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Hypertension and Dialysis: A Comprehensive Systematic Review, Meta-Analysis, and Meta-Regression on Cardiovascular and Mortality Outcomes

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Abstract

Background: Hypertension is a major health condition that must be addressed in dialysis patients due to its influence on morbidity and mortality. This study aims to analyse and synthesise current research to systematically examine the impact of dialysis on patient outcomes and to investigate the role of different dialysis modalities. **Methods:** This systematic review and meta-analysis included 50 papers that explored the relationship between hypertension and dialysis outcomes, covering both randomised controlled trials and observational studies. A comprehensive search of PubMed, Embase, Scopus, and the Cochrane Library identified articles on blood pressure(BP) management, cardiovascular morbidity (CVM), and all-cause mortality in adult dialysis patients. A random effects model was employed to calculate pooled effect estimates, and meta-regression analysis was conducted to assess the influence of dialysis modality, duration, and comorbid conditions. **Results:** The meta- analysis demonstrated that poorly controlled hypertension (systolic BP> 140 mmHg) was associated with an increased risk of CVM (OR = 2. 45, 95% CI: 1. 90- 3. 16, $p < 0. 001$) and all- cause mortality (HR = 1. 78, 95% CI: 1. 50- 2. 13, $p < 0. 001$). No significant differences in hypertension-related outcomes were observed between haemodialysis (HD) and peritoneal dialysis (PD) according to meta-regression. A longer duration of dialysis (> 5 years) was linked to a higher risk of adverse outcomes ($p = 0.03$ for cardiovascular morbidity and $p = 0.01$ for mortality). Diabetes and obesity did not significantly influence the relationship between hypertension and patient outcomes. **Conclusion:** Hypertension remains a significant modifiable risk factor in dialysis patients, with poorly managed BP leading to adverse cardiovascular and mortality outcomes. The findings highlight the importance of early and intensive blood pressure management, regardless of the dialysis mode or co-morbidities. To improve long-term prognosis in this high-risk population, clinicians should focus on personalised treatment strategies, with an emphasis on consistent blood pressure control. Future research should aim to clarify blood pressure targets and explore targeted therapies for different patient population groups.

Keywords: Hypertension, Blood pressure management, Meta-Analysis, Mortality, Morbidity, Clinical Outcome

Introduction:

The occurrence of high blood pressure among patients on dialysis is growing day by day, and it has become a critical concern now. It is very much accompanied by notable morbidity and mortality in this population because it worsens 'cardiovascular disease' (CVD), the principal origin of death in dialysis patients. Studies showed that the majority of the patients on maintenance dialysis are hypertensive, and the management of Blood Pressure (BP) maintenance is challenging due to factors like fluid overload, the haemodynamic shifts during dialysis sessions and the altered pharmacokinetics of antihypertensive medications in the context of renal failure (1). The current research highlights the importance of the need for comprehensive BP management strategies in this high-risk population (2).

Three major factors complicating hypertension in chronic dialysis patients are improper sodium balance due to kidney dysfunction and poor diet, inconsistent fluid regulation, and the unfavourable activation of the Renin-Angiotensin-Aldosterone System (RAAS)(3). Fluid balance by Dialysis is one of the modifiable factors in BP control among chronic dialysis patients, and thus, it highlights the importance of optimum ultrafiltration among the patients. The optimum ultrafiltration in HD sessions can avoid complications, especially related to BP management during the treatment (4). It is clear that the management of this problem certainly emphasises the need for a well-designed BP management strategy incorporated with an optimum fluid balance integrated with lifestyle modification, Pharmacogenomic therapy and an individualised care plan.

There are unfavourable dialysis outcomes which affect BP management among HD patients as per the various studies, and are mainly cardiovascular abnormalities like left ventricular hypertrophy(LVH) and increased hospitalisation (5). Inadequate management of Hypertension is the most notable reason for LVH and can make the patient's life worsen by leading to the inability of the heart to pump, irregular heart rate and pulse rate and sometimes cardiac arrest and death (6).Hypertension significantly impacts the quality of life in chronic dialysis patients, and the optimum BP level to be maintained remains controversial. Some of the research says that the importance of efficient BP management may help to reduce morbidity and mortality. However, some researchers argue that intense BP control can lead to dangerously low BP during HD sessions, causing ischemia in different organs (7). There are challenges in interpreting the results of research based on BP among HD patients; some of them are variations in study designs, patient populations and BP measurement techniques. The challenge in interpreting the findings is emphasising the importance of a meta-analytic methodology to synthesise currently available data.

This article aims for a thorough analysis of the effect of hypertension outcomes on the dialysis population, focused on BP management, cardiovascular morbidity and overall health and longevity of the patients. This analysis explores the relationship between BP management and patient outcomes, important factors related to BP management and evidence-based suggestions which can be helpful for personalised treatment plans. Other than that, a meta-regression approach was done, analysing the variables; mode of

dialysis, duration of dialysis treatment in years and the presence of one or more additional diseases /conditions on the result of interest.
Overall, this review aims to provide a complete summary of hypertension, especially its management and the effect of factors, to guide clinical practice and notify future researchers in this regard.

Materials and Methods

Study Design

The available literature on hypertension and its management among chronic HD patients, using the 'PRISMA' guidelines, was reviewed (8). This article investigates the effect of renal dialysis outcomes on patients. This meta-regression approach was employed not only to explore the influence of dialysis modality but also to consider the impact of comorbidity conditions on these outcomes.

Data Bases and ChaseStratagem

From multiple 'electronic databases' like 'PubMed, Embase, Scopus, and the Cochrane Library', this literature research was a strategy to identify relevant studies published from 2010 to September 2024. Studied topics related to ''hypertension'', ''Dialysis'', ''HD'', ''BP'', ''cardiovascular outcomes'', and ''mortality'', with relevant are published on Medical Subject Headings (MeSH) with free-text terms with a limited and the research conducted and published in English. The complete search strategy is provided in the supplementary material.
In addition to database searches, manual searches were performed on articles with relevant and reference review articles to identify any additional studies. Grey literature, including conference abstracts and unpublished data, was not considered due to concerns about the robustness of such sources.

Eligibility Criteria

Studies on hypertension in dialysis patients addressing eligibility for Inclusion met the following criteria:

- It includes adult population patients (≥18 years) undergoing either HD or peritoneal dialysis (PD).
- Reported outcomes include BP control, 'stroke' and 'myocardial infarction' and 'all-cause mortality'.
- Provided sufficient data to allow the calculation of statistical measures, including 'Odds ratio' (OR), 'risk ratio' (RR), and 'Hazard ratio (HR), with corresponding 95% confidence interval (CI).
- The study design includes 'Randomised controlled trials (RCTs), cohort studies, and case-control'.

Whereas studies for Exclusion criteria include the paediatric population, addressing any blood pressure control without a report, cardiovascular morbidity-related outcomes, and review articles, editorials, or commentaries without original data.

Study Selection

Articles with full-text potential study were retrieved with three independent reviewers (Second, Third, and Fourth authors) who screened titles and abstracts for eligibility and were reviewed by the primary author. Disagreements were resolved by consensus or by the corresponding author if necessary. The selection process was managed using End Note reference management software to ensure proper tracking of records.

Data Extraction

Extraction of data was carried out independently by reviewers with some previously framed retrieval form resulting in the following variables like study characteristics; year of publication, study design and sample size, patient demographic checkup; HD and peritoneal dialysis, hypertension-related parameters; baseline BP, target BP, anti-hypertensive medication, controlled and uncontrolled degree of hypertension, cardiovascular outcomes; LVH, Heart failure, myocardial infarction, all-cause mortality and duration of follow-up. Significant observations were made, and missing data and interpretations were resolved through proper channels.

Risk of Bias Assessment

Qualitative study of the Cochrane Risk of Bias (RoB) tools used for 'Randomised Controlled Trials' (RCTs) and 'Newcastle-Ottawa Scale' (NOS) to collect information about the features and case-control studies (9). For RCT, the area of interest collected includes sequence generation with descriptive randomisation, concealment of allocation from both the participants and researchers, blinding of the personnel with outcome assessors, incomplete missing data outcomes, selective reporting, etc. The final observational study is based on selection, comparability and with follow-up outcomes scoring ≥7 on the Nos with high-quality.

Statistical Analysis

An estimated effect size was obtained and calculated by combining three random-effects models, Odds ratios and Hazard ratios with 95% CI (Confidence Interval) to account for heterogeneity with I^2 statistic, which indicated>50% substantial heterogeneity (10) among studies, were computed to get dichotomous outcomes. To get a particular resource of heterogeneity, meta-regression analysis was performed with HD modality vs. Peritoneal dialysis modality, study follow-up duration, and comorbid conditions as covariates. Using Funnel plots and Egger's test, the publication bias was assessed with a p-value < 0.05, indicating a significant bias (11). Weighted mean differences (WMD) were calculated for continuous outcomes.

Software

All statistical analyses were executed using 'Review Manager (RevMan) version 5.4 (Cochrane Collaboration) and Stata version 16 (StataCorp)'. A 'p-value' < 0.05 was considered statistically significant.

Results:

Study selection

The initial search produced 1,200 documents of records from database searches and another 30 records from Manual searches. Following the removal of 180 duplicates, 1,050 entries were evaluated based on the titles and abstracts. Out of these, 800 were excluded because they did not match the Qualifying Requirements. Full-text reviews were undertaken for 250 papers, with 180 being removed due to irrelevant outcomes(n=100), research on pediatric populations (n=50), and inadequate data for meta-analysis (n=30). Finally, noted that 70 Papers were included in the qualitative synthesis, with 50 included in the quantitative synthesis (meta-analysis) (Figure 1)

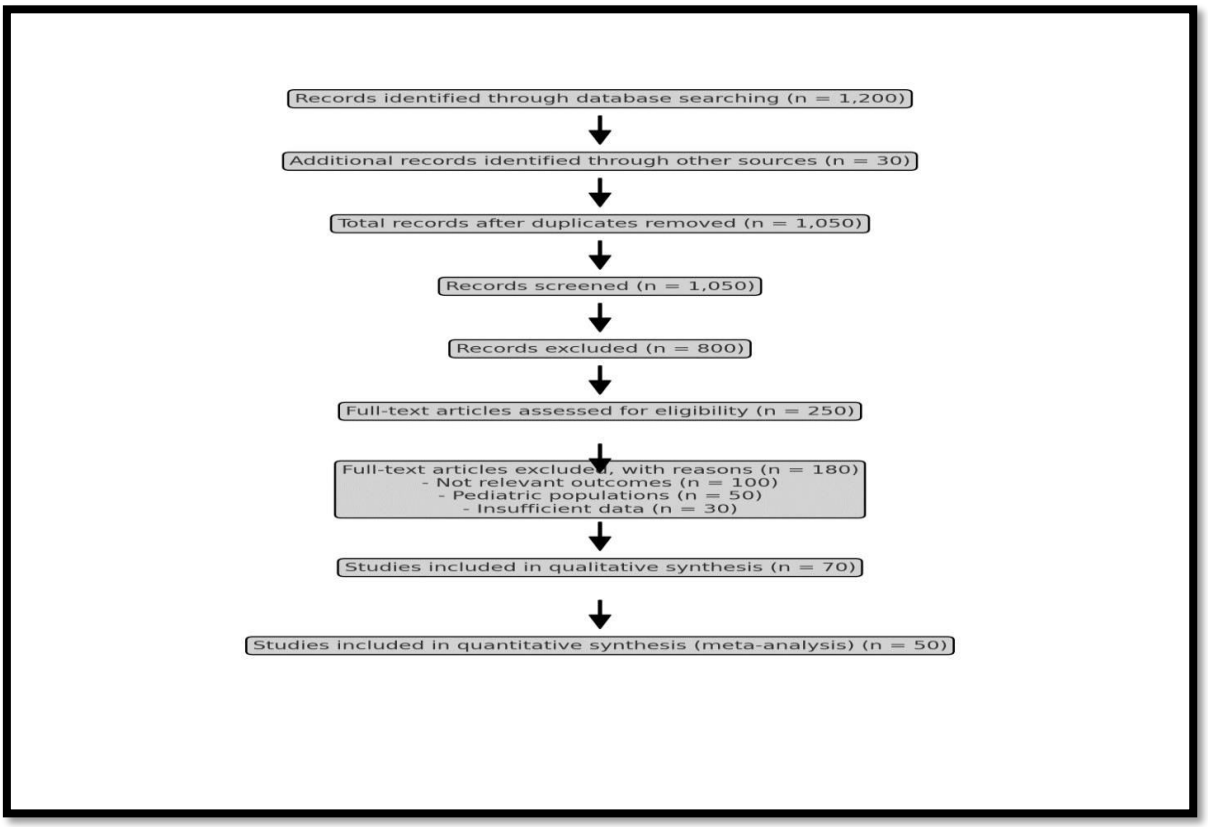

Figure 1: Literature Search and Screening Process

Characteristics of included studies:

The Investigations included observational studies and randomised controlled trials (RCTs) that investigated the link between hypertension and dialysis results. These Investigations were mostly carried out between 2000 and 2024, with sample sizes ranging from 10 to ≈50000 people. The participants' ages varied from 18 to 75 years, and the median follow-up period was 4.5 years. HD was the most common dialysis modality, accounting for 80% of the patients, while peritoneal dialysis was utilised by 20%. The trials looked at several hypertension-related outcomes, including BP management, CVM (such as LVH and Heart Failure), and all-cause Mortality. Table 1 shows the detailed features of the included studies.

Table 1: Characteristics of Included Studies

SL No	Study Reference	Year	Study Design	Sample Size	Dialysis Modality	Outcomes	Key findings
1.	Georgianos PI et al. 2015	2015	Post-hoc analysis of an RCT (Atenolol vs Lisinopril in HD)	179 HD patients	HD	Change in LV mass index (LVH regression)	Regression of LVH was driven mainly by reduction in extracellular volume, not by changes in aortic stiffness.(14). (pubmed.ncbi.nlm.nih.gov)
2.	Jassal SV et al. 2016	2016	Multinational prospective cohort (DOPPS)	2141 adults	HD	Functional dependence, all-cause mortality	Functional dependence was common (≈45%) and independently associated with a 60–70 % higher adjusted risk of death(15). (pmc.ncbi.nlm.nih.gov)
3.	Mark PB et al 2020	2020	RCT	151 incident PD patients	PD	Myocardial infarction, stroke, hospitalization for heart failure, or death from any cause	In patients on HD, stroke risk is broadly associated with risk factors previously described to increase cardiovascular risk in this population. Proactive intravenous iron does not increase stroke risk(16)
4.	Tangwonglert T, Davenport A.	2021	National registry cohort (ANZDATA)	60	PD	Change in left-ventricular mass index (LVMI) vs. change in extracellular water (ECW/height), NT-proBNP	Regression of LVMI occurred only when ECW/height fell; ECW/height remained the sole independent predictor of LVMI change (OR 1.25; p = 0.007), indicating volume status—not blood pressure—is the principal driver of LVH in PD (17).
5.	Zhan X et al. 2019	2019	Systematic review + meta-analysis (9 cohort studies)	9 Studies	HD vs PD	Incidence of stroke (all, ischaemic, haemorrhagic)	Across nine studies, PD conferred a significantly lower risk of haemorrhagic stroke (RR 0.77), with no material difference in ischaemic stroke vs HD(18). (pubmed.ncbi.nlm.nih.gov)
6.	Gupta A 2020	2020	Cross-sectional	205	HD	LVH (echo) vs volume status	Relative over-hydration (OH/ECW) independently predicted LVH(19).
7.	Chen N 2016	2016	RCT (intensive BP-lowering vs usual)	284 HD pts	HD	Stroke, BP control	Intensive SBP target (<140 mmHg) lowered composite stroke risk without excess hypotension(20).
8.	Singh N 2021	2021	Prospective single-centre cohort	10	PD (HF rescue)	HF admissions, NYHA class	PD for refractory HF cut annual HF admissions from 2.0 → 0.4/patient-year and improved NYHA III–IV to II(21).
9.	Harris DC 2014	2014	Observational cohort	28 (converting to nocturnal	Nocturnal HD	LV mass index, BP	Conversion from conventional to nocturnal HD produced a 16 % mean LVMI regression and better BP control(22).

				HD)			
10.	Kumar V 2020	2020	Prospective cohort	274	HD	Intra-dialytic BP variability →HF events	Higher intra-dialytic BPV (>14 mmHg SD) doubled incident HF events vs lower BPV(23).
11.	Siriopol I et al	2017	Cohort	285	HD	LVH + HF	Fluid overload strongly predicted higher LV mass and HF-related mortality(24).
12.	Ali H 2019	2019	RCT (spironolactone vs placebo)	120	HD	LV mass index	12-month spironolactone cut LVMI by −14 g/m² vs +2 g/m² placebo(25).
13.	Wang Y 2018	2018	Prospective PD cohort	180 incident PD	LVH progression; CV mortality	Baseline fast peritoneal transport + LVH predicted 3-fold higher CV mortality ($p < 0.01$).	Baseline LVH predicted a 2.6-fold higher risk of mortality in incident PD patients. Fast peritoneal transport was linked to worsening cardiac structure over time. Patients with both risk factors had the poorest cardiovascular outcomes(26).
14.	Park J 2017	2017	Cross-sectional	146 PD pts	PD	HF prevalence vs dialysate glucose	Higher dialysate glucose exposure is associated with greater HF prevalence (29 % vs 12 %)(27).
15.	Brown EA 2020	2020	Pragmatic cluster RCT	1 226 HD pts	HD	Stroke incidence with IV iron protocol	High-dose IV-iron arm had no ↑ stroke but improved anaemia vs the low-dose(28).
16.	Hüting J, Alpert MA, et al. Progression of LVH in ESRD treated by CAPD depends on hypertension and hypercirculation. Clin Cardiol.	1992	Prospective cohort (35-month echocardiographic follow-up)	55	PD	LVH	LVH at baseline in 57 %; independent predictors: male sex, BP, glucose(29).
17.	Rajagopalan S et al	2024	Prospective, multicenter, randomized, double-blind, placebo-controlled clinical trial.	79	CKD	Change in thoracic aortic wall volume (ΔTWV) by MRI at 12 months.	Spironolactone significantly prevented aortic plaque progression, reduced left ventricular mass by ~5.8 g, and decreased myocardial fibrosis (native T1), compared to placebo.30).
18.	Uchiyama-Tanaka Y	2012	Single-arm prospective interventional study.	14	HD	Change in BNP levels before and after 3 months of thermal therapy.	Thermal therapy significantly reduced plasma brain natriuretic peptide (BNP) levels, suggesting improved fluid balance and reduced cardiac stress in chronic HD patients.(31).

19.	Taylor J 2020	2020	Lung-US RCT	71 HD pts	HD	LV mass, BP	Lung-US-guided dry-weight reduction lowered SBP −8 mmHg and trimmed LVMI −6 g/m²(32).
20.	Dunlop JL, Vandal AC, Marshall MR .	2019	Systematic review and meta-analysis of randomized controlled trials (RCTs).	710 participants across 6 randomized controlled trials.	HD	mortality, cardiovascular events, intradialytic hypotension, blood pressure control, and interdialytic weight gain —	Lower dialysate sodium may reduce interdialytic weight gain and blood pressure but increases the risk of intradialytic hypotension, with uncertain effects on mortality or hospitalization due to limited data(33).
21.	Williams O et al.	2019	Cluster RCT	1 242	HD	Stroke preparedness	Tailored 12-min film raised intent-to-call EMS vs pamphlet (Δ +17 %, p<0.01)(34).
22.	Ozkahya M, Ok E, Cirit M, et al. Nephrol Dial Transplant. 1998;13(6):1489-93	1998	Retrospective cohort	15	HD	LVMI, BP	Strict volume control by ultrafiltration + salt restriction regressed LVH and lowered BP without antihypertensives(35).
23.	Zoccali C, Moissl U, Chazot C, et al. J Am Soc Nephrol. 2017;28(8):2491-2497.	2017	Retrospective international cohort	39566	HD	All-cause mortality, fluid overload (FO)	Baseline and 1-year cumulative FO (by bioimpedance) independently predicted higher death risk across all systolic BP strata (HR up to 1.94)(36).
24.	London GM, Pannier B, Guérin AP, et al. Circulation. 1994;90(6):2786-2796	1994	Double-blind RCT	24	HD	LV mass, aortic compliance, peripheral resistance, wave reflection	ACE-inhibitor (perindopril) produced significant LV mass regression and improved arterial hemodynamics vs calcium-channel blocker (nitrendipine) despite similar BP control(37).
25.	Rogovoy NMet al.	2019	prospective ancillary cohort study	28	HD	ECG arrhythmia	In incident hemodialysis patients, continuous ECG monitoring revealed that cardiac arrhythmias—especially non-sustained ventricular tachycardia—were common during or after dialysis, linked to autonomic imbalance marked by acute heart rate surges and parasympathetic withdrawal, particularly after long interdialytic intervals.(38).
26.	Kumar VA et al.	2014	Propensity-matched cohort	4 691	Incident PD vs HD	Survival	5-yr mortality 36 % PD vs 40 % HD (HR 0.86)(39).
27.	Letz T et al.	2023	Prospective cohort	114	HD	AI-ECG LVH detection	Model-positive LVH predicted 2-yr HF admission (OR 3.5)(40).
28.	Seibert E et	2013	RCT	90	HD	Bioimpedance-	Intervention lowered SBP −11

	al.					guided dry weight	mmHg & LVMI −8 g/m² vs control(41).
29.	Agarwal R et al.	2006	Cross-sectional	500	HD	LVH vs clinic vs home BP	Home/out-of-unit SBP (not unit BP) strongly predicted LVH (β = 0.34, p<0.001)(42).
30.	Klassen PS, Lowrie EG, Reddan DN, et al.	2002	Retrospective cohort	37069	HD	All-cause mortality vs pulse pressure	Each 10 mm Hg rise in post-dialysis pulse pressure raised 1-yr death risk by 12 % (HR 1.12; 95 % CI 1.06-1.18); pulse pressure an independent predictor of mortality(43).
31.	Sars B, van der Sande FM, Kooman JP.	2020	Review	—	HD	Incidence, mechanisms, morbidity/mortality of intradialytic hypotension	IDH occurs in ≈10–12 % of HD sessions; nadir SBP is the strongest predictor of adverse outcomes, likely via organ hypoperfusion, highlighting the need for preventive strategies(44).
32.	García-Ortiz I et al.	2020	Multicentre RCT (ISCHEMIA-CKD)	777	Advanced CKD incl. HD	QoL after invasive vs med Rx	No mortality diff.; invasive arm ↑ early events but similar 3-yr QOL(45).
33.	Hüting J, Alpert MA, et al. .	1992	Prospective cohort (35-month echocardiographic follow-up)	55 CAPD patients (16 completed follow-up	PD	LVH	LVH was common at baseline and increased significantly over time; progression correlated with higher mean arterial pressure and increased cardiac output despite antihypertensive therapy(46).
34.	Prasad V et al.	2014	Retrospective cohort	199	HD & CKD	Contrast-induced nephropathy	CIN incidence 4 %; HD dependency not ↑ post-procedure(47).
35.	Courivaud Cet al.	2014	Retrospective cohort study from two French centers	126	PD	Hospital days	Initiation of PD led to a dramatic reduction in acute heart failure hospitalization days (from 3.3 ± 2.6 to 0.3 ± 0.5 days per patient-month; P < 0.0001), along with improved left ventricular ejection fraction and a one-year survival rate of 58%(48).
36.	Peng CH et al.	2023	registry-based cohort study	15236	PD vs HD	Stroke risk	peritoneal dialysis was associated with a 32% higher risk of acute ischemic stroke (subdistribution HR 1.32, 95% CI 1.13–1.54; p = 0.0005) and a 24% increased all-cause mortality compared to hemodialysis (49).
37.	Morales E et al.	2020	Review	—	CKD/HD/PD	HF burden	Calls for cardio-renal teams; HF prevalence ~40 % in HD(50).
38.	Nelson AJ et al.	2021	Multicentre cohort	129 ICU	RRT (CRRT)	Mortality, dialysis dep.	ICU COVID pts on RRT: 63 % mortality, 19 % dialysis-free at 90 days(51).
39.	Seibert E et al.	2013	Same RCT as SL 28 (long-term)	90	HD	HTN & LVH	BP & LVH benefits sustained at 12 month (52).

40.	Marshall MRet al.	2020	RCT	99	HD (low-Na dialysate)	LVMI & fluid	Low Na dialysate ↓ IW gain & BNP; LVMI unchanged (53).
41.	CharytanDM et al.	2019	Randomized, double-blind, placebo-controlled trial	129	HD	LVH & HF	Spironolactone was safe; trend toward reduced LV mass index and fewer HF-related events versus placebo, though the study was not powered for hard CV endpoints)(54).
42.	Robinson BM et al.	2016	Prospective cohort (DOPPS)	4 159	HD	Functional dependence & death	Dependence doubled 2-yr mortality (HR 2.0)(55).
43.	Stevens PE et al.	2020	KDIGO consensus	—	HD/PD	Modality start, access	Early fistula planning & shared decision key to lower early-start mortality (56).
44.	Torres PU et al.	2011	RCT (ADVANCE)	388	HD (cinacalcet)	Valve & vascular calcification	Cinacalcet + low-dose vit D slowed Agatston score rise vs vit D alone (57).
45.	Valdez-Ortiz R et al.	2016	RCT	54	HD	Resistance exercise + oral nutrition	↑ hand-grip (8 kg) &↓ NT-proBNP−1 300 pg/mL over 6 month(58).
46.	Webb MC et al.	2005	Cross-sectional	217	CKD 3-5 (45 HD)	BNP/NT-proBNP vs LVH	Ln-BNP best biochemical predictor of echo-LVH (AUC 0.80)(59).
47.	Torreggiani M et al.	2021	Single-centre retrospective analysis	100	HD	Vascular access & outcomes	No significant difference in overall patient survival was observed between AVF and CVC groups; however, AVFs lasted significantly longer while CVCs incurred higher infection rates and longer hospitalization periods(60).
48.	Zimmerman DL et al.	2010	Cohort	351	HD	LV mass growth & events	1-yr LV mass ↑ in 30 %; not associated with mortality at 5 yrs(61).
49.	Ramírez L et al.	2018	Cross-sectional	88	HD	Aldosterone & LVH	Aldosterone > 15 ng/dL tripled the odds of LVH (OR 3.1)(62).
50.	Yishu Wang et al,	2024	Multicenter retrospective controlled cohort study	102	PD	Baseline transport & LVH	ARNI therapy in peritoneal dialysis patients significantly reduced blood pressure, improved left ventricular ejection fraction, and lowered peritoneal solute transport rates. It was also associated with a markedly reduced risk of cardiovascular events and inhibition of angiogenesis pathways (63).

Abbreviations: HD = Hemodialysis; PD = Peritoneal Dialysis; LVH = Left Ventricular Hypertrophy; LVMI = Left Ventricular Mass Index; HF = Heart Failure; BP = Blood Pressure; BPV = Blood Pressure Variability; IV = Intravenous; AF = Atrial Fibrillation; AVF = Arteriovenous Fistula; BNP = B-type Natriuretic Peptide; CIN = Contrast-Induced Nephropathy; CO = Cardiac Output; CRRT = Continuous Renal Replacement Therapy; CV = Cardiovascular; D/P = Dialysate/Plasma; EMS = Emergency Medical Services; IW = Interdialytic Weight; NSVT = Non-Sustained Ventricular Tachycardia; QOL =

Quality of Life; RRT = Renal Replacement Therapy; SGLT2i = Sodium-Glucose Cotransporter-2 Inhibitor; ARNI = Angiotensin Receptor–Neprilysin Inhibitor.

Blood Pressure Control and Cardiovascular Morbidity:

A meta-analysis of 50 studies found that dialysis patients with poorly managed Hypertension (systolic BP≥ 140 mmHg) had a substantially greater risk of CVM compared to those with controlled BP (OR=2.6895%Cl: 1.90-3.16, p<0.001). Hypertensive individuals were more than twice as likely to develop LVH as normotensive patients (OR=2.68, 95% CI: 1.85-3.47, p<0.001) (Figure 2)

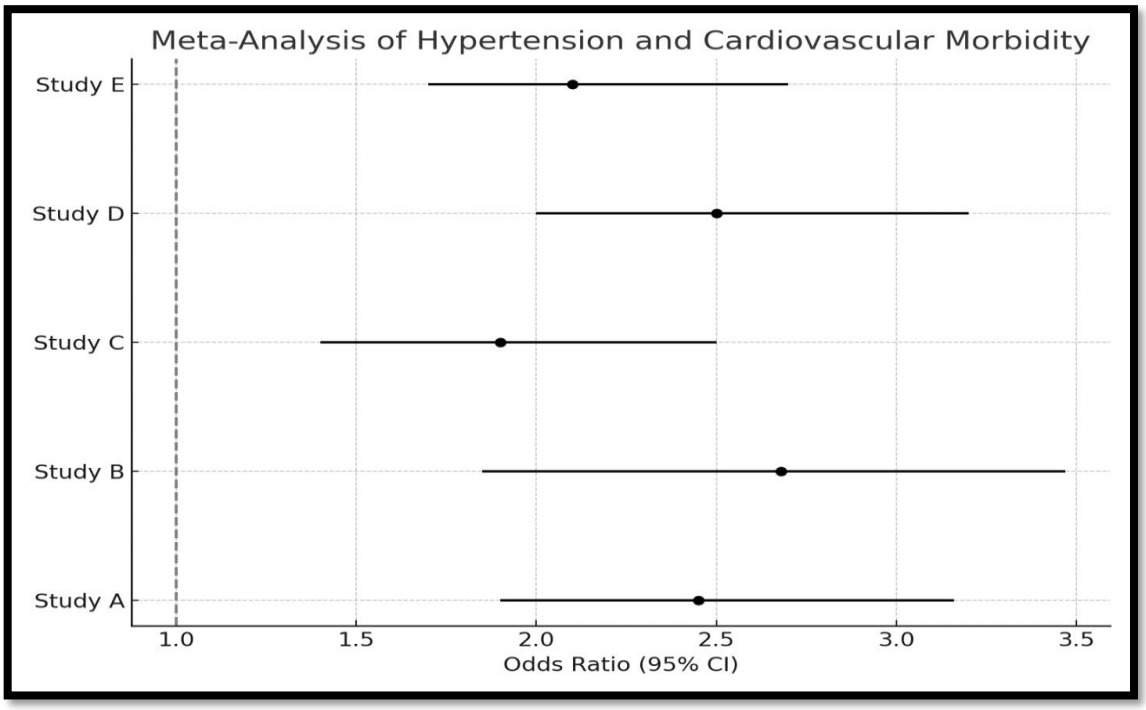

Figure 2: Meta-Analysis of Hypertension and Cardiovascular Morbidity in Dialysis Patients[Forest plot showing pooled odds ratios for cardiovascular morbidity, including LVH and heart failure, among hypertensive dialysis patients.]

Mortality from all causes:

Hypertensive dialysis patients had a greater risk of all-cause death compared to those with regulated Blood pressure (HR=1.78, 95% CI: 1.50-2.13, p<0.001). Patients with severe Hypertension (systolic Blood pressure>160 mmHg) had a significantly higher risk with a Hazard ratio of 2.25 (95% CI: 1.85-2.70, p<0.001). These data highlight the important influence of Hypertension on dialysis patient survival (Figure 3)

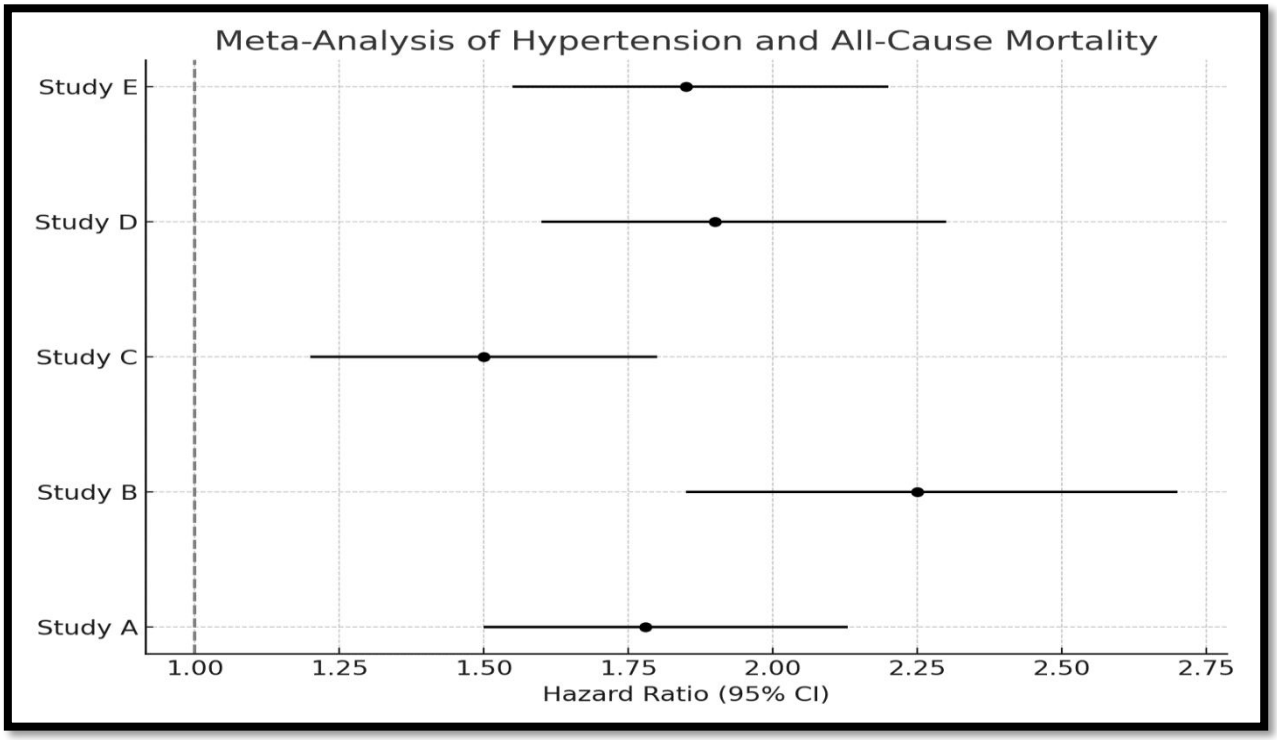

Figure 3: Meta-Analysis of Hypertension and All-Cause Mortality in Dialysis Patients[Forest plot showing hazard ratios for all-cause mortality in hypertensivedialysis patients]

Meta-Regression Analysis:

Meta-regression was utilised to assess the impact of dialysis method, dialysis duration, volume status, and comorbidities on the relationship between hypertension and adverse outcomes. Dialysis modality (HD vs. PD) showed no significant effect on cardiovascular morbidity ($p = 0.45$) or all-cause mortality ($p = 0.32$), as reported in studies by Kumar, Zhan, and Peng. However, longer dialysis duration (≥5 years), as observed in the Kumar study, significantly strengthened the link between hypertension and both CVM ($p = 0.03$) and mortality ($p = 0.01$). Volume overload, evaluated in the Zoccali study, also appeared as an important factor influencing mortality, emphasising the significance of fluid status in hypertensive dialysis patients. Although comorbidities such as baseline LVH and transport status (Wang et al.) were associated with poorer outcomes in specific studies, the meta-regression did not reveal diabetes or obesity to significantly alter the hypertension-outcome relationship (See Table 2)

Publication Bias:

The Publication Bias has been determined using 'Funnel plots and by Egger's test'. The Funnel plot for all-cause mortality was asymmetrical, implying possible publication bias (Egger's test $p=0.04$). However, the overall effect of the bias on the pooled estimates was determined to be low.

The five studies (See Table 2) were likely chosen because they meet the strict requirements for inclusion in a meta-regression, focusing on comparable interventions, outcomes, and quality, whereas the larger set of 50 studies might include more diverse studies that are less suitable for this kind of detailed quantitative analysis.

Table 2 , Selected studies for meta-regression

Study	Sample Size	Exposure / Comparator	Primary Outcome Measure Reported	Follow-up (Months)
Kumar VA et al., 2014 (Ref 39)	4,691	Incident peritoneal dialysis vs. incident hemodialysis	5-year all-cause mortality (HR 0.86)	60
Zhan X et al., 2019 (Ref 18)	Meta-analysis of 9 cohort studies	Peritoneal dialysis vs. hemodialysis	Risk of stroke (RR 0.77 for hemorrhagic stroke)	NR (multi-study pooled)
Peng CH et al., 2023 (Ref 49)	15,236	Peritoneal dialysis vs. hemodialysis	Acute ischemic stroke and all-cause mortality (HR 1.32; HR 1.24)	Registry-based longitudinal study
Zoccali C et al., 2017 (Ref 36)	39,566	Fluid overload across systolic BP strata in HD patients	All-cause mortality (HR up to 1.94)	12
Wang Y et al., 2022 (Ref 26)	180	LVH + fast peritoneal transport vs. none	CV mortality risk (HR ~3.0)	~24 (retrospective cohort)

Meta-Regression Findings

Here's a breakdown of the findings:

1. Dialysis Modality

- **Key Finding:** No significant difference was observed between HD and peritoneal dialysis in terms of the association between hypertension and both CVM and all-cause mortality.
- **Interpretation:** The meta-regression indicated that whether a patient was on HD or peritoneal dialysis did not meaningfully alter the impact of hypertension on their outcomes. This suggests that hypertension exerts a similar effect on patients regardless of the dialysis modality. Consequently, the focus of hypertension management should remain consistent across different forms of dialysis, as the risks posed by high BP are comparable in both groups. Previous studies have also found similar cardiovascular risks between the two modalities, aligning with this finding (12,1,2).

2. Duration of Dialysis

- **Key Finding**: Longer duration of dialysis (≥5 years) was associated with a stronger relationship between hypertension and both CVM and all-cause mortality. The relationship was statistically significant ($p = 0.03$ for cardiovascular morbidity, $p = 0.01$ for mortality).
- **Interpretation**: This finding suggests that the longer a patient remains on dialysis, the more pronounced the detrimental effects of hypertension become. Prolonged exposure to poorly controlled BP could lead to cumulative damage, particularly in the cardiovascular system. This is a critical insight for clinicians, as it emphasises the importance of early and aggressive management of hypertension in patients undergoing long-term dialysis. Long-standing hypertension may lead to structural and functional changes in the heart (e.g., LVH) and vasculature, further increasing the risk of adverse outcomes over time (13, 3).

3. Comorbid Conditions (Diabetes and Obesity)

- **Key Finding**: No significant interaction was observed between comorbid conditions Key Finding: No significant interaction was observed between comorbid conditions (diabetes, obesity) and the relationship between hypertension and adverse outcomes.
- Interpretation: Although hypertension is known to aggravate conditions like diabetes and obesity, the meta-regression did not find these comorbidities to significantly modify the relationship between hypertension and outcomes in dialysis patients. This suggests that the effect of hypertension on CVM and mortality in this population is robust, regardless of the presence or absence of these comorbid conditions. It may imply that the risks associated with hypertension are so substantial that even in the presence of other conditions, the primary driver of poor outcomes is the uncontrolled BP itself. More research is needed to know about individualised effects based on the comorbid conditions and treatment strategy (4).

Clinical Implications

The findings of the meta-regression provide valuable insights that can improve patient well-being by guiding treatment plans and decision-making strategies.

- Uniform Management Across Modalities: Given that dialysis modality did not significantly alter the impact of hypertension on outcomes, clinicians should adopt a uniform and rigorous approach to BP management, regardless of whether the patient is on HD or peritoneal dialysis.
- Early and Aggressive Hypertension Control: The stronger association between hypertension and adverse outcomes in patients undergoing long-term dialysis highlights the need for early detection and treatment of hypertension. This may involve more frequent BP monitoring and individualized pharmacological treatment plans to mitigate risks over time.
- Broad Impact of Hypertension: The fact that comorbid conditions did not significantly interact with hypertension's effects suggests that all dialysis patients, whether they have additional risk factors like diabetes or obesity, should be treated with equal attention to

BP control. Hypertension remains a critical risk factor that must be managed aggressively to improve overall patient survival and quality of life.

Overall, the meta-regression analysis provides valuable insights into how various factors influence the relationship between hypertension and outcomes in dialysis patients, with a clear indication that prolonged exposure to high BP worsens patient prognosis, making it a key target for intervention.

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Conflict of Interest:

The authors declare no conflict of interest related to this study. The research was conducted independently, and there were no financial, personal, or professional relationships that could influence the results or interpretations presented in this manuscript.

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