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SPECIAL ARTICLE

Volume Control

Myocardial markers are highly altered by higher rates of fluid removal during hemodialysis

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Abstract

Introduction: Although hemodialysis is lifesaving in patients with kidney failure extensive interdialytic weight gain (IDWG) between dialyses worsens the prognosis. We recently showed a strong correlation between IDWG and predialytic values of cardiac markers. The aim of the present study was to evaluate if the cardiac markers N-terminal pro-B-type natriuretic peptide (proBNP) and troponin T were influenced by IDWG and speed of fluid removal (ultrafiltration-rate).

Methods: Twenty hemodialysis patients performed in total 60 hemodialysis (three each). Predialytic values of proBNP and troponin T and changes from predialysis to 180 min hemodialysis (180–0 min) were compared with the IDWG calculated in percent of body weight. The ultrafiltration-rate was adjusted (UF-rate$_{adj}$) to IDWG: (100 × weight gain between dialysis [kg])/(estimated body dry weight [kg] × length of hemodialysis session [hours]).

Results: UF-rate$_{adj}$ correlated (Spearman) with (1) predialytic values of IDWG ($r = 0.983$, $p < 0.001$), proBNP ($r = 0.443$, $p < 0.001$), and troponin T ($r = 0.296$, $p = 0.025$); and (2) differences in proBNP$_{180\text{–}0min}$ ($r = 0.572$, $p < 0.001$) and troponin T$_{180\text{–}0min}$ ($r = 0.400$, $p = 0.002$). UF-rates$_{adj}$ above a breakpoint of 0.60 caused more release of proBNP$_{180\text{–}0min}$ ($p = 0.027$). Remaining variables in multiple regression analysis with ProBNP$_{180\text{–}0min}$ as dependent factor were predialytic proBNP ($p < 0.001$) and the ultrafiltration-rate ($p < 0.001$).

Conclusion: Higher UF-rate$_{adj}$ during dialysis was correlated to increased levels of cardiac markers. Data support a UF-rate$_{adj}$ lower than 0.6 to limit such increase. Further studies may confirm if limited fluid intake and a lower UF-rate$_{adj}$ should be recommended to prevent cardiac injury during dialysis.

KEYWORDS
biocompatibility, embolies, heart, hemodialysis, interdialytic weight gain

INTRODUCTION

Hemodialysis is a lifesaving therapy in patients with kidney failure. Patients treated with chronic hemodialysis generally have a shorter life expectancy.[1,2] One main reason for shorter life expectancy is the development of cardiovascular diseases in patients with chronic kidney disease.[3] In dialysis patients, cardiovascular diseases and infections are especially prevalent.[4] Further, myocardial stunning is notably developed in chronic hemodialysis patients in contrast to those performing peritoneal dialysis, and is independently associated with high ultrafiltration volumes.[5,6]

Before dialysis, markers of myocardial strain such as N-terminal pro-B-type natriuretic peptide (proBNP), troponin T,[7–11] and pentraxin-3 (pentraxin)[11] are frequently increased. These cardiac markers increase even further under hemodialysis despite removal of uremic toxins and fluid.[10,11]

Since most hemodialysis patients have limited urine production, many patients retain water between hemodialysis sessions, reflected as weight gain. Such weight gain, in percent of the patient's estimated normal body weight, is reported as interdialytic weight gain (IDWG).[12] High IDWG constitutes a risk for increased morbidity of the patient,[12–15] and is a strong predictor for shortened life expectancy in dialysis patients.[15,16]

In a previous study, we found a strong correlation between IDWG and the predialytic values of the cardiac markers proBNP, troponin T, and pentraxin-3.[11] In addition, the study showed that patients with an IDWG above 2.5% also had a greater increase of proBNP during hemodialysis.[11]

The aim of the present study was to evaluate if the cardiac markers proBNP and troponin T were influenced by IDWG and speed of fluid removal (ultrafiltration).

PATIENTS AND METHODS

This study was performed in the framework of a previously conducted prospective study. Information on demography, material, methods, and other variables were published in detail elsewhere.[11] In brief, 20 chronic hemodialysis patients were included. All patients performed, besides their regular dialyses, one hemodialysis in three consecutive weeks within the frame of the study. That way, for each patient, a total of three hemodialysis sessions were assessed. Patients were informed and consented to participate in the study. The study complied with the Declaration of Helsinki and was approved by the local ethics committee in Umea, Sweden (EPN 05-138M, addition date October 16, 2007; EPN2012-42-31M, March 6, 2012).

Dialyses were done using Fresenius 4008 and 5008 monitors and Gambro monitors 200. Low-flux dialyzers were used to minimize elimination of proBNP, troponin T and pentraxin-3 by dialysis. The present study focused on the values predialysis (pentraxin$_{0min}$, ProBNP$_{0min}$, troponin T$_{0min}$) and 180 min into hemodialysis (proBNP$_{180min}$, troponin T$_{180min}$), as well as the difference between these two (δproBNP$_{180–0min}$, δtroponin T$_{180–0min}$). The impact of a specific ultrafiltration-rate depends on the body constitution. For instance, removal of 1000 mL/h has different implications in a patient weighing 100 kg than in a patient weighing 50 kg. We therefore adjusted ultrafiltration-rate (UF-rate$_{adj}$) to IDWG using the following formula: (100 (%) × weight gain between dialyses [kg])/(estimated body dry weight [kg] × length of hemodialysis session [hours]). Assuming a hemodialysis session of 4 h, a weight gain of 4 kg would yield a UF-rate$_{adj}$ of 1.0 in a patient with an estimated body dry weight of 100 kg and 2.0 in a patient with 50 kg.

We corrected laboratory values of proBNP and troponin T for dilution by infusion or concentration by removal of fluid of the intravascular volume by using the formula for change in erythrocyte volume fraction by Schneditz et al.[17]

Since the half-lives of cardiac markers are short, each hemodialysis was considered independent from the previous and following treatment.

Laboratory variables analyzed within 2 h of sampling: hemoglobin (Hb, reference value 100–120 gL^{-1}), erythrocyte volume fraction (reference value 0.30–0.36) to correct for change in plasma concentrations.

Analysis of stored samples included highly sensitive troponin T (reference value <15 ng/L, Roche) and proBNP (reference value <150 ng/L for patients aged 0–74 and < 450 ng/L for elderly, Roche). Analysis of pentraxin 3 (pentraxin, Perseus Proteomics Inc., Tokyo, Japan, reference value <3.5 μg/L) was included as a marker for inflammation and endothelial state. Samples representing each patient were analyzed in one batch.

ProBNP upper limit of analysis for the laboratory was 70,000 ng/L. For patients surpassing 70,000 ng/L, 70,000 was set for predialysis. An increase of proBNP above this value during hemodialysis could not be calculated. The study included ejection fraction measured from a predialysis echocardiogram (%) and the QRS-duration (in milliseconds) measured automatically from the latest 12-lead ECG performed before the study.

Statistical analyses

Data were presented as means and standard deviations (SD) or as medians with minimum to maximum values for data that were not normally distributed. Comparisons between groups were made by non-parametric Mann–Whitney *U* test and by Spearman's correlation analysis (*r*). Spearman's correlation analysis was used to adjust for eventual outliers. Multivariate stepwise regression analyses were performed with δproBNP$_{180–0min}$ as the dependent factor. The independent variables were sex, age, dry weight, length of hemodialysis session in hours, IDWG, ejection fraction, and ProBNP$_{0min}$. A two-tailed *p*-value <0.05 was considered significant. SPSS software version 28 was used (IBM, Armonk, NY, USA).

TABLE 1 Dialysis parameters and cardiac markers.

	N	Mean	SD	Median	Min–Max
IDWG (% of body weight)	60	1.69	1.20	1.76	0–4.7
Length of HD (hours)	60	4.2	0.43	4	3.5–5.0
Adjusted UF-rate (IDWG/hour)	60	0.40	0.29	0.40	0–1.2
$ProBNP_{0min}$ (ng/L)	57	17,041	21,556	5743	478–70,000
Troponin T_{0min} (ng/L)	57	103.7	93.7	81.0	12–422
$ProBNP_{180min}$ (ng/L)	57	18,424	22,679	6156	490–76,199
Troponin T_{180min} (ng/L)	57	104.8	92.8	80.7	13–447
$\delta proBNP_{180\text{-}0min}$ (ng/L)	52	2271	2801	764	−228 to 10,243
δTroponin $T_{180\text{-}0min}$ (ng/L)	56	6.48	18.6	3.95	−74.5 to 97

Note: ProBNP and Troponin T at different time points: Predialysis (0 min), and 180 min, and their differences. ProBNP and Troponin T samples from three sessions were missing at predialysis and at 180 min. In five of the HD sessions, proBNP was above the upper limit and thus was not included in the results related to the change of proBNP over 180 min of HD time.

Abbreviations: IDWG, interdialytic weight gain in % of body weight; HD, hemodialysis session; UF, ultrafiltration; proBNP, N-terminal pro-B-type natriuretic peptide.

RESULTS

The 20 patients, eight women and 12 men, performed a total of 60 hemodialysis sessions that were included in the study. Women did not differ from men in age (mean 65 ± 12 years vs. 66 ± 10 years) or hemodialysis vintage time (mean 33 ± 27.6 vs. 43 ± 27.1 months on hemodialysis). Table 1 shows means (±SD) and medians of IDWG, length of the hemodialysis sessions, UF-rate_{adj}, ProBNP, and troponin T at predialysis and at 180 min and the changes from predialysis to 180 min. The mean blood pump speed (Qb) was 317 mL/min (±44.7), and the median was 300 mL/min (range 200–415).

Influence of sex

Men had longer hemodialysis sessions ($p < 0.001$) compared to women, and higher troponin T_{0min} ($p = 0.006$) and troponin T_{180min} ($p = 0.032$); however, there was no sex difference in IDWG, UF-rate_{adj}, $proBNP_{0min}$, $proBNP_{180min}$, $\delta proBNP_{180\text{–}0min}$, or δtroponin $T_{180\text{–}0min}$.

Influence of blood pump speed

The blood pump speed (Qb) was correlated to age ($r = -0.275$, $p = 0.035$) but not to the variables IDWG, dry weight, UF-rate_{adj}, length of hemodialysis, proBNP, or troponin T.

ProBNP

There existed a negative correlation of $proBNP_{0min}$ to the left ventricular ejection fraction at predialysis ($r = -0.467$, $p < 0.001$) and a positive correlation to the QRS duration ($r = 0.319$, $p = 0.016$). Patients with an IDWG below 2.5% had a lower $proBNP_{0min}$ ($p = 0.007$) and a smaller increase in $\delta proBNP_{180\text{–}0min}$ ($p = 0.009$).

Pentraxin-3

The $pentraxin_{0min}$ (mean 6.35 ± 4.3, median 5.45, $n = 60$) increased at $pentraxin_{30min}$ ($p < 0.001$) and further increased at $pentraxin_{180min}$ ($p < 0.001$). The UF-rate_{adj} correlated with the $pentraxin_{0min}$ ($r = 0.276$, $p = 0.032$) and with the change at $\delta pentraxin_{30\text{–}0min}$ ($r = 0.301$, $p = 0.019$). The increases in $\delta pentraxin_{30\text{–}0min}$ and $\delta pentraxin_{180\text{–}0min}$ were more pronounced in older age ($p < 0.01$) and in those who increased in $\delta proBNP_{180\text{–}0min}$ ($p \leq 0.001$).

Inter dialytic weight gain

IDWG correlated with $proBNP_{0min}$ ($r = 0.471$, $p < 0.001$), $proBNP_{180min}$ ($r = 0.58$, $p < 0.001$) and $\delta proBNP_{180\text{-}0min}$ ($r = 0.60$, $p < 0.001$). Further, IDWG correlated with troponin T_{0min} ($r = 0.31$, $p = 0.010$), troponin T_{180min} ($r = 0.36$, $p = 0.007$), and δtroponin $T_{180\text{–}0min}$ ($r = 0.39$, $p = 0.003$).

Adjusted UF-rate

The UF-rate_{adj} correlated with $proBNP_{0min}$ ($r = 0.443$, $p < 0.001$), $proBNP_{180min}$ ($r = 0.552$, $p < 0.001$), and with $\delta proBNP_{180\text{–}0min}$ ($r = 0.572$, $p < 0.001$), but not with the ejection fraction. The UF-rate_{adj} also correlated with

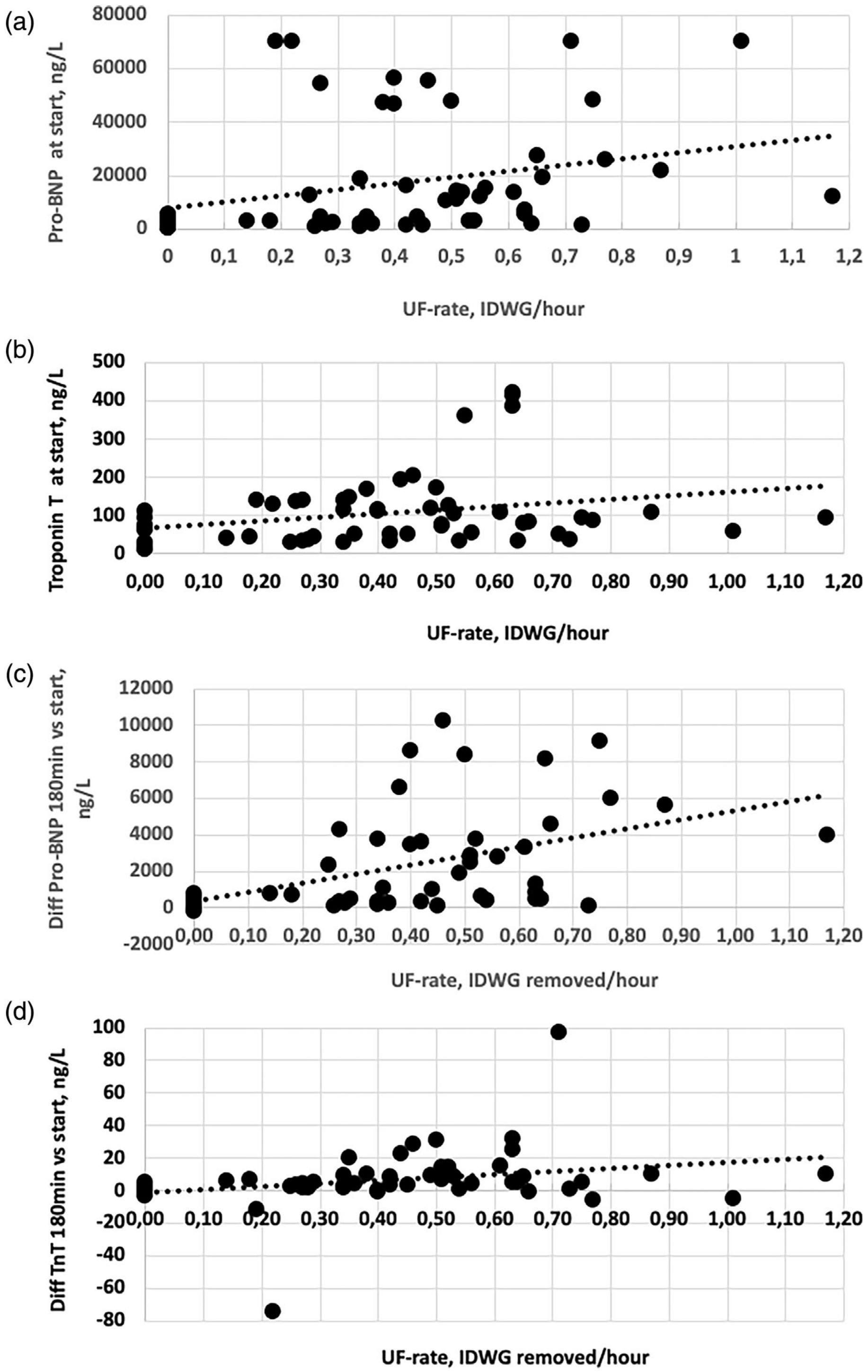

FIGURE 1 Displays correlations between the adjusted UF-rate based on the IDWG and the length of the hemodialysis session (IDWG/h). The correlation line displays the one achieved by parametric correlation. The results were not normally distributed; therefore, the correlations results were presented as Spearman's data (non-parametric results). Predialysis is given as "start." (a) Adjusted UF-rate in relation to predialytic proBNP. (b) Adjusted UF-rate in relation to predialytic troponin T. (c) Adjusted UF-rate in relation to difference in proBNP between 180 min hemodialysis and the predialysis value. (d) Adjusted UF-rate in relation to difference in troponin T between 180 min hemodialysis and the predialysis value.

troponin T_{0min} ($r = 0.309$, $p = 0.019$), troponin T_{180min} ($r = 0.346$, $p = 0.008$), and δtroponin $T_{180–0min}$ ($r = 0.400$, $p = 0.002$).

Figure 1a–d shows the relationship between the UF-$rate_{adj}$ and $proBNP_{0min}$ and troponin T_{0min}, respectively, as well as the relationship between the UF-$rate_{adj}$ and $δproBNP_{180\text{-}0min}$ and δtroponin $T_{180\text{-}0min}$, respectively. When probing the data for a recommendable breakpoint for UF-$rate_{adj}$, a UF-$rate_{adj}$ below versus above 0.60 resulted in significantly lower levels of $proBNP_{0min}$ ($p = 0.031$), $proBNP_{180min}$ ($p = 0.005$), and $δproBNP_{180–0min}$ ($p = 0.027$). The values did not differ for troponin T. When the breakpoint for the UF-$rate_{adj}$ was set at <0.40, the differences were more pronounced and included significant changes of troponin T_{180min} ($p = 0.029$) and δtroponin $T_{180–0min}$ ($p < 0.001$).

Multivariate stepwise regression analysis was done with δPro-$BNP_{180–0min}$ as dependent variable. The independent variables were sex, age, dry weight, length of HD session in hours, IDWG, and Pro-BNP_{0min}. Analyses exhibited a significant model (r-square 0.861, $p < 0.001$) containing the variables $\text{proBNP}_{0\text{min}}$ ($p < 0.001$) and IDWG ($p < 0.001$). Since IDWG and $\text{UF-rate}_{\text{adj}}$ were correlated to each other ($r = 0.983$, $p < 0.001$), a new calculation was made exchanging these variables with each other. The new calculation with $\delta\text{proBNP}_{180\text{–}0\text{min}}$ as the dependent variable showed a significant model with an r-square of 0.855 ($p < 0.001$) with the remaining variables $\text{ProBNP}_{0\text{min}}$ ($p < 0.001$) and the $\text{UF-rate}_{\text{adj}}$ ($p < 0.001$).

Percentage change in proBNP and troponin T

The ratio of the proBNP and troponin T at 180/0 min was also analyzed. In bivariate analysis the proBNP ratio at 180/0 min was related to the troponin T ratio at 180/0 min, the IDWG, the UF-rate, the length of hemodialysis and the vintage time (all with a $p < 0.01$); The above variables with the proBNP ratio 180/0 min as dependent factor were included in a multivariate analysis. A significant model included IDWG and vintage time ($r = 0.54$, $p = 0.011$). The UF-rate and vintage time were significant in the model (also $r = 0.54$, $p = 0.011$), if IDWG was removed. This was done since an increased IDWG is a condition for an UF-rate. No variable was retained when analyzing the troponin T ratio at 180/0 min as dependent factor.

Adverse events

No hypotensive episodes were reported in the case notes during the study dialyses. One patient experienced milder constrictions in the lower legs at the end of the hemodialysis.

DISCUSSION

To our knowledge, the present study is the first to show that a higher $\text{UF-rate}_{\text{adj}}$ was related to increased release of cardiac markers, that is, a faster fluid removal/body weight/hour caused a greater strain to the heart. This negative effect was noted for troponin T, proBNP, and pentraxin. This was unexpected since larger amounts of fluid were eliminated during hemodialysis especially from the patients with a higher IDWG, and thereby the heart would be expected to be relieved from strain. This indicates that we need to adjust the prescription of dialysis time not only regarding the Kt/V but also to the extent of $\text{UF-rate}_{\text{adj}}$, based on the IDWG that needs to be removed.

In congruence with previous studies,[8,11,18] the present study also showed that a high IDWG was associated with higher predialytic cardiac markers. It is more likely that a constant large IDWG leads to a progressively strained heart than that patients with a strained heart would drink more fluid. In addition, a higher IDWG was present in those who responded with a more extensive release of cardiac markers during hemodialysis.

An overall risk of removing fluid too quickly was previously shown using DOPPS data by Saran et al.[19] The authors showed the outcome for patients with rapid fluid removal to be worse and proposed a limit of fluid removal of less than 10 mL/kg body weight/hour. This would correspond to a $\text{UF-rate}_{\text{adj}}$ of 1.0 IDWG/hour. In the light of our data, we feel that this UF-rate may be still too rapid. ProBNP was significantly more released at higher $\text{UF-rates}_{\text{adj}}$ than 0.6 IDWG/hour and 0.4 IDWG/hour for troponin T. To limit myocardial strain, limitation of IDWG may be considered as well as the length of the hemodialysis session. The $\text{UF-rate}_{\text{adj}}$ is based on the extent and speed of fluid removal and is independent of the time required to meet the Kt/V criteria.

In general, elevated level of proBNP indicates increased myocardial tension,[20] and increase in troponin T indicates myocardial damage.[21–23] The results for the hemodialysis patients of the present study do not rule out an increased cardiac strain but also a myocardial damage induced by too excessive $\text{UF-rate}_{\text{adj}}$. Although no obvious hypotensive episodes were reported by the patients, the data may indicate subclinical alterations, such as hypoperfusion and osmotic changes, appearing during the hemodialysis, especially when the $\text{UF-rate}_{\text{adj}}$ was faster. As expected, the left ventricular ejection fraction correlated inversely with predialytic proBNP. However, the ejection fraction was not related to proBNP-changes at different flowrates in the regression model. In the present study, the blood pump speed was 300 mL/min. Since a higher blood pump speed is associated with an increased extent of microbubbles that derive from the extracorporeal circuit, such bubbles may enter the return line of the patient.[24] A recent autopsy study[25] showed deposits of microbubble containing microemboli in various organs in hemodialysis patients. We cannot rule out that the observed myocardial damage at higher blood pump speed also is caused by microemboli in coronary arteries.

Excess fluid, uremic toxin accumulation and subsequent rapid removal with dialysis are factors that contribute to the high morbidity and mortality of the long interdialytic gap.[14]

An example of the importance of dialysis prescription is the almost doubled life expectancy of Japanese hemodialysis patients compared to those in North America and Europe.[26,27] While the mean dialysis time is shorter (210 min) in the United States of America (USA), European and Japanese patients have similarly long dialysis sessions (≈240 min).[26] Having an almost doubled blood pump speed in North America compared to Japan (400 vs. 200 mL/min) resulted in a similar Kt/V.[26] However, the mean weight of the hemodialysis patients in the USA was 83.7 kg[28] compared to 52.8 kg in Japan.[29] Effective time is prolonged after adjustments for the body fluid compartments (≈60% of the body weight). By calculating the minutes of dialysis of each kg of body weight, the Japanese patients will receive 80% more hemodialysis time/kg body weight. Thus, the time for the uremic toxins and fluid to shift between the compartments will be much longer, allowing a more smooth exchange of solutes between the compartments.[27] The results of slow, prolonged dialyses fit well with a previous study by the Tassin group.[30] Those authors showed superior survival in patients treated with prolonged hemodialysis sessions and a lower blood pump speed of 200 mL/min instead of shorter hemodialysis sessions and higher blood pump speed.[30]

LIMITATIONS

Limitations of the study were that many of the dialysis patients had extensively high proBNP values over 70,000 ng/L at predialysis and after 180 min hemodialysis. This made it impossible to include data of a change of ProBNP during dialysis in these patients. The design of the study did not allow to determine whether the release of cardiac markers was caused by high IDWG per se or the relative speed of volume removal. Based on the results of the present study, we have now initiated a prospective multicenter clinical interventional study. This is to further clarify if a reduced UF-rate$_{adj}$ at a given IDWG prevents the release of cardiac damage markers.

CONCLUSION

Higher UF-rate$_{adj}$ during dialysis showed increased levels of cardiac markers. Data indicate a fluid removal not faster than 0.6 % IDWG/hour could limit such increase. Further studies may confirm if limited fluid intake and a lower UF-rate$_{adj}$ should be recommended to prevent cardiac injury during dialysis.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data may be obtained from a third party and are not publicly available. Permission to access the data used on this study can be obtained following approval from the authors.

ETHICS STATEMENT

The study complies with the Declaration of Helsinki. The research protocol has been approved by the locally appointed ethics committee and informed consent was obtained from subjects. Necessary ethics committee approval was secured for the study reported by the local ethics committee in Umea, Sweden (EPN 05-138M, addition date October 16, 2007; EPN2012-42-31M, March 6, 2012).

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REFERENCES

1. Lamb EJ, Levey AS, Stevens PE. The kidney disease improving global outcomes (KDIGO) guideline update for chronic kidney disease: evolution not revolution. Clin Chem. 2013;59:462–5. https://doi.org/10.1373/clinchem.2012.184259
2. Neovius M, Jacobson SH, Eriksson JK, Elinder CG, Hylander B. Mortality in chronic kidney disease and renal replacement therapy: a population-based cohort study. BMJ Open. 2014;4:e004251. https://doi.org/10.1136/bmjopen-2013-004251
3. Vanholder R, Massy Z, Argiles A, Spasovski G, Verbeke F, Lameire N. Chronic kidney disease as cause of cardiovascular morbidity and mortality. Nephrol Dial Transplant. 2005;20:1048–56. https://doi.org/10.1093/ndt/gfh813
4. Kaur KP, Chaudry MS, Fosbol EL, Ostergaard L, Torp-Pedersen C, Bruun NE. Temporal changes in cardiovascular disease and infections in dialysis across a 22-year period: a nationwide study. BMC Nephrol. 2021;22:340. https://doi.org/10.1186/s12882-021-02537-1
5. Burton JO, Jefferies HJ, Selby NM, McIntyre CW. Hemodialysis-induced cardiac injury: determinants and associated outcomes. Clin J Am Soc Nephrol. 2009;4:914–20. https://doi.org/10.2215/CJN.03900808
6. Burton JO, Jefferies HJ, Selby NM, McIntyre CW. Hemodialysis-induced repetitive myocardial injury results in global and segmental reduction in systolic cardiac function. Clin J Am Soc Nephrol. 2009;4:1925–31. https://doi.org/10.2215/CJN.04470709
7. Madsen LH, Ladefoged S, Corell P, Schou M, Hildebrandt PR, Atar D. N-terminal pro brain natriuretic peptide predicts mortality in patients with end-stage renal disease in hemodialysis. Kidney Int. 2007;71:548–54. https://doi.org/10.1038/sj.ki.5002087
8. Sommerer C, Beimler J, Schwenger V, et al. Cardiac biomarkers and survival in haemodialysis patients. Eur J Clin Investig. 2007;37:350–6. https://doi.org/10.1111/j.1365-2362.2007.01785.x
9. Kawagoe C, Sato Y, Toida T, Nakagawa H, Yamashita Y, Fukuda A, et al. N-terminal-pro-B-type-natriuretic peptide associated with 2-year mortality from both cardiovascular and non-cardiovascular origins in prevalent chronic hemodialysis patients. Ren Fail. 2018;40:127–34. https://doi.org/10.1080/0886022X.2018.1437047
10. Laveborn E, Lindmark K, Skagerlind M, Stegmayr B. NT-proBNP and troponin T levels differ after haemodialysis with a low versus high flux membrane. Int J Artif Organs. 2015;38:69–75. https://doi.org/10.5301/ijao.5000387

11. Goto J, Forsberg U, Jonsson P, Matsuda K, Nilsson B, Nilsson Ekdahl K, et al. Interdialytic weight gain of less than 2.5% seems to limit cardiac damage during hemodialysis. Int J Artif Organs. 2021;44:539–50. https://doi.org/10.1177/0391398820981385
12. Stegmayr BG, Brannstrom M, Bucht S, Dimeny E, Ekspong A, Granroth B, et al. Minimized weight gain between hemodialysis contributes to a reduced risk of death. Int J Artif Organs. 2006;29:675–80.
13. Holmberg B, Stegmayr BG. Cardiovascular conditions in hemodialysis patients may be worsened by extensive interdialytic weight gain. Hemodial Int. 2009;13:27–31. https://doi.org/10.1111/j.1542-4758.2009.00335.x
14. Rhee CM, Kalantar-Zadeh K. Implications of the long interdialytic gap: a problem of excess accumulation vs. excess removal? Kidney Int. 2015;88:442–4. https://doi.org/10.1038/ki.2015.193
15. Zoccali C, Moissl U, Chazot C, et al. Chronic fluid overload and mortality in ESRD. J Am Soc Nephrol. 2017;28:2491–7. https://doi.org/10.1681/ASN.2016121341
16. Wang AY, Lam CW, Yu CM, Wang M, Chan IHS, Zhang Y, et al. N-terminal pro-brain natriuretic peptide: an independent risk predictor of cardiovascular congestion, mortality, and adverse cardiovascular outcomes in chronic peritoneal dialysis patients. J Am Soc Nephrol. 2007;18:321–30. https://doi.org/10.1681/ASN.2005121299
17. Schneditz D, Putz-Bankuti C, Ribitsch W, Schilcher G. Correction of plasma concentrations for effects of hemoconcentration or hemodilution. ASAIO J. 2012;58:160–2. https://doi.org/10.1097/MAT.0b013e318243660f
18. Chazot C, Rozes M, Vo-Van C, Deleaval P, Hurot JM, Lorriaux C, et al. Brain natriuretic peptide is a marker of fluid overload in incident hemodialysis patients. Cardiorenal Med. 2017;7:218–26. https://doi.org/10.1159/000471815
19. Saran R, Bragg-Gresham JL, Levin NW, Twardowski ZJ, Wizemann V, Saito A, et al. Longer treatment time and slower ultrafiltration in hemodialysis: associations with reduced mortality in the DOPPS. Kidney Int. 2006;69:1222–8. https://doi.org/10.1038/sj.ki.5000186
20. Zhao X, Li H, Liu C, Ren Y, Sun C. NT pro-BNP can be used as a risk predictor of clinical atrial fibrillation with or without left atrial enlargement. Clin Cardiol. 2022;45:68–74. https://doi.org/10.1002/clc.23760
21. Alpert JS, Thygesen K, Antman E, Bassand JP. Myocardial infarction redefined—a consensus document of The Joint European Society of Cardiology/American College of Cardiology Committee for the redefinition of myocardial infarction. J Am Coll Cardiol. 2000;36:959–69.
22. Sato Y, Kita T, Takatsu Y, Kimura T. Biochemical markers of myocyte injury in heart failure. Heart. 2004;90:1110–3. https://doi.org/10.1136/hrt.2003.023895
23. Clerico A, Padoan A, Zaninotto M, Passino C, Plebani M. Clinical relevance of biological variation of cardiac troponins. Clin Chem Lab Med. 2021;59:641–52. https://doi.org/10.1515/cclm-2020-1433
24. Stegmayr B. Air contamination during hemodialysis should be minimized. Hemodial Int. 2017;21:168–72. https://doi.org/10.1111/hdi.12474
25. Forsberg U, Jonsson P, Stegmayr B. Microemboli induced by air bubbles may be deposited in organs as a consequence of contamination during medical care. Clin Kidney J. 2023;16:159–66. https://doi.org/10.1093/ckj/sfac217
26. Hecking M, Bieber BA, Ethier J, Kautzky-Willer A, Sunder-Plassmann G, Säemann MD, et al. Sex-specific differences in hemodialysis prevalence and practices and the male-to-female mortality rate: the dialysis outcomes and practice patterns study (DOPPS). PLoS Med. 2014;11:e1001750. https://doi.org/10.1371/journal.pmed.1001750
27. Matsuda K, Fissell R, Ash S, Stegmayr B. Long-term survival for hemodialysis patients differ in Japan versus Europe and the USA. What Might the Reasons Be? Artif Organs. 2018;42:1112–8. https://doi.org/10.1111/aor.13363
28. USRDS. USRDS Annual report, 2022. 2022 Chronic Disease Research Group.
29. Tsuruta Y, Nitta K, Akizawa T, Fukuhara S, Saito A, Karaboyas A, et al. Association between allopurinol and mortality among Japanese hemodialysis patients: results from the DOPPS. Int Urol Nephrol. 2014;46:1833–41. https://doi.org/10.1007/s11255-014-0731-0
30. Charra B, Chazot C, Jean G, Hurot JM, Vanel T, Terrat JC, et al. Long 3 × 8 hr dialysis: the Tassin experience. Nefrologia i Dializoterapia Polska. 2006;10:141–6.

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