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Optimized Blood Pressure Control and Medication Burden Reduction in Bilateral Renal Artery Stenosis Patients Without Pickering Syndrome: A Retrospective Study

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ABSTRACT

Bilateral renal artery stenosis is a major cause of secondary hypertension, yet the benefits of percutaneous transluminal renal angioplasty and stenting in patients without Pickering syndrome remain uncertain. This retrospective study evaluated its effects on blood pressure control, medication burden, and renal function stability in 69 patients treated between 2010 and 2021. Patients with heart failure or pulmonary edema were excluded. Over a mean follow-up of 67.25 months, systolic and diastolic blood pressure significantly decreased, from 152.97 ± 16.97 to 135.48 ± 15.09 mmHg ($p < 0.01$) and from 84.33 ± 10.69 to 77.83 ± 11.94 mmHg ($p < 0.01$), respectively. The number of antihypertensive medications was also reduced, from 2.41 ± 1.28 to 1.68 ± 0.93 ($p < 0.01$). Renal function remained stable overall, with no significant change in serum creatinine ($p = 0.094$). However, patients with preoperative proteinuria exhibited greater deterioration in renal function during follow-up ($p = 0.039$), suggesting it may predict post-procedural outcomes. These findings indicate that percutaneous transluminal renal angioplasty and stenting provide sustained benefits in blood pressure control and medication reduction for bilateral renal artery stenosis patients without Pickering syndrome, though those with proteinuria may be at higher risk of renal function decline. Further studies are needed to refine treatment strategies based on individual risk factors.

1 | Introduction

Renovascular disease, resulting from progressive renal artery narrowing, manifests as renovascular hypertension (RVH) and ischemic nephropathy. RVH is a leading cause of secondary hypertension and has been extensively researched as a key example of angiotensin-dependent hypertension [1, 2]. In prior studies, the prevalence of bilateral disease among patients with renal artery stenosis (RAS) requiring intervention has varied between 16% and 50% [3–6], influenced by population bias and the criteria for stenosis severity. Patients with bilateral disease

are also suggested to have more extensive arterial involvement, a higher risk of complications such as pulmonary edema, and reduced long-term survival rates [5, 7, 8].

Although percutaneous transluminal renal angioplasty and stenting (PTRAS) for RAS expanded rapidly from the late 20th to early 21st century, increasing numbers of researchers have begun to question whether interventional therapy offers additional benefits over medication alone in terms of blood pressure control, renal function, cardiovascular events, and mortality [3, 9]. Due to the unique nature of bilateral RAS, patients with bilateral RAS

Siyuan Shen and Pengyu Li contributed equally to this study and are considered as the co-first authors.

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are more likely to develop Pickering syndrome, characterized by recurrent acute pulmonary edema [10], for which PTRAS is strongly recommended by current guidelines [11]. Some authoritative guidelines include patients with concomitant high-risk features (rapidly progressive, treatment-resistant arterial hypertension; rapidly declining renal function; flash pulmonary edema; solitary kidney) [11–13] as indications for renal revascularization. Current clinical data primarily focused on high-risk patients with concurrent heart failure or pulmonary edema [14, 15]. However, the benefits of revascularization in patients without Pickering syndrome remain unclear. Post hoc analyses of ASTRAL [16] indicated that patients with bilateral RAS > 70% or severe stenosis in a solitary kidney tended to derive greater benefit from revascularization, with signals toward reduced mortality and composite outcomes. However, these findings did not reach statistical significance, reflecting the trial's limitations of heterogeneous inclusion criteria and underpowered subgroup analyses. Notably, CORAL did not provide a dedicated subgroup analysis for bilateral RAS, leaving the potential benefit in this high-risk population less clearly defined.

This study focuses on a distinct subgroup of bilateral RAS patients without Pickering syndrome, referred to as the non-Pickering cohort, aiming to evaluate their clinical outcomes following PTRAS, including blood pressure control, reduction in medication burden, and renal function stability.

2 | Methods

2.1 | Study Population

This retrospective cohort study, approved by the Institutional Review Board of Peking University First Hospital, enrolled patients with bilateral RAS from 2010 to 2021. All patients provided written informed consent.

All patients diagnosed with bilateral RAS at our center underwent noninvasive imaging, including Doppler ultrasound, computed tomography (CT), and magnetic resonance imaging (MRI). The inclusion criteria were (1) bilateral RAS confirmed by digital subtraction angiography (DSA) with a stenosis severity of > 60%; (2). Exclusion criteria were (1) history of heart failure or pulmonary edema; (2) admission BNP > 500 pg/mL; (3) preoperative echocardiography showing an ejection fraction (EF) < 50%.

2.2 | Intervention: PTRAS

The procedure was performed through a femoral artery approach under local anesthesia. A 7F sheath and guide catheter were used to reach the ostium of the renal artery. A guidewire with a diameter between 0.014 and 0.018 inches was used to cross the stenotic lesion and was placed in the renal artery distally. Balloons used in PTRAS ranged in diameter from 2 to 5 mm, with balloon-expandable stents deployed with 1:1 sizing with the normal renal artery.

After the procedure, patients were prescribed dual antiplatelet therapy with aspirin and clopidogrel for at least 6 months,

followed by lifelong aspirin or clopidogrel therapy. Regular follow-up visits were scheduled after discharge.

2.3 | Data Collection

Upon admission, all patients underwent a thorough collection and review of medical history. Past medical history and consultations with other specialties were discussed within a professional team to exclude high-risk comorbidities such as heart failure and pulmonary edema. Preoperative use of antihypertensive medications, including types and adherence, was also verified. Baseline blood pressure measurements were conducted by specialized vascular surgery nursing staff, with patients seated and resting for at least 5 min prior to measurement. Blood pressure was assessed on the right arm using an electronic sphygmomanometer (Omron HBP-1320, Omron Healthcare, Kyoto, Japan) with a cuff size matched to the arm circumference. Three consecutive measurements were taken, and the mean value was calculated. Preoperative blood pressure was obtained from the last outpatient visit before the procedure, under a stable condition after at least 30 min of rest. Postoperative blood pressure was measured during outpatient follow-up visits under the same protocol to ensure consistency. Preoperative patients underwent blood and urine tests to assess serum creatinine, estimated glomerular filtration rate (eGFR), brain natriuretic peptide (BNP) levels, and urinary protein. The radionuclide-derived GFR (rGFR) was calculated using 99mTc-DTPA renal dynamic imaging. Urinary protein was measured using a dry chemical method, with trace, 1+, 2+, and 3+ corresponding to urinary protein levels of 15–30, 30–100, 100–300, and > 300 mg/dL, respectively. eGFR was calculated using the CKD-EPI equation. Routine echocardiography was performed to assess the risk of perioperative cardiovascular events and to exclude patients with heart failure or significant pulmonary hypertension.

2.4 | Follow-Up

Patient follow-up was managed collaboratively by specialized follow-up physicians from our center and primary care health professionals. Long-term follow-up on hypertension control was conducted at primary care centers, with adjustments in antihypertensive medication made by a team comprising hypertension specialists, cardiologists, and vascular surgeons. Adjustments were tailored based on patient tolerance, adherence, and target blood pressure, with education provided on home blood pressure monitoring. The follow-up team also provided basic health consultations and regular updates on patients' recent medical history through telephone follow-ups.

2.5 | Definitions of Clinical Endpoints

Renal events were defined as the initiation of dialysis, renal transplantation, or nephrectomy (excluding tumor-related nephrectomy). Cardiovascular and cerebrovascular events were defined according to conventional international standards, including nonfatal myocardial infarction, hospitalization for unstable angina, coronary revascularization, ischemic or hemorrhagic stroke, transient ischemic attack, hospitalization for heart failure,

or cardiovascular death. The composite endpoint was defined as all-cause mortality plus renal and cardiovascular/cerebrovascular events.

2.6 | Statistical Analysis

All statistical analyses were performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables are presented as mean $\pm$ standard deviation (SD) or median with interquartile range (IQR), depending on the data distribution. Categorical variables are reported as frequencies and percentages. The Kolmogorov–Smirnov test was used to assess data normality. For continuous variables with normal distribution, paired *t*-tests were applied to compare pre- and post-intervention values. Non-normally distributed variables were analyzed using the Wilcoxon signed-rank test or Kruskal–Wallis test, as appropriate. Categorical variables were compared using chi-square tests.

To explore predictors of renal function outcomes, we performed stepwise regression analysis with serum creatinine change as the dependent variable. Independent variables considered in the model included follow-up duration, preoperative urinary protein levels, age, sex, revascularization status, baseline systolic and diastolic blood pressures, initial serum creatinine, and number of antihypertensive medications. Statistical significance was set at $p < 0.05$.

3 | Results

A total of 69 patients with bilateral RAS were included in this study (Table 1), with a mean age of 63.15 ± 10.99 years. Among these patients, 62.3% (43/69) were male. The majority (82.6%) underwent bilateral intervention, while 17.4% received unilateral intervention. Regarding occlusion status, 69.6% had no occlusion, 29.0% had unilateral occlusion, and 1.4% had bilateral occlusion. Among patients with occlusive lesions, successful revascularization was achieved in 35.0% of those with unilateral occlusion and in the only patient with bilateral occlusion.

Renal function and biomarker levels were as follows: preoperative serum creatinine averaged 134.07 ± 58.27 $\mu\text{mol/L}$, with an eGFR of 50.02 ± 20.87 mL/min/1.73 m^2 . Preoperative B-type natriuretic peptide (BNP) levels averaged 147.37 ± 117.40 pg/mL , while homocysteine levels were 23.37 ± 21.50 $\mu\text{mol/L}$. Urinary protein levels varied, with 63.6% showing normal levels, while others exhibited trace, 1+, 2+, and 3+ proteinuria. The right and left renal artery resistive index (RARI) values were 0.639 ± 0.118 and 0.635 ± 0.126 , respectively, indicating similar resistance across both renal arteries. The preoperative left ventricular ejection fraction (LVEF) was $68.9\% \pm 6.7\%$, suggesting preserved cardiac function in this patient population.

At a mean follow-up of 67.25 months, both systolic and diastolic blood pressures were significantly reduced (SBP: from 152.97 ± 16.97 mmHg pre-procedure to 135.48 ± 15.09 mmHg at last follow-up, $p < 0.01$; DBP: from 84.33 ± 10.69 mmHg to 77.83 ± 11.94 mmHg, $p < 0.01$), indicating improved blood pressure control post-PTRAS. The average number of antihypertensive

medications was also reduced from 2.41 ± 1.28 to 1.68 ± 0.93 ($p < 0.01$), suggesting decreased reliance on medication (Table 2).

Renal function, assessed by serum creatinine and eGFR, showed slight but nonsignificant changes. Serum creatinine increased from 143.46 ± 60.66 $\mu\text{mol/L}$ pre-procedure to 183.16 ± 185.06 $\mu\text{mol/L}$ at follow-up ($p = 0.094$). Although not statistically significant, these findings suggest a need for ongoing renal function monitoring in patients undergoing PTRAS.

A stepwise regression analysis was performed to identify predictors of serum creatinine change. Variables considered included follow-up time, preoperative urinary protein level, age, sex, revascularization status (bilateral untreated/unilateral treated/bilateral treated), preoperative SBP, preoperative DBP, baseline creatinine, and the number of antihypertensive medications. The final model retained only preoperative urinary protein, explaining 23.1% of the variance in creatinine change ($R^2 = 0.231$, $F = 7.531$, $p = 0.011$). An independent-samples *t*-test was performed to compare preoperative rGFR, renal length (as measured by ultrasound), and RARI between patients with postoperative increases in serum creatinine and those with decreases. No statistically significant differences were observed in any of these parameters between the two groups (all $p > 0.05$).

Table 3 shows serum creatinine values at baseline, follow-up, and the changes (Δ serum creatinine) across urinary protein groups. Baseline creatinine was lower in the normal protein group (117.38 ± 34.96 mg/dL) than in the trace (166.89 ± 62.05 mg/dL) and Positive (159.51 ± 73.97 mg/dL) groups. At follow-up, the positive group had the highest creatinine (367.13 ± 333.67 mg/dL). Kruskal–Wallis tests revealed significant differences in baseline creatinine ($p = 0.050$) and Δ serum creatinine ($p = 0.039$) between groups, suggesting an association between preoperative urinary protein and creatinine changes.

The overall incidence of endpoint events was 12.7%, with a relatively higher occurrence among patients with elevated urinary protein levels, and a median time to event occurrence of 40 months. Additionally, with a median follow-up time of 67.25 months, the cumulative incidence of cardiovascular events was 5.45%, while the incidence of renal events reached 10.91%. Kaplan–Meier survival curves were generated to illustrate the cumulative incidence of the composite endpoint (Figure 1). To further explore potential predictors of adverse outcomes, Cox proportional hazards regression analyses were performed separately for renal events, cardiovascular/cerebrovascular events, and the composite endpoint. Candidate variables included age, sex, etiology, preoperative blood pressure, number of antihypertensive medications, baseline serum creatinine, baseline eGFR, baseline proteinuria, and renal resistive index (RRI) of both kidneys. Across all three models, none of the examined baseline clinical or laboratory parameters were significantly associated with the occurrence of renal, cardiovascular, or composite events (all $p > 0.05$).

Multivariable linear regression was performed to identify predictors of blood pressure reduction. For Δ SBP, preoperative SBP was the only independent predictor ($\beta = 0.730$, $p < 0.001$). For Δ DBP, both preoperative SBP ($\beta = 0.317$, $p = 0.047$) and preoperative DBP ($\beta = 0.332$, $p = 0.062$) were positively associated with reduction.

TABLE 1 | Baseline demographics and clinical characteristics of patients.

Characteristic	Effective sample size (<i>n</i>)	Value (mean ± SD or %)
Age (years)	69	63.1 ± 11.0
Sex	69	
Male	43	62.3%
Female	26	37.7%
Etiology	69	
Atherosclerosis	66	95.7%
Takayasu arteritis	2	2.9%
Fibromuscular dysplasia	1	1.4%
Revascularization status	69	
Unilateral intervention	12	17.4%
Bilateral intervention	57	82.6%
Occlusion status	69	
None	48	69.6%
Unilateral occlusion	20	29.0%
Occlusion revascularized	7	35.0%
Bilateral occlusion	1	1.4%
Bilateral revascularized	1	100%
Antihypertensive medication use	69	
ACEI/ARB	35	50.7%
Calcium channel blocker	59	85.5%
Diuretic	16	23.2%
Beta-blocker	33	47.8%
Preoperative laboratory values		
Creatinine (μmol/L)	69	134.1 ± 58.3
eGFR (mL/min/1.73 m ²)	47	50.0 ± 20.9
Radionuclide GFR (<i>R</i>) (mL/min)	53	22.0 ± 16.0
Radionuclide GFR (<i>L</i>) (mL/min)	53	21.6 ± 12.5
BNP (pg/mL)	45	147.4 ± 117.4
Homocysteine (μmol/L)	30	23.4 ± 21.5
Urinary protein	55	
Normal	35	63.6%
Trace	9	16.4%
1+	7	12.7%
2+	3	5.5%
3+	1	1.8%
Renal artery resistive index (RARI)	49	
Right		0.639 ± 0.118
Left		0.635 ± 0.126
Renal length (cm, ultrasound)	39	
Right		14.7 ± 9.3
Left		12.2 ± 8.0
Left ventricular ejection fraction (LVEF, %)	57	68.9 ± 6.7

Abbreviations: BNP, B-type natriuretic peptide; eGFR, estimated glomerular filtration rate; rGFR, radionuclide-derived GFR; LVEF, left ventricular ejection fraction; RARI, renal artery resistive index.

TABLE 2 | Changes in clinical outcomes before and after intervention.

Variable	Paired (mean ± standard deviation)		Difference	<i>p</i>	Cohen's <i>d</i>
	Pre-procedure	At last follow-up ^a			
Systolic BP (mmHg)	152.97±16.97	135.48 ± 15.09	17.49	< 0.01	0.911
Diastolic BP (mmHg)	84.33±10.69	77.83 ± 11.94	6.51	< 0.01	0.54
Number of antihypertensives	2.41±1.28	1.68 ± 0.93	0.72	< 0.01	0.653
Creatinine (μmol/L)	143.46±60.66	183.16 ± 185.06	−39.7	0.094	0.23

^aMean follow-up duration: 67.25 months.

TABLE 3 | Preoperative proteinuria levels and serum creatinine changes.

Preoperative urinary protein	Normal (<i>n</i> = 35)	Trace (<i>n</i> = 9)	Positive (<i>n</i> = 11)	<i>p</i> value (KW test)
Baseline serum creatinine (mg/dL)	117.38 ± 34.96	166.89 ± 62.05	159.51 ± 73.97	0.050*
Follow-up serum creatinine (mg/dL)	141.82 ± 140.41	211.63 ± 164.00	367.13 ± 333.67	0.098
Δ Serum creatinine (follow-up—Baseline) (mg/dL)	16.83 ± 131.38	35.36 ± 169.04	198.32 ± 312.44	0.039*

Abbreviation: Δ, change from baseline to follow-up.

**p* < 0.05 is considered statistically significant.

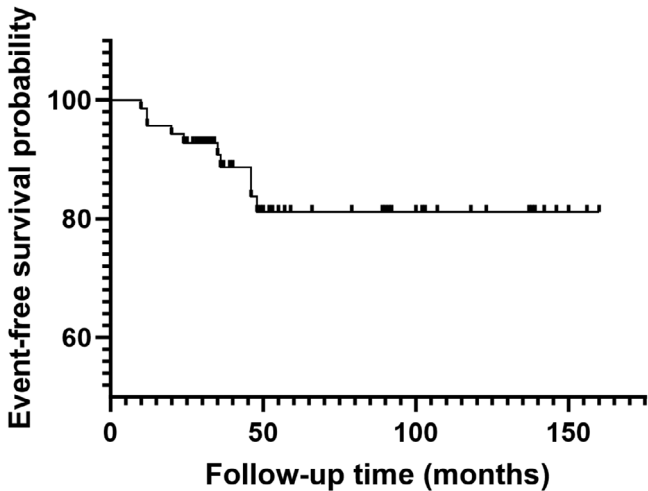


FIGURE 1 | Kaplan-Meier survival curve showing event-free survival over follow-up in patients with bilateral renal artery stenosis. The composite endpoint included cardiovascular and renal events. Tick marks indicate censored observations.

Other variables, including age, sex, etiology, eGFR, and urine protein, were not significant in either model. Detailed regression results are provided in Table S1.

Subgroup analyses stratified by age, sex, baseline BNP, baseline eGFR, and proteinuria demonstrated consistent reductions in SBP and DBP across all categories (Table S2). Notably, DBP reduction reached statistical significance in patients aged ≥ 60 years (−4.61 ± 10.80 mmHg, *p* = 0.026). Renal function changes were comparable across most subgroups, although patients with preoperative proteinuria showed a trend toward greater creatinine elevation (198.3 ± 312.4 μmol/L, *p* = 0.063).

4 | Discussion

This study demonstrates that in patients with bilateral RAS without heart failure or pulmonary edema, PTRAS effectively reduces blood pressure and lowers the need for antihypertensive medications. Over the past decade, significant academic debate has revolved around whether patients with RAS benefit from PTRAS compared to medical therapy alone and, if so, which subgroups may experience specific benefits. Early trials, including CORAL [3] and ASTRAL [4], showed that PTRAS provided limited benefits for BP control and no clear advantage over medical therapy alone in reducing all-cause mortality, end-stage renal disease, or major cardiovascular events [9, 17–19]. However, it has to be mentioned that these trials may have selection biases, potentially excluding high-risk groups such as patients with heart failure, recurrent flash pulmonary edema, or resistant hypertension [15, 20–23] who could benefit from PTRAS.

Recent prospective cohort studies have demonstrated that renal artery stenting in patients with refractory hypertension or recurrent heart failure or flash pulmonary edema is associated with clear benefits, including reductions in mean 24-h ambulatory systolic blood pressure and antihypertensive medication use [20]. These findings highlight that certain high-risk populations may indeed benefit from PTRAS [24]. Notably, patients with bilateral RAS often exhibit these high-risk characteristics. Consequently, an increasing number of guidelines now emphasize that the treatment strategies for bilateral RAS may differ from those for unilateral RAS [11].

Our study aims to highlight that in patients with bilateral RAS, PTRAS can provide significant and long-term clinical benefits even in the absence of high-risk factors such as recurrent heart failure or flash pulmonary edema. In this cohort from our center, patients experienced a significant reduction

in both systolic and diastolic blood pressure over long-term follow-up. Additionally, the use of antihypertensive medications decreased substantially. Notably, 53.62% of patients required fewer antihypertensive medications, and only 7.25% required an increase in medication types. These findings suggest that PTRAS may provide sustained benefits in blood pressure control and reduce the medication burden in patients with bilateral RAS.

In prior randomized controlled trials (RCTs), such as the Essai Multicentrique Medicaments vs Angioplastie (EMMA) [25] and the Scottish and Newcastle RAS Collaborative Group studies [26], the blood pressure benefits of PTRAS were generally less pronounced compared to those observed in observational studies [27], with no additional advantage shown for PTRAS over medical therapy alone in terms of BP control. When comparing our findings to those from the CORAL trial [3], we observed that patients who underwent PTRAS in our study not only achieved a comparable reduction in systolic blood pressure (SBP) (17.493 ± 19.212 mmHg in our study vs. 16.6 ± 21.2 mmHg in CORAL) but also experienced a significant reduction in antihypertensive medication use, despite similar baseline antihypertensive medication usage. However, in the CORAL study, the number of antihypertensive medications increased in both the stent and medical therapy groups by the end of the study (3.3 ± 1.5 vs. 3.5 ± 1.4 , respectively). An increased medication burden may elevate the risk of drug interactions [28] and is associated with poorer outcomes in hospitalized patients [29]. Moreover, polypharmacy presents challenges to patient adherence and access to medications and significantly increases healthcare costs [30].

In ASTRAL, initiation of dialysis (10.7% vs. 12.4%) and cardiovascular events (HR 0.98, $p = 0.864$) were comparable between the revascularization and medical groups, while CORAL reported extremely low rates of permanent renal replacement therapy (0.9% vs. 0.6%), stroke (2.6% vs. 3.4%), myocardial infarction (6.5% vs. 5.7%), and hospitalization for heart failure (5.9% vs. 5.5%), suggesting that CORAL may have enrolled patients with relatively low risk of renal function deterioration. In contrast, our study focused exclusively on patients with bilateral RAS, a subgroup typically associated with worse hemodynamic burden and clinical prognosis. Despite this higher-risk population, the cumulative incidences of renal and cardiovascular events in our cohort were 10.9% and 5.5%, respectively, over a median follow-up of more than 5 years, indicating that outcomes after endovascular intervention were at least comparable to those reported in ASTRAL. These findings underscore that targeted intervention in high-risk bilateral RAS patients may achieve meaningful renal and cardiovascular outcomes and highlight the need for studies specifically addressing this subgroup.

According to the results presented in Table 3, patients with higher baseline proteinuria exhibited a greater increase in serum creatinine levels during follow-up, suggesting that those with elevated proteinuria may be more prone to postoperative renal function deterioration. Although RAS reduces renal blood flow, some patients do not develop significant renal impairment; despite restricted renal blood flow and reduced kidney volume, the kidney may still maintain sufficient oxygenation

under these conditions [31]. However, when stenosis exceeds 70%–80%, significant cortical hypoxia can develop, activating inflammation and oxidative pathways associated with interstitial fibrosis [32], eventually resulting in irreversible renal parenchymal damage [13]. Our findings suggest that preoperative proteinuria may serve as an indicator of the extent of parenchymal damage; in patients with positive proteinuria, renal parenchymal injury may not be fully reversible with PTRAS, and these patients are more likely to experience worsening renal function following revascularization. Further prospective studies with larger sample sizes are needed to validate whether PTRAS offers greater benefit in patients with early-stage bilateral RAS (proteinuria-negative) compared to those with positive proteinuria.

This study has certain limitations, including a relatively small sample size, a single-center retrospective design, and the lack of a control group of patients who did not undergo PTRAS. The observed improvements might reflect improved medication adherence, or other noninterventional factors. Future research may require larger, multicenter randomized controlled trials to further substantiate the benefits for this patient population. Another limitation of our study is the lack of standardized follow-up data at intermediate time points (e.g., 1 month, 6 months, or 1–3 years after the procedure). Because of the retrospective nature of our cohort, blood pressure and renal function measurements were not consistently available at these intervals. Therefore, we reported the baseline values and the last available follow-up data to provide a reliable long-term assessment while avoiding potential bias from incomplete records. Future prospective studies with scheduled follow-up visits are warranted to better delineate the short- and medium-term effects of PTRAS. Our findings underscore the potential of preoperative proteinuria as a prognostic marker, emphasizing the importance of early renal damage indicators, such as urinary microalbumin, urinary immunoglobulin G, blood urea nitrogen, and cystatin C [27, 33], which may provide a basis for personalized treatment strategies in RAS.

5 | Conclusion

This retrospective study demonstrates that PTRAS significantly reduces blood pressure and decreases the dependence on antihypertensive medication in the non-Pickering cohort of bilateral RAS. Although there was no statistically significant improvement in renal function post-PTRAS, patients with preoperative proteinuria exhibited progressive renal function decline over the follow-up period, suggesting that baseline proteinuria may serve as a predictor of renal function outcomes following revascularization.

Author Contributions

Siyuan Shen: conceptualization, methodology, formal analysis, data curation, writing – original draft. **Pengyu Li:** methodology, investigation, resources, visualization, writing – review and editing. **Bihui Zhang:** study design participation, key experimental data collection, manuscript revision (based on peer review comments). **Ziguang Yan:** validation, software, formal analysis. **Guochen Niu:** ethics approval coordination, clinical data acquisition, resources. **Min Yang:** Supervision, project administration, funding acquisition, final approval of the manuscript.

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Ethics Statement

All methods were carried out in accordance with the principles of the Declaration of Helsinki.

Consent

All the participants participated in this project voluntarily and written informed consent was obtained from all participants.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data supporting this study are not publicly available due to institutional privacy policies and ethics board restrictions. Access may be granted upon reasonable request and approval by the relevant ethics committee.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.

Supplementary Table 1: Multivariable Linear Regression Analysis of Factors Associated with Δ SBP and Δ DBP ($n = 40$). **Supplementary Table 2:** Subgroup analyses of blood pressure reduction and renal function change after PTR. **Plain language summary**