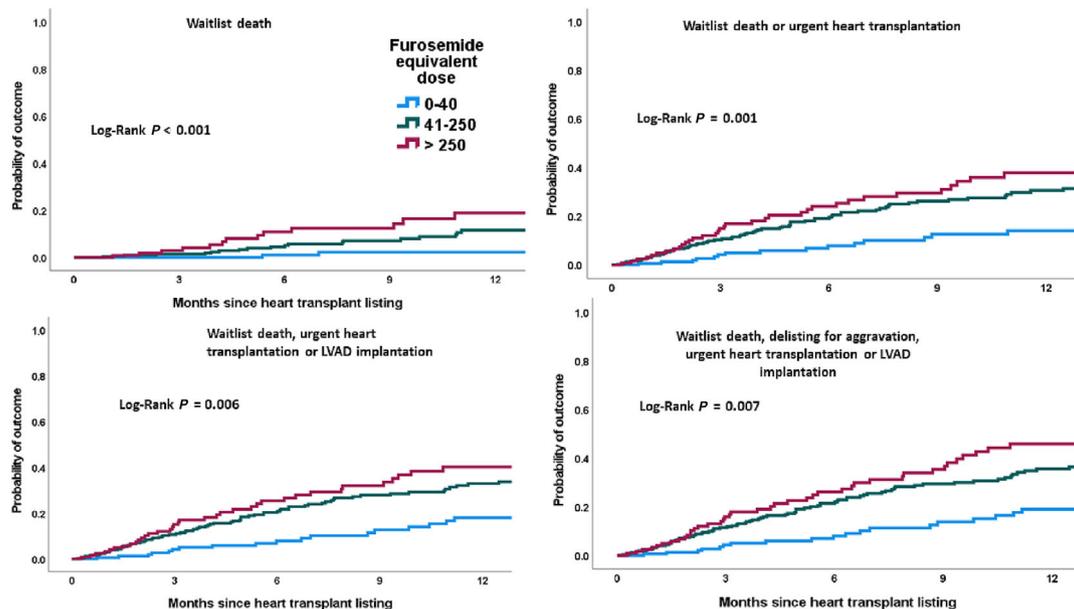


Table 3 Unadjusted and adjusted association of furosemide dose groups with outcomes

| | Furosemide equivalent dose 0–40 mg (n = 202) | Furosemide equivalent dose 41–250 mg (n = 365) | Furosemide equivalent dose >250 mg (n = 133) |
|---|--|--|--|
| Univariate model | | | |
| Waitlist mortality ^a | Ref | 2.48 (0.95–6.48) <i>P</i> = 0.064 | 5.61 (2.11–14.90) <i>P</i> < 0.001 |
| Waitlist mortality or urgent heart transplantation ^b | Ref | 1.66 (1.10–2.51) <i>P</i> = 0.017 | 2.45 (1.56–3.87) <i>P</i> < 0.001 |
| Waitlist mortality, urgent heart transplantation, or LVAD implantation ^c | Ref | 1.45 (1.00–2.09) <i>P</i> = 0.047 | 2.06 (1.36–3.11) <i>P</i> < 0.001 |
| Waitlist mortality, delisting for aggravation, urgent heart transplantation, or LVAD implantation ^d | Ref | 1.34 (0.96–1.87) <i>P</i> = 0.084 | 2.02 (1.39–2.93) <i>P</i> < 0.001 |
| Adjusted model for age, gender, estimated glomerular filtration rate, BNP/NT-proBNP Z-score, and total bilirubin | | | |
| Waitlist mortality ^a | Ref | 2.45 (0.87–6.92) <i>P</i> = 0.091 | 6.18 (2.16–17.72) <i>P</i> < 0.001 |
| Waitlist mortality or urgent heart transplantation ^b | Ref | 1.48 (0.95–2.31) <i>P</i> = 0.081 | 2.23 (1.33–3.73) <i>P</i> = 0.002 |
| Waitlist mortality, urgent heart transplantation, or LVAD implantation ^c | Ref | 1.35 (0.91–2.01) <i>P</i> = 0.130 | 1.97 (1.23–3.15) <i>P</i> = 0.004 |
| Waitlist mortality, delisting for aggravation, urgent heart transplantation, or LVAD implantation ^d | Ref | 1.29 (0.90–1.86) <i>P</i> = 0.170 | 1.99 (1.30–3.05) <i>P</i> = 0.001 |

LVAD, left ventricular assist device.

Bolded values are used to highlight significant results and facilitate reading. Bold highlighting can be removed.

^aThe Fine–Gray subdistribution hazard model with non-urgent heart transplantation, delisting for aggravation, urgent heart transplantation, or LVAD implantation as a competing risk event.

^bThe Fine–Gray subdistribution hazard model with non-urgent heart transplantation, delisting for aggravation, or LVAD implantation as a competing risk event.

^cThe Fine–Gray subdistribution hazard model with non-urgent heart transplantation or delisting for aggravation as a competing risk event.

^dThe Fine–Gray subdistribution hazard model with non-urgent heart transplantation as a competing risk event.

Sensitivity analysis

The quartile or modified (rounded to 40 mg multiple) quartile analyses revealed a non-significant rise in risk for Quartiles 2 and 3. However, it was only the quartile representing a daily furosemide dose exceeding 250 mg that exhibited a significant association with the outcomes (Supporting Information, *Table S1*).

When dichotomized (≤ 20 and > 20 mmHg), PCWP was added in addition to Model 2, and the results remained statistically significant in the ‘high dose’ group (*P*-value < 0.05 for all), with no significant interaction between diuretic dose and dichotomized PCWP (Supporting Information, *Table S2*).

Discussion

In the present study, we report the prognostic value of high-dose loop diuretics in a cohort of patients with advanced HF listed for HT. We found a significant and sizeable association between diuretic dose, haemodynamic congestion status, and prognosis on the waitlist in this specific population. This suggests that congestion (and its treatment) remains an important issue in advanced HF. Diuretic dose should be perceived as an important risk stratifier in patients awaiting HT.

Prognosis of high diuretic dose

The effects of diuretics in chronic HF on morbidity and mortality have yet to be studied in large prospective randomized controlled trials. However, many observational studies have found an association between diuretic prescription and outcome,^{5,11–13} indicating that loop diuretics are powerful prognostic markers. In the EMPHASIS trial, loop diuretic use at baseline was associated with the risk of cardiovascular death or HF hospitalization in a stepwise manner, with a doubling of the risk for patients receiving between 1 and 40 mg of furosemide and a three-fold increase for those receiving more than 40 mg.⁵ In a post hoc analysis of Studies Of Left Ventricular Dysfunction (SOLVD), loop diuretic treatment was associated with a greater risk of hospitalization or death [risk ratio (RR) = 1.31, 1.09 to 1.57] compared with patients without diuretics.¹³ In a propensity match study, Ahmed *et al.* found a 31% increased risk of death in patients with diuretics.¹² The relationship between loop diuretic dose and prognosis was investigated more recently in two different studies using propensity score.^{14,15} Dini *et al.* showed that the risk of death increased linearly across quartiles of furosemide dose in a population of HF outpatients (HR 1.38, 95% CI 1.14 to 1.68). The median furosemide dose was 25 mg reflecting a low-risk population. In this latter study, a daily dose of 50 mg was identified as the best threshold value to predict a high risk of death within 3 years. This threshold appears concordant with the threshold set in our study

between 'low dose' patients (furosemide equivalent dose ≤ 40 mg) vs. 'intermediate dose' and 'high dose' patients. Similarly, in a population of symptomatic HF of ischaemic aetiology, composite outcomes of cardiovascular death or hospitalization associated with low-, medium-, and high-dose groups were 1.71 (1.41–2.06), 1.99 (1.50–2.64), and 2.94 (1.95–4.41), respectively.¹⁵ In our study, in the specific population of patients awaiting HT, the 'high dose' group was significantly associated with a six-fold increased risk of waitlist death and a two-fold risk of a composite outcome of waitlist death or urgent HT after adjustment for confounding factors. Loop diuretic dose consequently appears as a strong risk marker of outcome in a wide range of HF patients as it is still sizably associated with outcome in extreme profiles such as patients awaiting HT.

Diuretic dose and congestion in chronic settings

Diuretics have a class I recommendation to alleviate signs and symptoms of congestion.¹ The optimal diuretic dose in chronic settings is unknown and in a recent statement from the Heart Failure Association of the European Society of Cardiology, it is advised to use to the lowest possible dose of diuretics with a need for individual adjustment.¹⁶ In the latest guidelines, the objective of diuretics is to obtain euvolaemia, despite the absence of 'consensual definition'.¹ Indeed, in a recent meta-analysis including 13 studies and over 8000 patients, patients who achieved euvolaemia had a better prognosis even in the presence of worsening renal function (WRF) than those without WRF or decongestion.¹⁷ Our study provides further, novel findings on the relationship between loop diuretic dose and decongestion. Interestingly, congestion increased concomitantly with diuretic dose. Indeed, pulmonary artery pressure, PCWP, and NT-proBNP were progressively higher from the 'low dose' group to the 'high dose' group, hence reflecting the inability of loop diuretics to reach euvolaemia in certain patients in a 'real life' cohort of severe patients awaiting HT. Many strategies have been proposed to obtain euvolaemia in congestive patients under loop diuretics, including an increase in routine loop diuretic dosage, use of adjunct continuous or bolus intravenous diuretics, and addition of thiazide,^{18,19} acetazolamide,²⁰ or tolvaptan.²¹ All these combinations were associated with increased natriuresis and diuresis in acute settings, although none of these strategies were assessed in chronic HF. In a recent position statement paper, experts indicated that it may be necessary to increase the treatment dose after an acute decompensation for patients already on loop diuretics at admission.¹⁶ However, in the ASCEND-HF trial, change in dosage at discharge was not associated with improved outcomes compared with no dose change (adjusted odds ratio 0.92, 0.79 to 1.07).²²

Risk marker or risk factor

Although the design and purpose of this study were not to assess the toxicity of loop diuretics, a 'high dose' defined by a daily dose of furosemide equivalent > 250 mg was associated with outcomes even after adjusting for other severity parameters. This threshold is close to the experts' definition of diuretic resistance (160 mg twice daily of furosemide or equivalent).²³ Unlike a previous study published by Pellicori *et al.* in a less ill population,²⁴ we found that diuretic dose was independently associated with outcome even after adjusting for natriuretic peptides, hepatic, and renal functions.

Pathophysiological hypotheses have recently emerged to better understand the role of diuretics in cardiorenal interaction. Indeed, it has been shown that the use of diuretics is associated with a decrease in the excretion of trimethylamine N-oxide causing renal and plasma accumulation.²⁵ This uraemic toxin is associated with an increased risk for all-cause mortality at 5 years in patients with chronic kidney disease (CKD) and in normal populations²⁶ as well as the risk of death and/or rehospitalization for HF in patients hospitalized for acute HF.²⁷ Moreover, all diuretic classes lead to a sustained increase in plasma renin activity with a gradual effect related to their natriuretic and diuretic efficacy (loop diuretics $>$ thiazide $>$ MRA).²⁸ This adaptive compensatory system could potentially participate in the long-term progression of HF and CKD, particularly in advanced HF, when patients are intolerant to drugs blocking the renin-angiotensin-aldosterone system (or treated with a suboptimal dose).

Diuretic dose thus appears to be both a risk factor for the cardiorenal syndrome²⁹ and a risk marker. Indeed, it integrates cardiovascular risk factors (hypertension and diabetes mellitus), severity of cardiac and renal disease (higher NT-proBNP and lower eGFR and peak VO_2), and congestive state (residual congestion despite high diuretic dose). Nevertheless, the fact that diuretics maintained a significant association with prognosis even after adjusting for these factors suggests that the prognostic value of diuretic dose extends beyond their influence.

Clinical implications

A 'high diuretic dose' identifies patients with advanced HF featuring a more congestive profile. Such profile may be due to the presence of residual congestion,^{30,31} which is associated with worse outcome, rather than the higher diuretic dose itself. Indeed, residual congestion has been shown to be related to worse outcome throughout the patient journey³¹ and should consequently be repeatedly evaluated, possibly using ultrasound approaches,^{30–32} to adapt congestion treatment. Using wireless pulmonary artery haemodynamic monitoring³³ or ultrasound imaging of inferior vena

cava or renal veins could be of particular interest in this context.³² Future studies investigating the effects of diuretic 'optimization' based on more advanced assessments of congestion are needed to better ascertain the long-term prognostic effects of loop diuretic exposure. Optimal dosage, the possibility of a decrease in diuretic dose and the use of thiazide or acetazolamide as co-diuretics, in chronic settings should be prospectively assessed in future studies.

Diuretic dose appears as an integrator of cardiorenal risk factors and a strong prognostic marker in patients with severe HF. A furosemide equivalent dose > 250 mg may be propitiously considered as a red flag for adverse cardiovascular outcomes and should encourage close monitoring into tertiary centre. This parameter could also be useful to take into account to optimize access to transplantation and/or the timing of mechanical cardiac support implantation.

Limitations

The present study was an observational study and loop diuretic dose was only assessed at time of listing for HT as were the proper catheter and biological parameter assessments. First, we noted a median interval of 2 months between right heart catheterization and listing for HT. Given that this study primarily involved outpatients, the probability of a substantial alteration in diuretic dose within this timeframe is minimal. Furthermore, it is important to note that diuretic dose is not a criterion for the graft allocation score, thus ruling out the possibility of adjusting the dose to enhance priority for HT. Second, the inclusion of renal function evolution over time, stratified by furosemide dose, would have been valuable in determining whether patients with higher diuretic doses are at an elevated risk for renal complications. Third, while this is a nationwide study, given that HT implementation differs worldwide, association of diuretic dose with outcome may vary according to geographical context.

Conclusions

Diuretic dose is a strong predictor of outcome in advanced HF. High-dose furosemide (>250 mg) is associated with waitlist death and a composite of waitlist death or urgent transplantation in ambulatory advanced HF patients awaiting transplantation.

References

- McDonagh TA, Metra M, Adamo M, Gardner RS, Baumbach A, Böhm M, Burri H, Butler J, Čelutkienė J, Chioncel O, Cleland JGF, Coats AJS, Crespo-Leiro MG, Farmakis D, Gilard M, Heymans S, Hoes AW, Jaarsma T, Jankowska EA, Lainscak M, Lam CSP, Lyon AR, McMurray JJV, Mebazaa A, Mindham R, Muneretto C, Francesco Piepoli M, Price

Conflict of interest

G.B. reports consulting fees from AstraZeneca, Boehringer-Ingelheim, and Abbott, outside the submitted work. G.C. reports personal fees from Institut de France and Fullbright, outside the submitted work. R.D., C.D., C.G., and J.G. have nothing to disclose. P.G. reports consulting fees or honoraria from Air Liquide Santé International, Abiomed, Amomed, and Abbott and support from Pfizer, outside the submitted work. A.B. has nothing to disclose. M.M. reports honoraria from LFB/Hemosims Cardio, outside the submitted work. E.E., R.G., C.C., K.N., S.P., and V.G. have nothing to disclose. F.B. reports consulting fees or honoraria from Jansen & Jansen, Boehringer, AstraZeneca, and Pfizer, outside the submitted work. E.V., N.O., S.G., and K.B. have nothing to disclose. L.S. reports personal fees or honoraria from Novartis, Vifor, and AstraZeneca, outside the submitted work. K.D. has nothing to disclose. N.G. reports personal fees from AstraZeneca, Bayer, Boehringer, Novartis, and Vifor, outside the submitted work. M.F.S., P.F., and C.A. have nothing to disclose.

Funding

The Nancy team is supported by the RHU Fight-HF, a public grant overseen by the French National Research Agency (ANR) as part of the second 'Investissements d'Avenir' programme (reference: ANR-15-RHUS-0004), the French PIA project 'Lorraine Université d'Excellence' (reference: ANR-15-IDEX-04-LUE), the ANR FOCUS-MR (reference: ANR-15-CE14-0032-01), ERA-CVD EXPERT (reference: ANR-16-ECVD-0002-02), the Contrat de Plan Etat Lorraine IT2MP, and FEDER Lorraine.

Supporting information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table S1: Primary outcome according to quartile and modified quartile analysis.

Table S2: Adjusted association of furosemide dose groups with outcomes.

- S, Rosano GMC, Ruschitzka F, Kathrine Skibelund A, ESC Scientific Document Group, de Boer RA, Christian Schulze P, Abdelhamid M, Aboyns V, Adamopoulos S, Anker SD, Arbelo E, Asteggiano R, Bauersachs J, Bayes-Genis A, Borger MA, Budts W, Cikes M, Damman K, Delgado V, Dendale P, Dilaveris P, Drexel H, Ezekowitz J, Falk V, Fauchier L, Filippatos G, Fraser A, Frey N, Gale CP, Gustafsson F, Harris J, Iung B, Janssens S, Jessup M, Konradi A, Kotecha D, Lambrou E, Lancellotti P, Landmesser U, Leclercq C, Lewis BS, Leyva F, Linhart A, Løchen M-L, Lund LH, Mancini D, Masip J, Milicic D, Mueller C, Nef H, Nielsen J-C, Neubeck L, Noutsias M, Petersen SE, Sonia Petronio A, Ponikowski P, Prescott E, Rakisheva A, Richter DJ, Schlyakhto E, Seferovic P, Senni M, Sitges M, Sousa-Uva M, Tocchetti CG, Touyz RM, Tschoepe C, Waltenberger J, Adamo M, Baumbach A, Böhm M, Burri H, Čelutkienė J, Chioncel O, Cleland JGF, Coats AJS, Crespo-Leiro MG, Farmakis D, Gardner RS, Gilard M, Heymans S, Hoes AW, Jaarsma T, Jankowska EA, Lainscak M, Lam CSP, Lyon AR, McMurray JJV, Mebazaa A, Mindham R, Muneretto C, Piepoli MF, Price S, Rosano GMC, Ruschitzka F, Skibelund AK. ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure. *Eur Heart J*. 2021; **42**: 3599–3726.
2. Crespo-Leiro MG, Metra M, Lund LH, Milicic D, Costanzo MR, Filippatos G, Gustafsson F, Tsui S, Barge-Caballero E, de Jonge N, Frigerio M, Hamdan R, Hasin T, Hülsmann M, Nalbantgil S, Potena L, Bauersachs J, Gkouziouta A, Ruhparwar A, Ristic AD, Straburzynska-Migaj E, McDonagh T, Seferovic P, Ruschitzka F. Advanced heart failure: a position statement of the Heart Failure Association of the European Society of Cardiology. *Eur J Heart Fail*. 2018; **20**: 1505–1535.
 3. Baumwöl J. “I need help”—a mnemonic to aid timely referral in advanced heart failure. *J Heart Lung Transplant*. 2017; **36**: 593–594.
 4. ter Maaten JM, Valente MAE, Damman K, Hillege HL, Navis G, Voors AA. Diuretic response in acute heart failure—pathophysiology, evaluation, and therapy. *Nat Rev Cardiol*. 2015; **12**: 184–192.
 5. Coiro S, Girerd N, McMurray JJV, Pitt B, Swedberg K, Van Veldhuisen DJ, Lamiral Z, Rossignol P, Zannad F. Diuretic therapy as prognostic enrichment factor for clinical trials in patients with heart failure with reduced ejection fraction. *Clin Res Cardiol*. 2021; **110**: 1308–1320.
 6. Levy WC, Mozaffarian D, Linker DT, Sutradhar SC, Anker SD, Cropp AB, Anand I, Maggioni A, Burton P, Sullivan MD, Pitt B, Poole-Wilson PA, Mann DL, Packer M. The Seattle Heart Failure Model: prediction of survival in heart failure. *Circulation*. 2006; **113**: 1424–1433.
 7. Packer M, O’Connor CM, Ghali JK, Pressler ML, Carson PE, Belkin RN, Miller AB, Neuberger GW, Frid D, Wertheimer JH, Cropp AB, DeMets DL. Effect of amlodipine on morbidity and mortality in severe chronic heart failure. *N Engl J Med*. 1996; **335**: 1107–1114.
 8. Eshaghian S, Horwich TB, Fonarow GC. Relation of loop diuretic dose to mortality in advanced heart failure. *Am J Cardiol*. 2006; **97**: 1759–1764.
 9. Jasseron C, Legeai C, Jacquelinet C, Leprince P, Cantrelle C, Audry B, Porcher R, Bastien O, Dorent R. Prediction of waitlist mortality in adult heart transplant candidates. *Transplantation*. 2017; **101**: 2175–2182.
 10. Austin PC, Lee DS, Fine JP. Introduction to the analysis of survival data in the presence of competing risks. *Circulation*. 2016; **133**: 601–609.
 11. Ahmed A, Young JB, Love TE, Levesque R, Pitt B. A propensity-matched study of the effects of chronic diuretic therapy on mortality and hospitalization in older adults with heart failure. *Int J Cardiol*. 2008; **125**: 246–253.
 12. Ahmed A, Husain A, Love TE, Gambassi G, Dell’Italia LJ, Francis GS, Gheorghiadu M, Allman RM, Meleth S, Bourge RC. Heart failure, chronic diuretic use, and increase in mortality and hospitalization: an observational study using propensity score methods. *Eur Heart J*. 2006; **27**: 1431–1439.
 13. Domanski M, Norman J, Pitt B, Haigney M, Hanlon S, Peyster E. Diuretic use, progressive heart failure, and death in patients in the Studies of Left Ventricular Dysfunction (SOLVD). *J Am Coll Cardiol*. 2003; **42**: 705–708.
 14. Dini FL, Ghio S, Klersy C, Rossi A, Simioniuc A, Scelsi L, Genta FT, Ciccoira M, Tavazzi L, Temporelli PL. Effects on survival of loop diuretic dosing in ambulatory patients with chronic heart failure using a propensity score analysis. *Int J Clin Pract*. 2013; **67**: 656–664.
 15. Damman K, Kjekshus J, Wikstrand J, Cleland JGF, Komajda M, Wedel H, Waagstein F, McMurray JJV. Loop diuretics, renal function and clinical outcome in patients with heart failure and reduced ejection fraction. *Eur J Heart Fail*. 2016; **18**: 328–336.
 16. Mullens W, Damman K, Harjola VP, Mebazaa A, Brunner-La Rocca HP, Martens P, Testani JM, Tang WHW, Orso F, Rossignol P, Metra M, Filippatos G, Seferovic PM, Ruschitzka F, Coats AJ. The use of diuretics in heart failure with congestion—a position statement from the Heart Failure Association of the European Society of Cardiology. *Eur J Heart Fail*. 2019; **21**: 137–155.
 17. Yamada T, Ueyama H, Chopra N, Yamaji T, Azushima K, Kobayashi R, Kinguchi S, Urate S, Suzuki T, Abe E, Saigusa Y, Wakui H, Partridge P, Burger A, Bravo CA, Rodriguez MA, Ivey-Miranda J, Tamura K, Testani J, Coca S. Systematic review of the association between worsening renal function and mortality in patients with acute decompensated heart failure. *Kidney Int Reports*. 2020; **5**: 1486–1494.
 18. Jentzer JC, Dewald TA, Hernandez AF. Combination of loop diuretics with thiazide-type diuretics in heart failure. *J Am Coll Cardiol*. 2010; **56**: 1527–1534.
 19. Trullàs JC, Morales-Rull JL, Casado J, Carrera-Izquierdo M, Sánchez-Martel M, Conde-Martel A, Dávila-Ramos MF, Llacer P, Salamanca-Bautista P, Pérez-Silvestre J, Plasín MÁ, Cerqueiro JM, Gil P, Formiga F, Manzano L, investigators C trial, Morales JL, Solé C, Carrera M, León M, Sánchez M, Horna VG, Conde A, Meneses MH, Dávila MF, Carballo CH, Casado J, Zabaleta JP, Iborra PL, García MCM, Trullàs JC, Bisbe J, del Prado Salamanca Bautista M, Bodas ÓA, Manzano L, Ruiz R, Silvestre JP, Plasín MÁ, González JMC, Chivite D, Formiga F, Gil P, Jordana R, Villalonga M, Rubio MIP, Rodrigo JMC, Pérez-Barquero MM, Muela A, Mateos L, Grau J, Armengou A, Herrero A, López RQ. Combining loop with thiazide diuretics for decompensated heart failure: the CLOROTIC trial. *Eur Heart J*. 2023; **44**: 411–421.
 20. Mullens W, Dauw J, Martens P, Verbrugge FH, Nijst P, Meekers E, Tartaglia K, Chenot F, Moubayed S, Dierckx R, Blouard P, Troisfontaines P, Derthoo D, Smolders W, Bruckers L, Droogne W, ter Maaten JM, Damman K, Lassus J, Mebazaa A, Filippatos G, Ruschitzka F, Dupont M. Acetazolamide in acute decompensated heart failure with volume overload. *N Engl J Med*. 2022; **387**: 1185–1195.
 21. Cox ZL, Hung R, Lenihan DJ, Testani JM. Diuretic strategies for loop diuretic resistance in acute heart failure: the 3T trial. *JACC Hear Fail*. 2020; **8**: 157–168.
 22. Devore AD, Hasselblad V, Mentz RJ, O’Connor CM, Armstrong PW, McMurray JJ, Ezekowitz JA, Tang WHW, Starling RC, Voors AA, Califf RM, Hernandez AF. Loop diuretic dose adjustments after a hospitalization for heart failure: insights from ASCEND-HF. *Eur J Heart Fail*. 2015; **17**: 340–346.
 23. Wilcox CS, Testani JM, Pitt B. Pathophysiology of diuretic resistance and its implications for the management of chronic heart failure. *Hypertension*. 2020; **76**: 1045–1054.
 24. Pellicori P, Cleland JGF, Zhang J, Kallvikbacka-Bennett A, Urbinati A, Shah P, Kazmi S, Clark AL. Cardiac dysfunction, congestion and loop diuretics: their relationship to prognosis in heart failure. *Cardiovasc Drugs Ther*. 2016; **30**: 599–609.
 25. Li DY, Wang Z, Jia X, Yan D, Shih DM, Hazen SL, Lusic AJ, Tang WHW. Loop diuretics inhibit renal excretion of trimethylamine N-oxide. *JACC Basic Transl Sci*. 2021; **6**: 103–115.

26. Tang WHW, Wang Z, Kennedy DJ, Wu Y, Buffa JA, Agatista-Boyle B, Li XS, Levison BS, Hazen SL. Gut microbiota-dependent trimethylamine N-oxide (TMAO) pathway contributes to both development of renal insufficiency and mortality risk in chronic kidney disease. *Circ Res.* 2014; **116**: 448–455.
27. Suzuki T, Heaney LM, Bhandari SS, Jones DJL, Ng LL. Trimethylamine N-oxide and prognosis in acute heart failure. *Heart.* 2016; **102**: 841–848.
28. McNally RJ, Faconti L, Cecelja M, Farukh B, Floyd CN, Chowienczyk PJ. Effect of diuretics on plasma renin activity in primary hypertension: a systematic review and meta-analysis. *Br J Clin Pharmacol.* 2021; **87**: 2189–2198.
29. Paper W, Zannad F, Rossignol P. Cardiorenal syndrome revisited. *Circulation.* 2018; **138**: 929–944.
30. Coiro S, Rossignol P, Ambrosio G, Carluccio E, Alunni G, Murrone A, Tritto I, Zannad F, Girerd N. Prognostic value of residual pulmonary congestion at discharge assessed by lung ultrasound imaging in heart failure. *Eur J Heart Fail.* 2015; **17**: 1172–1181.
31. Girerd N, Seronde M-F, Coiro S, Chouihed T, Bilbault P, Braun F, Kenizou D, Maillier B, Nazeyrollas P, Roul G, Fillieux L, Abraham WT, Januzzi J, Sebbag L, Zannad F, Mebazaa A, Rossignol P, INI-CRCT, Great Network and the E-HG. Integrative assessment of congestion in heart failure throughout the patient journey. *JACC Heart Fail.* 2018; **6**: 273–285.
32. Pellicori P, Platz E, Dauw J, ter Maaten JM, Martens P, Pivetta E, Cleland JGF, McMurray JJV, Mullens W, Solomon SD, Zannad F, Gargani L, Girerd N. Ultrasound imaging of congestion in heart failure: examinations beyond the heart. *Eur J Heart Fail.* 2020; **23**: 703–712.
33. Abraham WT, Adamson PB, Bourge RC, Aaron MF, Costanzo MR, Stevenson LW, Strickland W, Neelagaru S, Raval N, Krueger S, Weiner S, Shavelle D, Jeffries B, Yadav JS. Wireless pulmonary artery haemodynamic monitoring in chronic heart failure: a randomised controlled trial. *Lancet.* 2011; **377**: 658–666.