Impact of Mental Health on Blood Pressure Nonresponse Following Renal Artery Stenting: A Prospective Cohort Study

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Abstract

Background: Renal artery stenosis (RAS) is a significant cause of secondary hypertension, often requiring percutaneous transluminal renal artery stenting. However, patient outcomes, particularly in terms of blood pressure (BP) response and mental health status, can vary widely post-intervention. The impact of these variables on anxiety and depression in this population remains underexplored.

Objective: This study aimed to evaluate the factors associated with BP nonresponse and the development of anxiety and depression following renal artery stenting in patients with severe unilateral RAS

Methods: A prospective cohort study was conducted at Beijing Hospital between October 2017 and December 2020. A total of 164 patients who underwent successful renal artery stenting were included. Patients were divided into BP response (n = 98) and BP nonresponse groups (n = 66) based on BP measurements at 12 months post-procedure. Clinical data, including demographic information, comorbidities, renal function, NT-proBNP levels, antihypertensive medications, and psychological status (using the Self-Rating Anxiety Scale and Self-Rating Depression Scale), were collected at baseline and at the 12-month follow-up. Multivariate logistic regression was performed to identify factors associated with BP nonresponse, anxiety, and depression.

Results: Compared to the BP response group, the BP nonresponse group had a higher proportion of current smokers (63.6% vs. 42.9%, P=0.009), more comorbidities (?3) (66.7% vs. 40.8%, P=0.001), lower eGFR (50.7 ± 15.7 vs. 56.7 ± 13.9 mL/min/1.73 m², P=0.011), higher NT-proBNP levels (379.2 ± 203.1 vs. 327.4 ± 154.9 pg/mL, P=0.033), and more frequent use of ?4 types of antihypertensive medications (75.8% vs. 58.2%, P=0.021). Multivariate analysis revealed that lower eGFR (OR=0.924, 95% CI: 0.883–0.966, P<0.001), higher NT-proBNP (OR=1.309, 95% CI: 1.075–1.595, P=0.008), higher SAS scores at 12 months (OR=1.102, 95% CI: 1.013–1.199, P=0.025), and use of ?4 antihypertensive medications (OR=1.785, 95% CI: 1.114–2.861, P=0.016) were independent predictors of BP nonresponse. Anxiety was associated with younger age (OR=0.951, 95% CI: 0.914–0.989, P=0.009), lower education level (OR=1.357, 95% CI: 1.108–1.661, P=0.001), higher degree of RAS (OR=2.253, 95% CI: 1.249–4.063, P=0.002), and BP nonresponse (OR=1.629, 95% CI: 1.137–2.334, P=0.003). Depression was more common in women (OR=1.163, 95% CI: 1.038–1.303, P=0.010), unmarried individuals (OR=1.140, 95% CI: 1.068–1.217, P<0.001), those with lower education (OR=1.205, 95% CI: 1.061–1.368, P=0.009), and those with BP nonresponse (OR=1.316, 95% CI: 1.105–1.568, P=0.008).

Conclusions: BP nonresponse following renal artery stenting was associated with lower renal function, elevated NT-proBNP levels, and increased psychological distress, particularly anxiety and depression. These findings highlight the need for targeted interventions in high-risk patients to improve both clinical and mental health outcomes post-stenting. Clinical Trial: This study was registered in the China Clinical Trial Registration Center (ChiCTR1800016252) and approved by the Institutional Review Board (IRB) of Beijing Hospital (No. 2018BJYYEC-043-02).

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Impact of Mental Health on Blood Pressure Nonresponse Following Renal Artery Stenting: A Prospective Cohort Study

Running head: BP Response and Mental Health Following Stenting

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Conflicts of interest
None.

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None.

Abstract

Objectives

Renal artery stenosis (RAS) is a significant cause of secondary hypertension, often requiring percutaneous transluminal renal artery stenting. However, patient outcomes, particularly in terms of blood pressure (BP) response and mental health status, can vary widely post-intervention. The impact of these variables on anxiety and depression in this population remains underexplored. This study aimed to evaluate the factors associated with BP nonresponse and the development of anxiety and depression following renal artery stenting in patients with severe unilateral RAS.

Methods

A prospective cohort study was conducted at Beijing Hospital between October 2017 and December 2020. A total of 164 patients who underwent successful renal artery stenting were included. Patients were divided into BP response (n = 98) and BP nonresponse groups (n = 66) based on BP measurements at 12 months post-procedure. Clinical data, including demographic information, comorbidities, renal function, NT-proBNP levels, antihypertensive medications, and psychological status (using the Self-Rating Anxiety Scale and Self-Rating Depression Scale), were collected at baseline and at the 12-month follow-up. Multivariate logistic regression was performed to identify factors associated with BP nonresponse, anxiety, and depression.

Results

Compared to the BP response group, the BP nonresponse group had a higher proportion of current smokers (63.6% vs. 42.9%, P=0.009), more comorbidities (≥3) (66.7% vs. 40.8%, P=0.001), lower eGFR (50.7 ± 15.7 vs. 56.7 ± 13.9 mL/min/1.73 m², P=0.011), higher NT-proBNP levels (379.2 ± 203.1 vs. 327.4 ± 154.9 pg/mL, P=0.033), and more frequent use of ≥4 types of antihypertensive medications (75.8% vs. 58.2%, P=0.021). Multivariate analysis revealed that lower eGFR (OR=0.924, 95% CI: 0.883–0.966, P<0.001), higher NT-proBNP (OR=1.309, 95% CI: 1.075–1.595, P=0.008), higher SAS scores at 12 months (OR=1.102, 95% CI: 1.013–1.199, P=0.025), and use of ≥4 antihypertensive medications (OR=1.785, 95% CI: 1.114–2.861, P=0.016) were independent predictors of BP nonresponse. Anxiety was associated with younger age (OR=0.951, 95% CI: 0.914–0.989, P=0.009), lower education level (OR=1.357, 95% CI: 1.108–1.661, P=0.001), higher degree of RAS (OR=2.253, 95% CI: 1.249–4.063, P=0.002), and BP nonresponse (OR=1.629, 95% CI: 1.137–2.334, P=0.003). Depression was more common in women (OR=1.163, 95% CI: 1.038–1.303, P=0.010), unmarried individuals (OR=1.140, 95% CI: 1.068–1.217, P<0.001), those with lower education (OR=1.205, 95% CI: 1.061–1.368, P=0.009), and those with BP nonresponse (OR=1.316, 95% CI: 1.105–1.568, P=0.008).

Conclusions

BP nonresponse following renal artery stenting was associated with lower renal function, elevated NT-proBNP levels, and increased psychological distress, particularly anxiety and depression. These findings highlight the need for targeted interventions in high-risk patients to improve both clinical and mental health outcomes post-stenting.

Keywords:

Renal artery stenosis; Blood pressure response; Anxiety; Depression; Stenting; Risk factor

Introduction

Hypertension secondary to renal artery stenosis (RAS) is a recognized clinical condition contributing to treatment-resistant hypertension (BP) and chronic kidney disease (CKD) [1]. Percutaneous transluminal renal artery stenting is widely used as an effective treatment to restore renal blood flow and reduce BP in patients with severe RAS [2]. However, the long-term efficacy of stenting in controlling hypertension remains variable in different populations [3]. Our previous study showed that several important clinical variables such as diabetes, cardiac function, number of antihypertensive agents, and perioperative renal microvascular perfusion were significantly associated with BP response in 164 patients with severe RAS who underwent renal artery stenting [3-4]. However, beyond the direct cardiovascular impact of renal artery stenosis and its treatment, increasing evidence suggests that psychological factors such as anxiety and depression may play a significant role in influencing blood pressure response after surgery [5-6].

Anxiety and depression are common in patients with cardiovascular disease and have been associated with worse clinical outcomes, including poor adherence to antihypertensive medications, increased activation of the sympathetic nervous system, and increased cardiovascular morbidity [7-

9]. Furthermore, the psychological stress caused by chronic diseases, particularly those affecting the renal and cardiovascular systems, may further exacerbate anxiety and depressive symptoms, thus creating a bidirectional relationship between psychological well-being and cardiovascular health [10-11]. In this context, patients with persistent hypertension after stent placement may be particularly vulnerable to developing or exacerbating anxiety and depression, complicating their overall treatment [12]. Despite the recognition of these psychological influences on cardiovascular outcomes, few studies have investigated the specific association between blood pressure response and the development of anxiety and depression after renal artery stenting. Recent studies have shown that mental health management can improve overall patient outcomes by reducing the burden of uncontrolled hypertension and improving patient quality of life [13-14]. Therefore, investigating this association is essential for the holistic management of patients undergoing stenting for RAS. This study aims to investigate the association between blood pressure response and the occurrence of anxiety and depression in patients who underwent successful renal artery stenting for severe unilateral RAS.

Patients and Methods

Study design

This prospective, single-center cohort study was conducted at Beijing Hospital from October 2017 to December 2020. This study conformed to the STROBE guidelines for observational studies [15]. This study was registered in the China Clinical Trial Registration Center (ChiCTR1800016252) and approved by the Institutional Review Board (IRB) of Beijing Hospital (No. 2018BJYYEC-043-02). Written informed consent was obtained for both the procedure and data collection in all cases. The study conformed to the ethical standards of the Declaration of Helsinki and all applicable local regulations for research involving human subjects.

Study population

A total of 164 patients with unilateral severe RAS were retrospectively reviewed for inclusion in the study. All patients had successfully undergone percutaneous transluminal renal artery stenting for severe unilateral RAS. Patients were divided into two groups based on their BP response 12 months after the procedure: the BP response group (n = 98) and the BP non-response group (n = 66)[4,16].

Patients were eligible for inclusion if they met the following criteria: (1) age ≥ 18 years at the time of stent implantation; (2) diagnosis of unilateral severe renal artery stenosis, defined as stenosis of 70–99% diameter confirmed by digital subtraction angiography (DSA) or contrast-enhanced ultrasound (CEUS)[17–18]; (3) long diameter of the affected kidney >7 cm; (4) no history of anxiety or depression requiring clinical intervention prior to enrollment; (5) no successful percutaneous transluminal renal artery stenting confirmed by no residual stenosis or residual stenosis of <30% determined by immediate postoperative DSA; (6) availability of complete follow-up data, including blood pressure measurements and anxiety/depression assessments at baseline and 12 months after stent implantation.

Patients were excluded if they met any of the following conditions: (1) bilateral RAS or RAS in a single functioning kidney; (2) presence of end-stage renal disease requiring dialysis at enrollment; (3) significant psychiatric comorbidities, including schizophrenia, bipolar disorder, or other severe mental illness, as determined by medical history; (4) incomplete follow-up data or missing baseline anxiety/depression assessments; (5) perioperative complications such as renal artery perforation or embolization requiring additional procedures beyond stent implantation; (6) patients undergoing concurrent procedures for other cardiovascular diseases, such as coronary stenting or peripheral vascular interventions.

Data collection

Patient data were collected retrospectively from the electronic medical records of Beijing Hospital.

Baseline information included demographic characteristics (age, gender, current smoking, current alcohol consumption, body mass index [BMI], marital status, employment status, and education level), comorbidities, medication history, and laboratory data. Pre-procedure assessments included measurement of blood pressure, estimated glomerular filtration rate (eGFR), N-terminal pro-B-type natiruretic peptide (NT-proBNP), and left ventricular ejection fraction (LVEF). Psychological status was assessed at baseline and follow-up using the Self-Rating Anxiety Scale (SAS) and Self-Rating Depression Scale (SDS)[19-20]. Anxiety and depression were assessed in the hospital setting by trained staff who administered the validated scales during routine clinical visits.

Follow-up and clinical outcomes

Patients were followed for 12 months after the renal artery stenting procedure. The primary clinical outcome was the presence of anxiety or depression, as determined by the SAS and SDS scores. Anxiety was defined as a SAS score ≥50, while depression was defined as a SDS score ≥53[19-20].

Statistical analysis

Continuous variables were summarized as means ± standard deviations for normally distributed data or as medians with interquartile ranges for non-normally distributed data. Categorical variables were reported as percentages. The chi-square test was used to compare categorical variables, and for continuous variables, the independent t-test or the Mann-Whitney U-test was used, depending on the data distribution. Paired t-tests were used to compare anxiety and depression scores at baseline and post-intervention in each group.

Univariate and multivariate *logistic* regression was performed to assess the association between each individual predictor variable and the outcome variable (BP absence, anxiety, or depression). Variables with a *P*-value < 0.2 in the univariate analysis were considered potentially significant and therefore selected for inclusion in the subsequent multivariate *logistic* regression model. Multivariate logistic regression models were used to identify factors associated with blood pressure non-response and increased anxiety or depression after stent placement. Odds ratios (*OR*) and 95% confidence intervals (*CI*) were calculated.

All statistical analyses were performed using SPSS software, version 26.0 (IBM Corp., Armonk, NY). A two-sided *P*-value of less than 0.05 was considered statistically significant.

Results

Patient Selection

A total of 2145 patients with suspected RAS were initially examined by grayscale and color Doppler ultrasound. Of these, 562 patients were excluded and 1583 patients were diagnosed with RAS (luminal stenosis, 30–99%) by CEUS or CTA. After applying the inclusion and exclusion criteria, 550 patients diagnosed as severe RAS were enrolled. Among those, 386 patients were excluded for reasons. Finally, 164 patients with severe ARAS who had undergone stent implantation were included and divided into the BP response group (n = 98) and the BP non-response group (n = 66) (**Figure 1**).

Comparison of basic characteristics between groups

Table 1 implied that there were no significant differences between the BP nonresponse and response groups in terms of age, sex, BMI, marital status, employment status, education level, left ventricular ejection fraction (LVEF), and the degree of renal artery stenosis (RAS) (all *P*>0.05). However, significant differences were observed in certain variables: the nonresponse group had a higher proportion of current smokers (63.6% vs. 42.9%, *P*=0.009), more comorbidities (≥3) (66.7% vs. 40.8%, *P*=0.001), lower eGFR (50.7±15.7 vs. 56.7±13.9 mL/min/1.73 m², *P*=0.011), higher NT-proBNP levels (379.2±203.1 vs. 327.4±154.9 pg/mL, *P*=0.033) and taking ≥4 types of

antihypertensive medication (75.8% vs. 58.2%, *P*=0.021) compared to the response group.

Table 1. Comparison of the basic characteristics between groups

Characteristics	Nonresponse group (n=66)	Response group (n=98)	$t/Z/\chi^2$ value	*P* value
Age,yr	55.6±14.7	54.3±12.8	0.291	0.771
Male,n(%)	38(57.6%)	62(63.3%)	0.534	0.464
Current smoking,n(%)	42(63.6%)	42(42.9%)	6.816	0.009
Current drinking,n(%)				
BMI,kg/m^2	26.1±3.4	26.4±3.1	0.584	0.560
Marital status,n(%)			5.265	0.072
Single	4 (6.1%)	4 (4.1%)		
Married	50 (75.8%)	87 (88.8%)		
Divorced	12 (18.1%)	7 (7.1%)		
Employment status,n(%)			0.423	0.517
Employed	45 (68.2%)	62 (63.3%)		
Unemployed	21 (31.8%)	36 (36.7%)		
Education level,n(%)			1.987	0.159
< high school	35 (53.0%)	41 (41.8%)		
≥ high school	31 (47.0%)	57 (58.2%)		
Comorbidities ≥3	44(66.7%)	40(40.8%)	10.542	0.001
Lab. test				
eGFR(ml/min/1.73m^2)	50.7±15.7	56.7±13.9	2.572	0.011
NT-proBNP(pg/mL)	379.2±203.1	327.4±154.9	1.951	0.033
LVEF,%	47.3(38.4,58.6)	49.7(43.7,55.2)	0.625	0.533
Degree of RAS,%	81.4±11.9	80.8±10.2	0.345	0.731
Antihypertensive medications type ≥4	50 (75.8%)	57 (58.2%)	5.384	0.021

BMI, body mass index; eGFR, estimated glomerular filtration rate; NT-proBNP, N-terminal pro-B-type natriuretic peptide; LVEF, left ventricular ejection fraction; RAS, renal artery stenosis

Comparison of mental health between groups

Table 2 indicated that at admission, there were no significant differences between the BP nonresponse and response groups in terms of SAS and SDS scores or the proportion of patients with clinically significant anxiety (SAS ≥50) and depression (SDS ≥53) (all *P*>0.05). However, at the 12-month follow-up, the BP nonresponse group exhibited significantly higher SAS scores (48.1 ± 10.5 vs. 43.2 ± 8.7, *P*=0.001) and SDS scores (47.4 ± 9.3 vs. 43.1 ± 8.4, *P*=0.002) **(Figure 2)**, with a greater proportion of patients experiencing clinically significant anxiety (28.8% vs. 15.3%, *P*=0.037) and depression (31.8% vs. 18.4%, *P*=0.047) compared to the response group **(Figure 3)**.

Table 2. Comparison of the mental status between groups

Characteristics	Nonresponse group (n=66)	Response group (n=98)	t/χ^2 value	*P* value
SAS score				
At admission	46.8 ± 7.1	45.6 ± 7.3	-0.732	0.465
12-month follow-up	48.1 ± 10.5	43.2 ± 8.7	3.408	0.001
SDS score				
At admission	48.9 ± 7.2	47.5 ± 7.6	-0.831	0.407
12-month follow-up	47.4 ± 9.3	43.1 ± 8.4	3.078	0.002
SAS score ≥50				

At admission	20 (30.3%)	28 (28.6%)	0.057	0.811
12-month follow-up	19 (28.8%)	15 (15.3%)	4.362	0.037
SDS score ≥53				
At admission	23 (34.8%)	32 (32.7%)	0.085	0.770
12-month follow-up	21 (31.8%)	18 (18.4%)	3.937	0.047

SAS: Self-Rating Anxiety Scale; SDS: Self-Rating Depression Scale

Related factors for BP nonresponse

Table 3 showed that lower eGFR, higher NT-proBNP levels, higher SAS scores at 12 months and types of hypertensive medication ≥4 were significantly associated with BP nonresponse. Specifically, for each unit increase in eGFR, the odds of BP nonresponse decreased (*OR*=0.924, 95% *CI*: 0.883–0.966, *P*<0.001). Conversely, higher NT-proBNP levels were associated with increased odds of BP nonresponse (*OR*=1.309, 95% *CI*: 1.075–1.595, *P*=0.008), higher SAS scores at 12 months were linked to a higher rate of BP nonresponse (*OR*=1.102, 95% *CI*: 1.013–1.199, *P*=0.025), and taking ≥4 types of antihypertensive medication (*OR*=1.785, 95% *CI*: 1.114–2.861, *P*=0.016) were also related with an increased risk of BP nonresponse **(Figure 4A)**.

Table 3. Multivariate logistic regression analysis of factors for BP nonresponse

Variable	β	SE	χ^2	*OR*	95%*CI*	*P* value
eGFR (mL/min/1.73 m²)	-0.079	0.021	14.16	0.924	0.883–0.966	<0.001
NT-proBNP (pg/mL)	0.269	0.102	7.02	1.309	1.075–1.595	0.008
SAS Score at 12 Months	0.097	0.043	5.04	1.102	1.013–1.199	0.025
Antihypertensive medication type ≥4	0.579	0.241	2.409	1.785	1.114-2.861	0.016

SE: Standard Error; OR, odds ratio; CI: confidence interval; eGFR: estimated glomerular filtration; NT-proBNP: N-terminal pro-B-type natiruretic peptide; SAS, self-rating anxiety scale

Related factors for anxiety and depression

Table 4 demonstrated that several factors were significantly associated with anxiety. Younger age (<60 years) was associated with a decreased likelihood of anxiety (OR=0.951, 95% CI: 0.914–0.989, *P*=0.009), while being unmarried (*OR*=1.104, 95% *CI*: 1.052–1.159, p=0.031), having a lower education level (<high school) (*OR*=1.357, 95% *CI*: 1.108–1.661, *P*=0.001), having ≥3 comorbidities (*OR*=1.382, 95% *CI*: 1.119–1.707, *P*=0.001), a higher degree of renal artery stenosis (90-99% vs. 70-89%) (*OR*=2.253, 95% *CI*: 1.249–4.063, *P*=0.002), taking ≥4 types of antihypertensive medication (*OR*=1.582, 95% *CI*: 1.176–2.129, *P*<0.001), and BP nonresponse (*OR*=1.629, 95% *CI*: 1.137–2.334, *P*=0.003) were all associated with an increased risk of anxiety **(Figure 4B)**.

Table 4. Multivariate logistic regression analysis of factors for anxiety

Variable	β	SE	χ^2	*OR*	95%*CI*	*P* value
Age (<60 years)	-0.050	0.019	6.92	0.951	0.914–0.989	0.009
Marital Status (Unmarried)	0.099	0.046	4.63	1.104	1.052–1.159	0.031
Education Level (< High School)	0.305	0.094	10.52	1.357	1.108–1.661	0.001
Comorbidities ≥3	0.324	0.096	11.40	1.382	1.119–1.707	0.001
Degree of RAS (90-99% vs 70-89%)	0.812	0.256	10.07	2.253	1.249–4.063	0.002

Antihypertensive medication type ≥4	0.459	0.131	12.32	1.582	1.176–2.129	<0.001
BP Nonresponse	0.488	0.162	9.07	1.629	1.137–2.334	0.003

Table 5 revealed that several factors were significantly associated with depression. Female gender was associated with an increased likelihood of depression (*OR*=1.163, 95% *CI*: 1.038–1.303, *P*=0.010). Being unmarried (*OR*=1.140, 95% *CI*: 1.068–1.217, *P*<0.001), having a lower education level (<high school) (*OR*=1.205, 95% *CI*: 1.061–1.368, *P*=0.009), having ≥3 comorbidities (*OR*=1.674, 95% *CI*: 1.139–2.459, *P*<0.001), a higher degree of renal artery stenosis (90-99% vs. 70-89%) (*OR*=2.075, 95% *CI*: 1.182–3.642, *P*=0.003), taking ≥4 types of antihypertensive medication (*OR*=1.782, 95% *CI*: 1.135–2.799, *P*<0.001), and BP nonresponse (*OR*=1.316, 95% *CI*: 1.105–1.568, *P*=0.008) were all associated with an increased likelihood of depression **(Figure 4C)**.

Table 5. Multivariate logistic regression analysis of factors for depression

Variable	β	SE	χ^2	*OR*	95%*CI*	*P* value
Female	0.151	0.059	6.55	1.163	1.038–1.303	0.010
Marital Status (Unmarried)	0.131	0.035	14.02	1.140	1.068–1.217	<0.001
Education Level (< High School)	0.186	0.072	6.68	1.205	1.061–1.368	0.009
Comorbidities ≥3	0.515	0.116	19.72	1.674	1.139–2.459	<0.001
Degree of RAS (90-99% vs 70-89%)	0.730	0.243	9.02	2.075	1.182–3.642	0.003
Antihypertensive medication type ≥4	0.577	0.147	15.40	1.782	1.135–2.799	<0.001
BP Nonresponse	0.275	0.104	7.01	1.316	1.105–1.568	0.008

Discussion

This study investigated the factors associated with BP nonresponse, anxiety, and depression in patients with severe RAS undergoing stent implantation. The results showed that decreased eGFR, increased NT-proBNP, and higher SAS scores were significant predictors of BP nonresponse at 12-month follow-up. Furthermore, anxiety and depression were highly prevalent in patients with BP nonresponse, with several clinical and demographic factors, including comorbidities, marital status, education level, and RAS severity, contributing significantly to these psychological outcomes. The results highlight the interplay between cardiovascular and mental health in patients undergoing renal artery stenting. Importantly, this study underscores the need for a more holistic approach to patient care that integrates both physiological and psychological aspects into the treatment of patients with RAS[21].

Several important clinical variables are associated with blood pressure response after stent placement. The association between reduced eGFR and blood pressure non-response in this study is consistent with the known role of renal function in regulating blood pressure. Impaired renal function in patients with RAS may lead to persistent hypertension due to impaired renal blood flow, reduced glomerular filtration, and increased activation of the renin-angiotensin-aldosterone system (RAAS) [22–23]. The reduced efficacy of stenting in improving blood pressure control in patients with lower eGFR may be due to irreversible renal damage that limits the ability of renal perfusion to normalize after revascularization [24–25]. Patients with advanced renal dysfunction are less likely to experience improvement in blood pressure after renal artery stenting. The results of our study are consistent with previous research [26]. A study by Kabłak-Ziembicka et al. [27] reported that lower

baseline eGFR was associated with a lower probability of achieving blood pressure control after renal artery stent implantation and developed simple, clinically applicable scores based on preprocedural clinical and renal ultrasound parameters to predict improvement in blood pressure and renal function after stent implantation. Furthermore, our study showed that NT-proBNP, a marker of cardiovascular stress, is also a significant predictor of blood pressure non-response. Previous studies have not consistently evaluated NT-proBNP as a predictor in this population, making our results particularly novel [28]. The relationship between elevated NT-proBNP and blood pressure non-response may reflect underlying cardiovascular stress and left ventricular dysfunction in these patients [29]. In the context of RAS, elevated NT-proBNP levels could indicate subclinical heart failure or significant myocardial stress, which could contribute to the persistence of hypertension despite revascularization. This finding suggests that NT-proBNP could serve as a useful biomarker to identify patients at risk for poor blood pressure outcomes after stent implantation and provide an opportunity for early intervention.

Regarding mental health, our results are consistent with studies that have shown the influence of psychological factors on cardiovascular outcomes. In this study, anxiety was found to be an important predictor of blood pressure non-response, supporting the growing body of evidence that mental health plays a critical role in cardiovascular outcomes. Anxiety is associated with increased sympathetic nervous system activity, which may worsen hypertension and reduce the effectiveness of antihypertensive treatments [30]. Liu et al. [30] confirmed that a significant association between anxiety and hypertension was found in cross-sectional studies (OR = 1.37) and prospective studies (OR = 1.40). However, our study uniquely contributes to this field by showing that anxiety not only affects blood pressure control but is also a predictor of non-response to stent implantation. Furthermore, the observed association between higher SAS scores and BP nonresponse highlights the importance of integrating mental health into the treatment paradigm for RAS patients, which has been poorly investigated in previous studies. The bidirectional association between anxiety and hypertension is well documented, with anxiety leading to poor BP control and poor BP control in turn exacerbating anxiety [31–32]. Incorporating psychological assessments as part of pre- and post-stent care could potentially help identify patients at higher risk of BP nonresponse and provide targeted interventions aimed at improving both mental health and cardiovascular outcomes.

There is a complex interplay between physiological and psychological health in patients with severe RAS who have undergone stent implantation. The impact of comorbidities on both BP nonresponse and mental health outcomes in our study underscores the complex interplay between physiological and psychological health. Patients with multiple comorbidities (≥3) were more likely to experience both anxiety and depression and BP nonresponse, suggesting that a higher burden of chronic disease exacerbates not only physical health problems but also psychological distress. This finding is consistent with research showing that patients with multimorbidity often face greater challenges in managing chronic conditions such as hypertension, partly due to increasing complexity of care and medication regimens [33–34]. The higher risk of BP nonresponse in this subgroup may reflect the cumulative impact of multiple conditions on overall vascular health and the body's ability to adapt to revascularization. Also of note is the association between the degree of RAS and both BP nonresponse and psychological health outcomes. Patients with more severe RAS (90%–99% stenosis) were more likely to have blood pressure unresponsiveness, anxiety, and depression. The association between higher stenosis severity and poor blood pressure control likely reflects the greater hemodynamic impact of more extensive stenosis, which can result in persistent renal ischemia even after revascularization[35]. Previous studies have shown that patients with more severe stenosis are at higher risk for adverse outcomes, including worsening renal function and poor blood pressure control, due to the permanent effects of ischemic damage to the kidneys[36–37]. In terms of mental health, the association between severe RAS and increased anxiety and depression

may be related to the increased physiological stress associated with higher stenosis severity, as well as the psychological burden of living with a more serious condition[38–39]. This finding highlights the importance of assessing both the physiological severity of the disease and its psychological impact when treating patients with RAS. Another important finding of our study is the association between medication burden (≥4 medications) and both blood pressure non-response and mental health outcomes. In patients taking four or more medications,medications were more likely to have both blood pressure non-response and higher levels of anxiety and depression. This association suggests that polypharmacy may contribute to poorer outcomes, possibly due to problems with medication adherence, side effects, or drug-drug interactions [40-41]. In particular, the psychological burden of managing multiple medications may increase anxiety and depression as patients struggle to manage complex treatment regimens. Furthermore, patients on more complex medication regimens are often those with more severe or refractory hypertension, which may contribute to an increased risk of blood pressure non-response [42]. These findings highlight the need for careful management of polypharmacy in patients with RAS, as well as the potential benefit of integrating mental health support into their care.

Our findings have important clinical implications for the management of patients undergoing renal artery stenting. First, the identification of predictors of blood pressure non-response, such as reduced eGFR, increased NT-proBNP, and anxiety, suggests that a more tailored approach to patient selection and post-procedure monitoring may be beneficial [43]. Furthermore, the association between multiple comorbidities and both blood pressure non-responsiveness and mental health outcomes suggests that patients with a higher burden of chronic disease may require more comprehensive treatment strategies that address both their physical and psychological needs. Regarding mental health, our findings suggest that depression and anxiety are common in patients undergoing renal artery stenting, particularly in those whose blood pressure is non-responsive, and that these psychological factors may significantly impact patient outcomes [44]. Given the known association between mental health and cardiovascular outcomes, it is crucial that mental health is considered a key component of care for patients with RAS. In particular, interventions to reduce anxiety and depression, such as cognitive behavioral therapy, stress management techniques or pharmacological treatments, could help improve blood pressure control and the patient's overall well-being[45].

Limitations

Our study has several limitations that should be considered. First, the single center, small sample-size of the study may limit the generalizability of the results to other populations. The patient population at our center may differ in important ways from that at other institutions, particularly with regard to demographic characteristics, comorbidities, and access to healthcare resources. In addition, while we included a number of clinical and psychological variables in our analyses, there may be other factors that we did not consider that could influence blood pressure nonresponse and mental health outcomes. For example, factors such as socioeconomic status, lifestyle behaviors, and social support were not included in our analyses but could play an important role in shaping patient outcomes. Future research should aim to include these additional variables to provide a more comprehensive understanding of the factors that influence blood pressure nonresponse and mental health in patients with RAS.

Conclusion

In this study, our results demonstrate that anxiety and depression were common in patients with BP nonresponse and were strongly influenced by several demographic and clinical factors, including the presence of multiple comorbidities, marital status, educational level, and RAS severity. These findings highlight the importance of a holistic approach to patient care that considers both

physiological and psychological factors when treating patients with RAS. Integrating mental health assessments and interventions into standard care for these patients may result in better BP control and improved overall outcomes.

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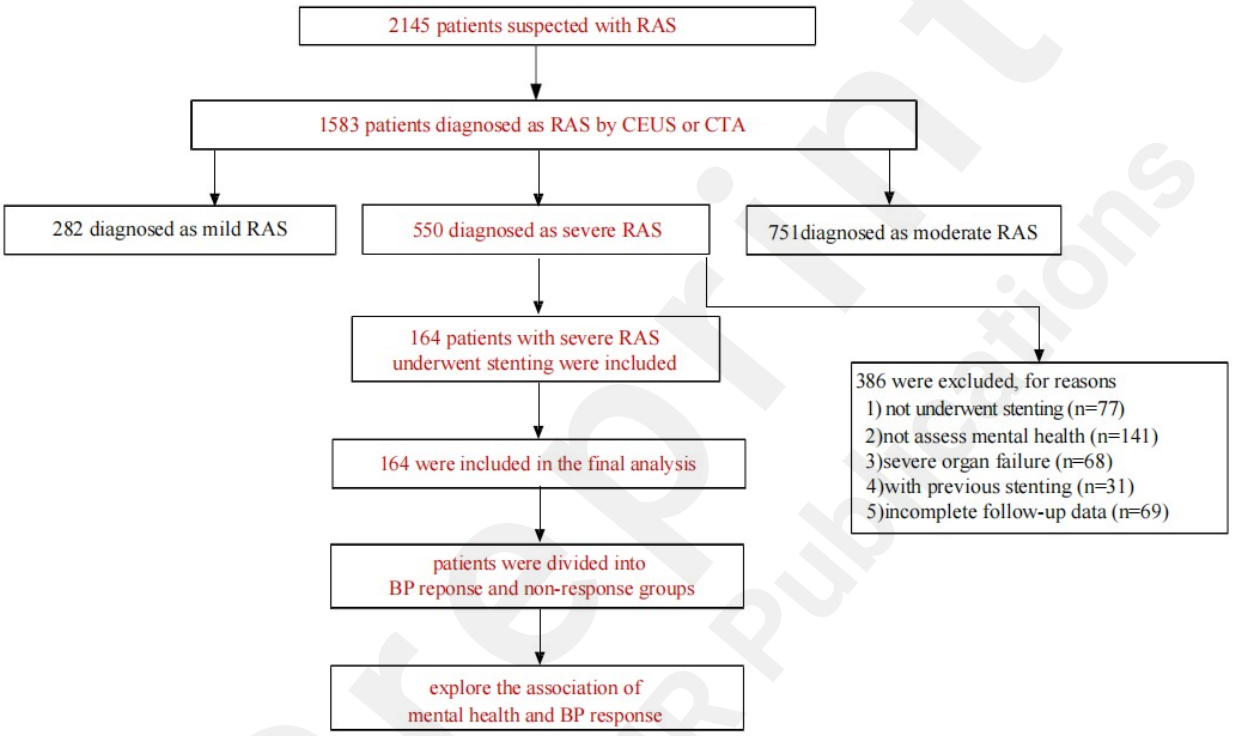

Figure 1. Flow chart

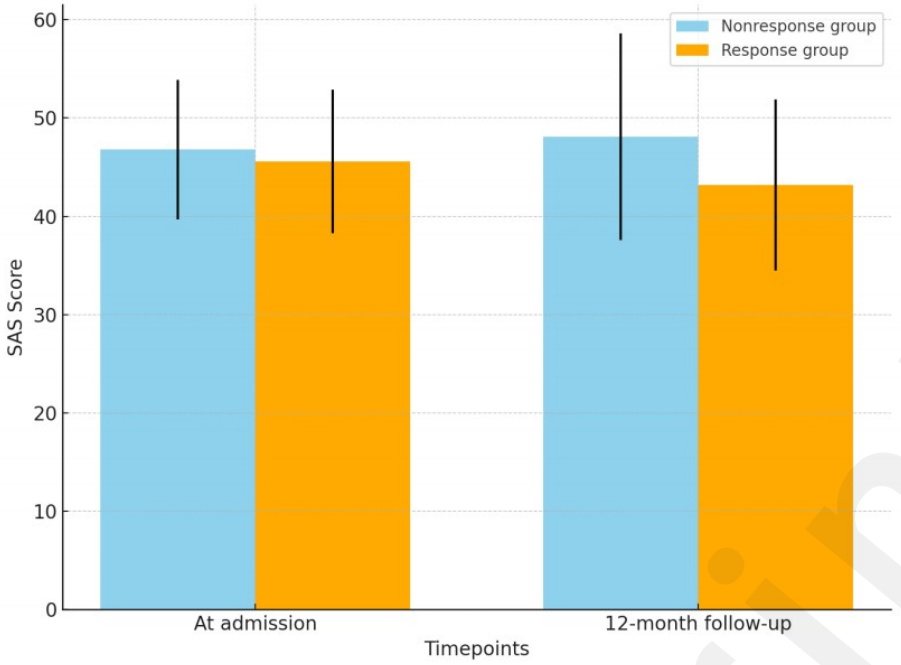

Figure 2a

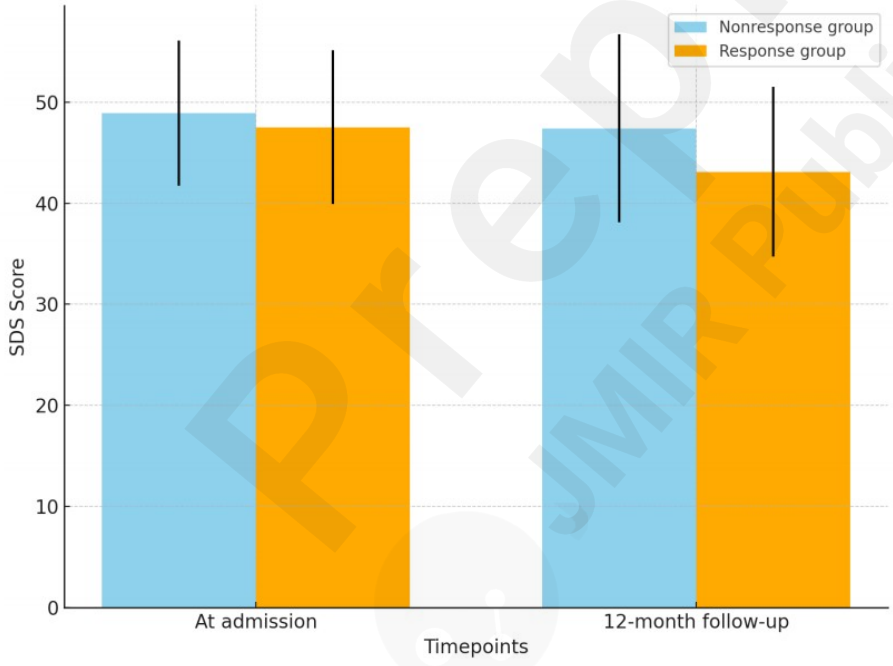

Figure 2b

Figure 2. Levels of mental health between groups
Figure 2A: SAS score; Figure 2B: SDS score

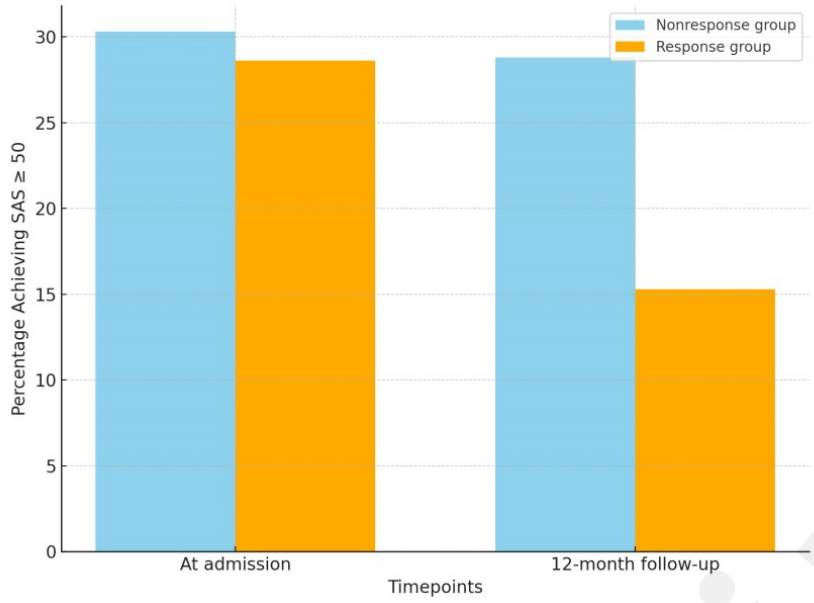

Figure 3a

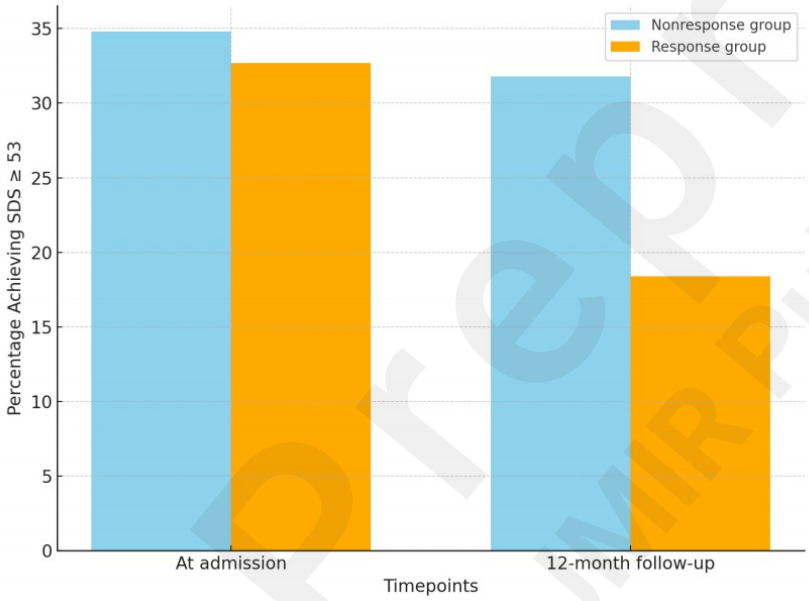

Figure 3b

Figure 3. Percentage of anxiety/depression between groups
Figure 3A: anxiety; Figure 3B: depression

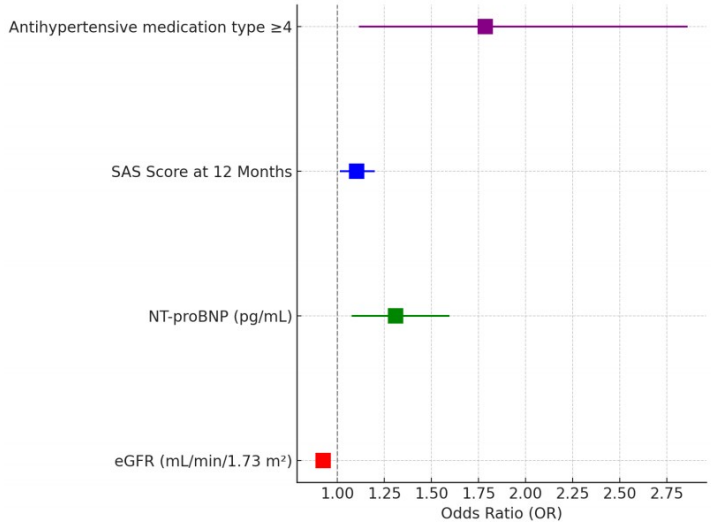

Figure 4a

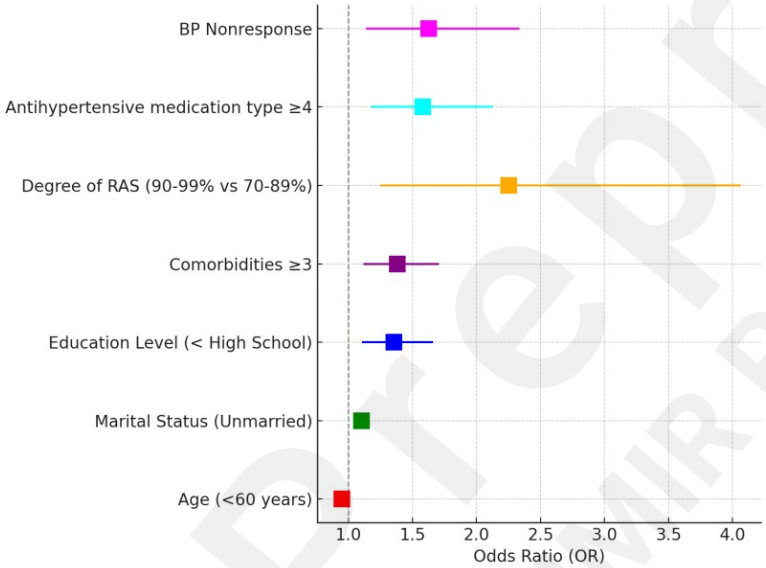

Figure 4b

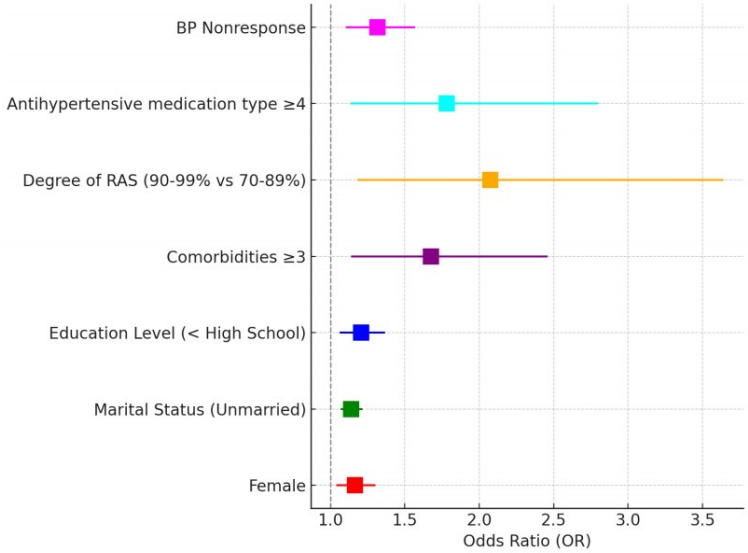

Figure 4c

Figure 4. Risk factor for BP nonresponse and mental health
Figure 4A: risk factor for BP nonresponse; Figure 4B: risk factor for anxiety; Figure 4C: risk factor for depression

Supplementary Files