Safety evaluation and cardiovascular effect of additional use of spironolactone in hemodialysis patients: a meta-analysis

Objective: To evaluate the safety and cardiovascular effect of low-dose spironolactone administration in end-stage renal failure patients undergoing hemodialysis coupled with conventional treatment.

Methods: We conducted a systematic search for clinical trials on the safety and cardiovascular effect of additional low-dose spironolactone in hemodialysis patients. The search was performed on PubMed, EMBASE, Cochrane Library, and CBM databases. Relevant references (up to February 2016) were retrieved and subsequent results analyzed with a random-effects model or a fixed-effects model.

Results: We identified nine trials with a total sample size of 765 patients. The results did not indicate significant differences regarding safety and serum potassium levels (mean difference [MD]=0.23, \( P=0.09 \)) between the two treatment options. However, patients receiving low-dose spironolactone exhibited improvements in left ventricular mass index (LVMI) (standardized mean difference=–0.58, \( P<0.00001 \)) and left ventricular ejection fraction (LVEF) (MD=–4.91, \( P<0.0001 \)) with an additional decrease in systolic blood pressure (MD=–6.97, \( P<0.0001 \)) and diastolic blood pressure (MD=–4.01, \( P=0.007 \)). Furthermore, the clinical (OR=0.4, \( P=0.0003 \)) or cardiovascular and cerebrovascular-related (OR=0.4, \( P=0.002 \)) mortality was significantly lower among those patients.

Conclusion: These results indicated that additional use of low-dose spironolactone associated with conventional treatment does not have a significant impact on serum potassium levels in hemodialysis patients. What’s more, it might exert a protective effect on the cardiovascular system by optimizing LVMI, improving LVEF, decreasing arterial blood pressure and reducing events-related mortality. Further large sample size studies are needed to support these findings.

Keywords: Spironolactone, hemodialysis, safety, cardiovascular protection, meta-analysis

Introduction

Heart disease is extremely recurrent in dialysis patients and coronary artery disease, hypertension and left ventricular failure account for the majority of cases in this subgroup of patients.\(^1\)–\(^5\) Patients with end-stage renal failure (ESRF) and on hemodialysis often die of heart disease at a much higher rate (20 to 40 times) than the general population.\(^6\)–\(^8\) According to the United States Renal Data System, cardiovascular disease accounts for more than 44% of all mortalities.\(^6\)–\(^8\)

Several studies conducted on ESRD patients indicated a significant increase in aldosterone.\(^3\)–\(^9,\)\(^10\) Aldosterone is thought to play a role in the development of
hypertension, vascular structure alteration, vascular smooth muscle hypertrophy, endothelial dysfunction, renal injury, proteinuria, left ventricular remodeling, collagen synthesis, and myocardial fibrosis. With excess aldosterone, both renal and extrarenal mineralocorticoid receptors are activated further exacerbating the effect of angiotensin II and other products of the renin-angiotensin-alderosterone system (RAAS). Excessive activation of RAAS contributes to the development of cardiac hypertrophy and myocardial fibrosis and leads to complex pathophysiological effects that may result in hypertension, heart failure, and other cardiovascular disorders. 

Currently, the most relevant pharmacological agents that block the RAAS are angiotensin-converting enzyme (ACE) inhibitors and AT1 receptor blockers (ARBs). Aldosterone has been overlooked as a consequential RAAS mediator and a relevant factor in target organ injury in spite of the widespread usage of RAAS blockers. Consequently, mineralocorticoid receptor antagonist (MRA) might have benefits for target organ injury mitigation.

Prior studies on the impact of spironolactone, a potent competitive mineralocorticoid receptor, on patients with heart failure and myocardial infarction without renal insufficiency have shown favorable outcomes. Nevertheless, safety risks still exist due to its effect on sodium and potassium levels. To date, several clinical studies have actively explored the safety and protective effects of spironolactone in dialysis patients. However, significant differences in outcome indicators and limitations such as small sample size or a limited follow-up period can be observed among those studies. Therefore, it is difficult to form a unified conclusion. Subsequently, the current study applied a systematic evaluation approach and meta-analysis methods to evaluate the safety and protective effect of spironolactone in hemodialysis patients aiming to provide clinical evidence for the optimization of patients prognosis.

Methods

Data sources and search strategy

The present meta-analysis was performed according to The Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines. PubMed, EMBASE, Cochrane Library, and CBM databases were searched using the following keywords: Spironolactone, Antisterone, Renal Dialysis, Renal Replacement, End Stage Renal Disease, Renal Insufficiency, and Kidney Failure. No restrictions were imposed on language and date of publication. The final search was run on February 01, 2016. Additional searches were performed based on retrieved articles to identify studies omitted by our primary search strategy.

Study selection

The study selection diagram is shown in Figure 1. All randomized controlled trials (RCTs) and quasi RCTs conducted on a population of adult CKD patients requiring dialysis and with a dialysis period of more than one month were included. Randomized, crossover studies were also considered for inclusion.

Exclusion criteria were as follows: studies with kidney transplant recipients (ESRD), RCTs with different outcomes than the ones of interest, studies lacking a comparable control or placebo, reviews, meeting abstracts, and case-only studies.

Endpoint definition

Endpoints of this study included serum potassium levels (mmol/L), changes in heart structure and function, blood pressure levels, All-cause mortality, cardiovascular and cerebrovascular (CCV) mortalities, Heart failure, Stroke, New or recurrent Acute myocardial infarction (AMI), Aortic dissection and sudden death.

Data extraction and quality assessment

Data from all included studies were extracted by two independent reviewers using a standardized data-extraction protocol. Disagreements were resolved by consensus. Data extracted from the study included: 1. study characteristics (title, first author name, year of publication, design, and duration); 2. participant characteristics (age, sex, the presence of other chronic diseases (hypertension, cardiac insufficiency, diabetes), the frequency of dialysis treatment, type of medication); 3. the nature of treatment and intervention (MRA type, dose, frequency, and follow-up duration); 4. the outcome (serum/plasma potassium levels, changes in heart structure and function, blood pressure, All-cause mortality, Cardiovascular mortality). The quality of each RCT was evaluated using the Cochrane risk of bias instrument which primarily assesses the randomization and allocation concealment, the blinding process of individuals involved in the trial, the completeness of follow-up, and the outcome. Each study outcomes were classified as low risk of bias, unclear, or high risk of bias. The quality assessments of the two none-randomized
studies were performed using The Newcastle-Ottawa Scale with few modifications to match the needs of this meta-analysis. This scoring system uses the following aspects of study design to assess quality: patient selection, comparability of study groups, and assessment of outcome. High-quality studies were defined as studies that have achieved five or more stars on the modified Newcastle-Ottawa Scale.

Data synthesis and statistical analysis

The statistical analysis was conducted on the Cochrane Review Manager (RevMan version 5.3). Continuous outcomes were analyzed using mean differences (MDs), standardized mean differences (SMDs) and dichotomous outcomes were analyzed using pooled odds ratio (OR) to combine different tests and measurement scales within each domain. Overall effect estimates were calculated for all analyses using inverse variance weighted fixed-effects analysis with 95% confidence intervals (CIs). Standard deviations (SDs) were calculated using the following formula: $SD = \sqrt{SD_{pretreatment}^2 + SD_{post-treatment}^2 - 2R \times SD_{pretreatment} \times SD_{post-treatment}}$, assuming a correlation coefficient of $R=0.5$.

Heterogeneity among studies was identified using a standard $\chi^2$ test and a $P$-value (two-sided) based on the Cochran Q statistic. $I^2$ index, as the percentage of variation across studies, was used to assess heterogeneity with an $I^2$ value of 25%, 50% or 75% representing low, moderate, or high heterogeneity, respectively. The fixed effect model was used for analysis in cases where the heterogeneity analysis indicated an $I^2<25%$. The source of heterogeneity and the stability of the results were further evaluated for an $I^2$ value of $25% \leq I^2 < 50%$. The random effect model was used for analysis when

Figure 1 Selection process of studies included in the meta-analysis.
I^2 ≥ 50%. Subgroup analysis or sensitivity analysis methods further explored the sources of heterogeneity and explained possible causes. We planned to construct a funnel plot to evaluate the risk of publication bias provided that the number of included studies was sizeable (more than ten).

Results
Study selection and characteristics
Of the 605 studies identified by our primary search, 19 articles were retrieved after initial assessment for detailed evaluation. Nine of those met the inclusion criteria and were incorporated in the final analysis (Figures 1 and 2). Tables 1 and 2 summarize the characteristics of those studies. In summary, seven randomized controlled trials and two non-randomized controlled trials with a sample size of 765 patients and an average follow-up period of 2 weeks to 3 years were included in this meta-analysis. The risk of bias among included trials was generally low. Two studies\textsuperscript{38,39} scored 5 or more stars on the modified Newcastle-Ottawa Scale.

More detailed informations on the number of studies involved and sample sizes for each outcome are as follows: serum potassium levels, 7 studies (spironolactone, 200 patients; control, 202 patients);\textsuperscript{38–43} LVMI, 4 studies (spironolactone, 138 patients; control, 137 patients);\textsuperscript{39,40,43,44} LVEF, 4 studies (spironolactone, 138 patients; control, 137 patients);\textsuperscript{39,40,43,44} BP, 5 studies (spironolactone, 101 patients; control, 105 patients);\textsuperscript{39,42,44–46} All-cause mortality, 3 studies (spironolactone, 285 patients; control, 293 patients);\textsuperscript{40,41,43} CCV events, 2 studies (spironolactone, 277 patients; control, 285 patients).\textsuperscript{40,41}

Serum potassium levels
Substantial heterogeneity in serum potassium levels was observed among studies with a significant effect seen in the spironolactone group (MD=0.23, 95%CI [–0.03, 0.49], \(P=0.09\)) (Figure 3). We carefully checked the extracted data, reviewed the characteristics of included studies, and concluded that heterogeneity might be partly due to two studies: Taheri 2009\textsuperscript{43} and Lin 2016.\textsuperscript{42} Therefore, we conducted a fixed-effect subgroup analysis by removing those two studies.\textsuperscript{42,43} As demonstrated in Figure 4, no significant treatment effect was observed in the spironolactone group (MD=0, 95%CI [–0.18, 0.18], \(P=0.98\)).

LVMI
Compared with control, the addition of spironolactone significantly decreased the LVMI (SMD=–0.58, 95%CI [–0.82, –0.334], \(P<0.00001\)) (Figure 5).

LVEF
As indicated by the results, additional spironolactone treatment elevated the LVEF significantly (MD=4.91, 95%CI [2.58, 7.24], \(P<0.00001\)). No significant heterogeneity was observed (Figure 6).

Blood pressure
The results indicated that additional spironolactone significantly decreased the systolic blood pressure (MD=–6.97, 95%CI [–10.56, –3.37], \(P=0.0001\)) (Figure 7) and diastolic blood pressure (MD=–4.01, 95%CI [–6.90, –1.12], \(P=0.007\)) of the treatment group (Figure 11). Secondary analysis of the data using a random effects model showed a downward trend in SBP in the spironolactone group (MD=–5.34, 95%CI [–11.36, 0.68], \(P=0.08\)) (Figure 8).
The subgroup analysis indicated that the SBP of the spironolactone group was considerably lowered in Subgroup1 [MD= –10.51, 95%CI (–15.04, –5.97), P<0.00001](Figure 9); meanwhile, there was no significant treatment effect in the subgroup 2 [MD= –1.00, 95%CI (–6.89, 4.89), P=0.74] (Figure 10).

All-cause mortality
Treatment with spironolactone was associated with a significant reduction in all-cause mortality [OR=0.4, 95%CI (0.24, 0.66), P=0.0003] (Figure 12).

CCV mortality
The spironolactone group showed a significant reduction in CCV mortality [OR=0.4, 95%CI (0.22, 0.72), P=0.002] (Figure 13).

Discussion
Our analysis included a total of 765 patients in nine studies, with seven being randomized controlled trials and two non-randomized controlled trials. The results indicated that additional use of low-dose spironolactone associated with conventional treatment does not significantly increase serum potassium levels in hemodialysis patients. Conversely, it might exert a protective effect on their cardiovascular system by optimizing LVMI and improving LVEF.

Mineralocorticoid receptors are present in major organs such as the brain, heart, blood vessels and kidneys, and interestingly, there is evidence suggesting the production of aldosterone within their tissues. Therefore, the activation of local mineralocorticoid receptors by aldosterone has a significant effect on the cardiovascular system. The existence of “aldosterone escape phenomenon” has been clarified with the widespread usage of ACEI/ARB in clinical settings. Several studies have confirmed that the addition of MRA coupled with conventional treatments (including ACEI/ARB drugs) can significantly improve the long-term survival rate of patients with heart failure and myocardial infarction.

### Table 1 Characteristics of 9 clinical trials included in the meta-analysis

| Study , year | Study design | Spironolactone usage | Hemodialysis frequency | Follow time | Cardiac function III-IV | Oliguria, no urine | Outcome |
|-------------|--------------|----------------------|------------------------|-------------|-------------------------|-------------------|---------|
| Feniman , 2015 | Random, placebo control, double blind | 12.5 mg daily (2 weeks) then 25 mg daily | Triweekly 2 weeks | 6 months | None | 0% | Serum potassium levels, LVMI, LVEF, BP |
| Gross, 2005 | Random, placebo control, cross | 50 mg semiweekly | Triweekly 2 years | None | 0% | Spironolacton 68% control 64% |
| Lin, 2016 | Random, placebo control, double blind | 25 mg daily | Triweekly | None | None | None |
| Matsumoto, 2016 | Random, control | 25 mg daily | Triweekly 3 years | None | None | None |
| Ni, 2014 | Random, placebo control, double blind | 25 mg daily | Triweekly 12 weeks | None | 100% |
| Sandan, 2003 | Non-random, unblind | 12.5 mg triweekly (2 weeks) then 25 mg triweekly | Triweekly 4 weeks | 0% | Spironolacton 86% control 0% |
| Taheri, 2009 | Random, placebo control, double blind | 25 mg triweekly | Triweekly 6 months | 100% | None | Serum potassium levels, LVMI, LVEF |
| Vukusich, 2010 | Random, placebo control | 50 mg triweekly | Triweekly 2 years | None | None | BP, CIMT |
| Liang, 2011 | Non-random, unblind | 25 mg triweekly | Triweekly 3 months | 100% | None | Serum potassium levels, LVMI, LVEF, BP |

**Abbreviations:** CCV, cardiovascular and cerebrovascular; LVMI, left ventricular mass index; LVEF, left ventricular ejection fraction.
| Study, year | Test group | Control group | Test group | Control group | Test group | Control group | Test group | Control group | Test group | Control group | Test group | Control group |
|------------|------------|---------------|------------|---------------|------------|---------------|------------|---------------|------------|---------------|------------|---------------|
| Feniman-De-Stefano, 2015 | 8 | 10 | 52 | 56 | 50 | 56 | 70.3 | 68.9 | NR | NR | 50 | 56 |
| Gross, 2005 | 8 | 8 | 53 | 53 | 37.5 | 37.5 | NR | NR | 37.5 | 37.5 | 37.5 | 37.5 |
| Lin, 2016 | 125 | 128 | 70.3 | 70.6 | 58.4 | 62.5 | 61.78 | 62.29 | 4.8 | 4.7 | 20.8 | 20.7 |
| Matsumoto, 2014 | 157 | 152 | 67.4 | 67.7 | 72 | 59.2 | NR | NR | 12.7 | 4.6 | 31.8 | 30.9 |
| Ni, 2014 | 40 | 36 | 55.7 | 54.9 | 60 | 58.3 | NR | NR | 5 | 5 | 15 | 19.4 |
| Sandan, 2003 | 14 | 21 | 54 | 59 | NR | NR | NR | NR | 14.3 | 23.8 | 57.1 | 52.4 |
| Taheri, 2009 | 8 | 8 | 59.5 | 56.8 | 62.5 | 75 | 31.25 | 33.75 | 75 | 100 | 62.5 | 62.5 |
| Vukusich, 2010 | 30 | 23 | 60.1 | 55.6 | 66.7 | 61 | 61.9 | 62.5 | 60 | 56.5 | 0 | 0 |
| Liang, 2011 | 22 | 22 | 60 | 59.8 | 72.7 | 68.2 | 30.49 | 28.66 | NR | NR | 27.3 | 31.8 |

**Abbreviations:** LVEF, left ventricular ejection fraction.

**Table 2** Characteristics of patients from 9 clinical trials included in the meta-analysis
However, fluctuations in blood potassium levels and hyperkalemia are likely to occur in patients with renal insufficiency.\(^4\) Another study showed that the blood potassium balance relied primarily on regular dialysis and timely adjustment of dialysate ion concentration in the ESRD hemodialysis population.\(^5\)

In earlier studies,\(^3,8,39,43,45,46\) the administration of spironolactone was timely adjusted, and it was usually administered after hemodialysis to avoid a short-term increase in blood potassium due to oral spironolactone. However, recent studies\(^40\)–\(^42,44\) on regular hemodialysis patients with a daily dosage of 25 mg of spironolactone did not indicate a significant increase in mean potassium levels after a follow-up period of 3 months to 2 years. These findings are consistent with the results of the RALES study\(^29\) suggesting that daily usage of 25 mg of spironolactone is safe in this subgroup.

A previous meta-analysis with 28 eligible studies\(^49\) found that the use of MRA is associated with a higher risk of hyperkalemia. Meanwhile, another study\(^51\) indicated that a higher potassium intake might significantly increase the risk of death in long-term HD patients. Therefore, education on risks related to potassium intake is crucial for hemodialysis patients especially those taking spironolactone.

The estimated prevalence of hypertension in patients with chronic kidney disease but not undergoing dialysis is 70%. Of these, 75% are treated with antihypertensive medications with only 36% achieving a blood pressure

---

**Figure 3** Forest plot for changes of serum potassium level.

**Figure 4** Forest plot for changes of serum potassium level after sensitivity analysis.
Several studies noted that the administration of spironolactone utilizes a non-diuretic mechanism to decrease pre-dialysis systolic blood pressure in oligo-anuric hemodialysis patients. Increased common carotid artery intima-media thickness (CCA-IMT) has been associated with an increase in myocardial infarction and stroke risks. Interestingly, fifty milligrams of spironolactone thrice weekly has been shown to significantly reduce the progression of CIMT in HD patients. Here, we indicate that blocking MR has a direct effect on vascular remodeling independent of BP.

The Hammer trial is a prospective, randomized, placebo-controlled, double-blind, parallel group, and a multicentered study investigating the effect of spironolactone (50 mg daily) on maintenance hemodialysis patients. The endpoints included changes in LV geometry and function, office and 24-h ambulatory blood pressure, cardiac arrhythmias, vascular function parameters, and measurements of heart failure and quality of life. MiREnDa will provide highly relevant insights into the cardiac and vascular effects as well as the safety of spironolactone in dialysis patients.

The present meta-analysis has several limitations. Firstly, the small sample size and a limited number of clinical trials might make our results susceptible to bias. The second limitation is the lack of long-term studies.

Figure 5 Forest plot for LVMI.
Abbreviation: LVMI, left ventricular mass index.

Figure 6 Forest plot for LVEF.
Abbreviation: LVEF, left ventricular ejection fraction.
For example, only 5 included studies were long-term studies (>6 months), among which, three concluded that spironolactone provided a long-term beneficial effect. Thirdly, the dosage of spironolactone varied between studies making the establishment of a maximum safe dose much harder. Fourthly, even
though some studies have reported changes in blood pressure before and after follow-up, blood pressure was not considered as a primary outcome. Therefore, there may be differences in the control of external factors affecting blood pressure in each group, which in turn might impact the final result. In summary, meta-analysis conclusions still need to be demonstrated by additional high-quality, large-sampled clinical studies.
Conclusion
This study indicated that the additional use of low-dose spironolactone exerts a protective effect on the cardiovascular system of hemodialysis patients by optimizing LVEF, improving arterial blood pressure and reducing clinical or CCV-related mortality. Additionally, its usage did not significantly increase serum potassium levels in those patients.

Disclosure
The authors report no conflicts of interest in this work.

References
1. Hussain S, Dreyfus DE, Marcus RJ, et al. Is spironolactone safe for dialysis patients? Nephrol Dial Transplant. 2003;18(11):2364–2368. doi:10.1093/ndt/gfg413
2. Ritz E, Dikow R, Adamzcak M, et al. Congestive heart failure due to systolic dysfunction: the Cinderella of cardiovascular management in dialysis patients[C]/Seminars in dialysis. Blackwell Sci Inc. 2002;15(3):135–140.
3. Ritz E, Dikow R, Adamzcak M, et al. Congestive heart failure due to systolic dysfunction: the Cinderella of cardiovascular management in dialysis patients[C]/Seminars in dialysis. Malden, US: Blackwell Sci Inc. 2002;15(3):135–140.
4. Szczek LA, Reddan DN, Owen WF Jr, et al. Differential survival after coronary revascularization procedures among patients with renal insufficiency. Kidney Int. 2001;60(1):292–299. doi:10.1046/j.1523-1755.2001.00799.x
5. Herzog CA, Ma JZ, Collins AJ. Comparative survival of dialysis patients in the United States after coronary angioplasty, coronary artery stenting, and coronary artery bypass surgery and impact of diabetes. Circulation. 2002;106(17):2207–2211.
6. Herzog CA, Ma JZ, Collins AJ. Poor long-term survival after acute myocardial infarction among patients on long-term dialysis. N Engl J Med. 1998;339(12):799–805. doi:10.1056/NEJM199809193391203.
7. Silberberg JS, Barre PE, Prichard SS, Sniderman AD. Impact of left ventricular hypertrophy on survival in end-stage renal disease. Kidney Int. 1989;36(2):286–290.
8. Collins AJ, Li S, Ma JZ, Herzog C. Cardiovascular disease in end-stage renal disease patients. Am J Kidney Dis. 2001;38(4):S26–S29. doi:10.1053/ajkd.2001.27392
9. Sato A, Funder JW, Saruta T. Involvement of aldosterone in left ventricular hypertrophy of patients with end-stage renal failure treated with hemodialysis. Am J Hypertens. 1999;12(9):867–873.
10. Clark BA, Shannon C, Brown RS, Gervino EV. Extrarenal potassium homeostasis with maximal exercise in end-stage renal disease. J Am Soc Nephrol. 1996;7(8):1223–1227.
11. Struthers AD. Aldosterone escape during angiotensin-converting enzyme inhibitor therapy in chronic heart failure. J Card Fail. 1996;2(1):47–54.
12. Naruse M, Tanabe A, Sato A, et al. Aldosterone breakthrough during angiotensin II receptor antagonist therapy in stroke-prone spontaneously hypertensive rats. Hypertension. 2002;40(1):28–33.
13. Bader M. Role of the local renin-angiotensin system in cardiac damage: a minireview focussing on transgenic animal models. J Mol Cell Cardiol. 2002;34(11):1455–1462.
14. Struthers AD, MacDonald TM. Review of aldosterone-and angiotensin II-induced target organ damage and prevention. Cardiovasc Res. 2004;61(4):663–670. doi:10.1016/j.cardiores.2003.11.037
15. MacFadyen RJ, Barr CS, Struthers AD. Aldosterone blockade reduces vascular collagen turnover, improves heart rate variability and reduces early morning rise in heart rate in heart failure patients. Cardiovasc Res. 1997;35(1):30–34.
16. Duprez DA, De Buyzere ML, Rietzschel ER, et al. Inverse relationship between aldosterone and large artery compliance in chronically treated heart failure patients. Eur Heart J. 1998;19(9):1371–1376.
17. Rocha R, Chander PN, Khanna K, Zuckerman A, Stier CT. Mineralocorticoid blockade reduces vascular injury in stroke-prone hypertensive rats. Hypertension. 1998;31(1):451–458.
18. Kannel WB. Fifty years of Framingham study contributions to understanding hypertension. J Hum Hypertens. 2000;14(2):83. doi:10.1038/sj.jhh.1000949
19. Ferrario CM, Flack JM. Pathologic consequences of increased angiotensin II activity. Cardiovasc Drugs Ther. 1996;10(5):511–518.
20. MacKenzie SM, Clark CJ, Fraser R, et al. Expression of 11beta-hydroxylase and aldosterone synthase genes in the rat brain. J Mol Endocrinol. 2000;24(3):321–328.
21. Bonvalet JP, Alfaidy N, Farman N, Lombès M. Aldosterone: intracellular and extracellular roles in experimental and human diseases. Curr Hypertens Rep. 2002;4(10):777–780. doi:10.1007/s11906-010-0036-2.
22. Kornel L. Colocalization of 11beta-hydroxysteroid dehydrogenase and mineralocorticoid receptors in cultured vascular smooth muscle cells. J Mol Endocrinol. 1996;16(suppl_N):97–104.
23. Coirini H, Mari A, De Nicola AF, et al. Further studies of brain aldosterone binding sites employing new mineralocorticoid and glucocorticoid receptor markers in vitro. Brain Res. 1985;361(1–2):212–216.
24. Klag MJ, Whelton PK, Randall BL, et al. Blood pressure and end-stage renal disease in men. N Engl J Med. 1996;334(1):13–18. doi:10.1056/NEJM199601103410103
25. Mizuno Y, Yoshimura M, Yasue H, et al. Aldosterone production is activated in failing ventricle in humans. Circulation. 2001;103(1):72–77.
26. Hatakeyama H, Miyamori I, Fujita T, et al. Vascular aldosterone. Biosynthesis and a link to angiotensin II-induced hypertrophy of vascular smooth muscle cells. J Biochem Physiol. 1994;269(39):24316–24320.

Figure 13 Forest plot for mortality caused by CCV events.
Abbreviation: CCV, cardiovascular and cerebrovascular.
Spironolactone reduces after acute myocardial infarction. Circulation. 2003;107(20):2559–2565. doi:10.1161/01.CIR.0000068340.96506.0F

Dong Q, Liu K-S, Liu H-B, et al. Effect of spironolactone on left ventricular remodeling in patients with acute myocardial infarction. Chin J Cardiol. 2005;33(4):315–319.

Libreri A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. PLoS Med. 2009;6(7):e100097. doi:10.1371/journal.pmed.100097

Libreri A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. PLoS Med. 2009;6(7):e100097. doi:10.1371/journal.pmed.1000100

Taggart DP, DAncio R, Altman DG. Effect of arterial revascularisation on survival: a systematic review of studies comparing bilateral and single internal mammary arteries. Lancet. 2001;358:870–875. doi:10.1016/S0140-6736(01)06069-X

Athanasio T, Al-Ruzzeh S, Kumar P, et al. Off-pump myocardial revascularization is associated with less incidence of stroke in elderly patients. Ann Thorac Surg. 2004;77:745–753. doi:10.1016/S0003-4975(03)01431-0

Higgins J, Thompson S, Deeks J, Altman D. Statistical heterogeneity in systematic reviews of clinical trials: a critical appraisal of guidelines and practice. J Health Serv Res Policy. 2002;7(1):51–61. doi:10.1258/1355819021927674

Hase M, Babazono T, Ujihara N, Uchigata Y. Comparison of spironolactone and trichlormethiazide as add-on therapy to renin-angiotensin blockade for reduction of albuminuria in diabetic patients. J Diabetes Investig. 2013;4(3):316–319. doi:10.1111/jdi.12029

Saudan P, Mach F, Perneger T, et al. Safety of low-dose spironolactone administration in chronic hemodialysis patients. Nephrol Dial Transplant. 2003;18(11):2359–2363. doi:10.1093/ndt/gfg388

Liang Y. The effects of spironolactone on LVEF and LVM in hemodialysis patients with end stage renal disease. Chin J Clinicians (Electronic Edition). 2011;18:5271–5275.

Lin CT, Zhang Q, Zhang HF, et al. Long-term effects of low-dose spironolactone on chronic dialysis patients: a randomized placebo-controlled study. J Clin Hypertens. 2015.

Matsumoto Y, Mori Y, Kageyama S, et al. Spironolactone reduces cardiovascular and cerebrovascular morbidity and mortality in hemodialysis patients. J Am Coll Cardiol. 2014;63(6):528–536. doi:10.1016/j.jacc.2013.09.056

Ni X, Zhang J, Zhang P, et al. Effects of spironolactone on dialysis patients with refractory hypertension: a randomized controlled study. J Clin Hypertens. 2014;16(9):658–663. doi:10.1111/jch.12374

Taheri S, Mortazavi M, Shahidi S, et al. Spironolactone in chronic hemodialysis patients improves cardiac function. N Engl J Med. 2009;20(3):392.

Feniman-De-Stefano GMM, Zanati-Basan SG, De Stefano LM, et al. Spironolactone is secure and reduces left ventricular hypertrophy in hemodialysis patients. Ther Adv Cardiovasc Dis. 2015;9(4):158–167. doi:10.1177/1753947715591448

Gross E, Rothstein M, Dombek S, Juknis HI. Effect of spironolactone on blood pressure and the renin-angiotensin-aldosterone system in oligo-anuric hemodialysis patients. Am J Kidney Dis. 2005;46(1):94–101.

Vukusich A, Kunstmann S, Varela C, et al. A randomized, double-blind, placebo-controlled trial of spironolactone on carotid intima-media thickness in nondiabetic hemodialysis patients. Clin J Am Soc Nephrol. 2010;5(8):1380–1387. doi:10.2215/CJN.09421209

Pitt B, Remme W, Zannad F, et al. Eplerenone, a selective aldosterone blocker, in patients with left ventricular dysfunction after myocardial infarction. N Engl J Med. 2003;348(14):1309–1321. doi:10.1056/NEJMoa030207

Modena MG, Aveta P, Menozzi A, Rossi R. Aldosterone inhibition limits collagen synthesis and progressive left ventricular enlargement after anterior myocardial infarction. Am Heart J. 2001;141(1):41–46. doi:10.1067/mhj.2001.111258

Ng KP, Arnold J, Sharif A, et al. Cardiovascular actions of mineralocorticoid receptor antagonists in patients with chronic kidney disease: a systematic review and meta-analysis of randomized trials. J Renin Angiotensin Aldosterone Syst. 2015;1470320315575849.

Choi HY, Ha SK. Potassium balances in maintenance hemodialysis. Electrolyte Blood Press. 2013;11(1):9–16. doi:10.5049/EBP.2013.11.1.9

Noori N, Kalantar-Zadeh K, Kovesdy CP, et al. Dietary potassium intake and mortality in long-term hemodialysis patients. Am J Kidney Dis. 2010;56(2):338–347. doi:10.1053/j.ajkd.2010.03.022

Agarwal R, Nissenson AR, Batte D, et al. Prevalence, treatment, and control of hypertension in chronic hemodialysis patients in the United States. Am J Med. 2003;115(4):291–297.

Lorenz MW, Markus HS, Bots ML, Rosvall M, Sitzer M. Prediction of clinical cardiovascular events with carotid intima-media thickness: a systematic review and meta-analysis. Circulation. 2007;115(4):459–467. doi:10.1161/CIRCULATIONAHA.106.628875

O’Leary DH, Polak JF, Kronmal RA, et al. Carotid-artery intima and media thickness as a risk factor for myocardial infarction and stroke in older adults. N Engl J Med. 1999;340(1):14–22. doi:10.1056/NEJM199901073400103

Tsivgoulis G, Vemmos K, Papamichael C, et al. Common carotid artery intima-media thickness and the risk of stroke recurrence. Stroke. 2006;37(7):1913–1916. doi:10.1161/01.STR.0000226399.13528.0a

Hammer F, Krane V, Stork S, et al. Rationale and design of the mineralocorticoid receptor antagonists in end-stage renal disease study (MiREnDa). Nephrol Dial Transplant. 2014;29(2):400–405. doi:10.1093/ndt/gft409
