

ORIGINAL ARTICLE

Simple clinical scores to predict blood pressure and renal function response to renal artery stenting for atherosclerotic renal artery stenosis

Anna Kablak-Ziembicka¹, Agnieszka Rosławiecka¹, Rafał Badacz¹, Andrzej Sokołowski², Daniel Rzeźnik¹, Mariusz Trystuła³, Piotr Musiałek⁴, Tadeusz Przewłocki^{1,4}

¹ Department of Interventional Cardiology, Institute of Cardiology, Jagiellonian University Medical College, The John Paul II Hospital, Kraków, Poland

² Department of Statistics, Cracow University of Economics, Kraków, Poland

³ Department of Vascular and Endovascular Surgery, The John Paul II Hospital, Kraków, Poland

⁴ Department of Cardiac and Vascular Diseases, Institute of Cardiology, Jagiellonian University Medical College, The John Paul II Hospital, Kraków, Poland

KEY WORDS

atherosclerotic renal artery stenosis, blood pressure and renal function improvement, prediction models, responders

ABSTRACT

INTRODUCTION There are no systematic tools to predict blood pressure (BP) or renal function (RF) improvement after stent-assisted percutaneous transluminal angioplasty (PTA) for atherosclerotic renal artery stenosis (ARAS).

OBJECTIVES This study aimed to develop simple, clinically applicable scores based on preprocedural clinical and renal ultrasonography parameters in order to predict BP and RF improvement following ARAS-PTA.

PATIENTS AND METHODS A total of 202 patients who underwent ARAS-PTA were categorized as RF responders (eGFR increase ≥ 11 ml/min/1.73 m²) or BP responders (systolic and diastolic BP decrease ≥ 20 mm Hg and ≥ 5 mm Hg, respectively) at 12 months following ARAS-PTA. The variables associated with the RF or BP response in univariable analysis were included in a multivariable logistic regression model. Point-based response scales were developed proportionally to odds ratios in each of the 2 models to embrace the maximum score of 10.

RESULTS The BP response to ARAS-PTA was 93.3% in the high-probability category (6–10 points), 66.7% in the medium-probability category (3–5 points), and 25.3% in the low-probability category (0–2 points), with the preprocedural variables of systolic BP ≥ 145 mm Hg (3 points), diastolic BP ≥ 83 mm Hg (4 points), PTA of a single functioning kidney (2 points), and bilateral PTA (1 point). The RF response was 77.3% in the high-probability category (8–10 points), 33% in the medium-probability category (4–7 points), and 10.9% in the low-probability category (0–3 points) for serum creatinine levels > 122 μ mol/l and eGFR > 30 ml/min/1.73 m² (3 points), index kidney length > 98 mm (3 points), renal artery end-diastolic velocity > 1.1 m/s (2 points), and arterial resistive index < 0.74 (2 points).

CONCLUSIONS Models of favorable BP and RF response may improve patient selection for ARAS-PTA. Further insights are expected from prospective validation.

INTRODUCTION Atherosclerotic renal artery stenosis (ARAS) is a relatively frequent disease, especially in older patients or those with either coronary or extracoronary athero-occlusive disease.^{1–3} Some patients benefit from ARAS revascularization, but the intervention (stent-assisted percutaneous transluminal angioplasty [PTA]) is

not routinely recommended.^{4–6} The results of randomized controlled trials of ARAS revascularization have been largely neutral in terms of blood pressure (BP) and/or renal function (RF) improvement, as compared with best medical therapy (BMT).^{4,7,8} Clinical series focused on BP and RF outcomes in selected patients have reported

Correspondence to:

Anna Kablak-Ziembicka, MD, PhD,
Department of Interventional
Cardiology, Institute of Cardiology,
Jagiellonian University Medical
College, The John Paul II Hospital,
ul. Piłsudskiego 80, 31-202 Kraków,
Poland, phone: +48 12 614 27 66,
email: kablakziembicka@op.pl

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WHAT'S NEW?

Current guidelines on atherosclerotic renal artery stenosis (ARAS) revascularization (stent-assisted percutaneous transluminal angioplasty [PTA]) offer little aid in clinical decision making. No baseline clinical, parameter-based scores for the assessment of the response to treatment have been established yet. Based on a detailed evaluation of a large ARAS-PTA patient cohort, we developed clinical scores to predict blood pressure and renal function response following ARAS revascularization. These simple scores may serve as useful tools to guide clinicians in patient selection for ARAS-PTA.

improved BP control in up to 65% of patients and RF improvement in approximately 30% to 40% of patients.^{4,9,10}

Identifying responders to the treatment—prior to ARAS-PTA—poses the major problem.¹¹ There are no clinical scores or decision making trees that would guide clinicians on patient selection either for BMT or PTA plus BMT. In consequence, guidelines addressing patient selection for ARAS-PTA are vague and leave clinicians without clear guidance.¹²

The issue is of clinical importance, as improvement in BP and RF translates into reduced risk of cardiovascular events.^{4,6,13-15} We noted that an increase in the estimated glomerular filtration rate (eGFR) by at least 11 ml/min/1.73 m² as well as systolic and diastolic BP decrease by 20 mm Hg and 5 mm Hg or greater, respectively, following PTA for ARAS, are related to cardiovascular death or stroke risk reduction over 5 years.¹⁶

Therefore, the aim of the present study was to develop clinically applicable scores incorporating routine preprocedural parameters to predict BP and RF response following PTA for ARAS.

PATIENTS AND METHODS **Study population** From January 2003 to December 2018, 202 patients with ARAS (60% to 99% lumen diameter stenosis on quantitative angiography) underwent PTA for ARAS provided that they had presented with accelerated or refractory hypertension on at least 3 antihypertensive drugs and/or RF impairment. Exclusion criteria were nonatherosclerotic renal artery stenosis, nondiagnostic renal ultrasonography, and lack of informed consent to participate in the study.

All patients provided informed consent before enrollment in accordance with the requirements of the local ethics committee (KBET/392/B/2003). The study was performed in line with the principles of the Declaration of Helsinki.

Blood pressure and renal function evaluation Data were collected on patient admission to the department, prior to any intervention, immediately after signed informed consent was obtained from the patients.

Blood pressure was measured according to the guidelines published by the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure

(the seventh report).¹⁷ Hypertension was defined as systolic and/or diastolic BP ≥ 140 mm Hg and ≥ 90 mm Hg, respectively. Blood pressure evaluation was based on an average of 2 BP measurements performed in a patient in a sitting position, within 5-minute intervals during separate outpatient office visits that followed optimization of pharmacotherapy.

Fasting blood samples, including serum creatinine, were taken upon admission. Renal function assessment including serum creatinine levels and eGFR was performed prior to PTA. The value of eGFR was estimated from the Modification of Diet in Renal Disease (MDRD) formula, according to the following equation: $\text{MDRD} = 175 \times \text{creatinine} [\text{mg/dl}]^{-1.154} \times \text{age} [\text{years}]^{-0.203} \times 0.742$ [if female].

Assessment of renal flow parameters and the kidneys on Doppler ultrasonography

Doppler ultrasonography was performed in a supine and/or left or right lateral position, depending on which renal artery was assessed. The examination was performed by 2 operators, using a high-resolution ultrasonograph (TOSHIBA APLIO [Canon Medical Systems GmbH, Neuss, Germany] with a 3.5–5-MHz probe). The assessment included the following parameters: systolic velocity in the aorta, peak systolic and end-diastolic velocity (EDV) in the index renal artery, the renal-aortic ratio, the resistive index (RI) in the renal artery, the intrarenal RI, acceleration time, and the pole-to-pole kidney length of the index and contralateral kidneys.

Renal artery stenting The PTA procedure was described in detail elsewhere.¹⁶ In brief, PTA was performed according to the standard protocol. All patients received dual antiplatelet therapy before the procedure, which was continued for 3 months after PTA, and then, single antiplatelet therapy was continued indefinitely. The choice of stent type and route of vascular access was left at the operator's discretion. A distal embolic protection device was used during a single procedure.

Follow-up examinations Follow-up including the evaluation of clinical symptoms, BP, and RF was conducted before discharge and at 6 and 12 months following PTA. The protocol for BP measurement and RF evaluation was the same as that used before PTA.

The study patients were categorized as responders or nonresponders in 2 categories: responders versus nonresponders in terms of BP or eGFR. Cutoff values for responders were defined as a systolic and diastolic BP reduction of at least 20 mm Hg and 5 mm Hg or greater, respectively, or an eGFR increase greater than 11 ml/min/1.73 m² and adopted from the previously published study on the reduction of cardiovascular death, myocardial infarction, or stroke risk following PTA for ARAS.¹⁶ Nonresponders were defined as patients showing no improvement in systolic or diastolic BP or eGFR.

Statistical analysis Continuous variables were presented as mean (SD), and categorical variables were expressed as numbers and percentages. Differences between mean values were verified using the *t* test and the analysis of variance, and categorical variables were compared using the χ^2 test for independence, as appropriate. The normal distribution of the analyzed variables was determined by the Shapiro–Wilk test.

Construction of models for the prediction of blood pressure and renal function improvement after percutaneous transluminal angioplasty Step 1: BP and RF outcomes were analyzed as a dichotomous variable (responder versus nonresponder).

The potential independent prognostic markers of BP and RF response during the follow-up period were established based on clinical, Doppler ultrasonography, and angiographic variables by univariable analysis (TABLE 1).

Step 2: receiver operating characteristic analysis was performed to determine optimal cutoff values (the common point of the most distant $y = x$ line with the receiver operating characteristic curve) for continuous variables established as potentially associated with RF and BP response based on univariable analysis.

Step 3: after identifying preprocedural parameters and their cutoffs associated with favorable BP and RF outcomes following PTA, multivariable logistic backward regression analysis was used to calculate adjusted odds ratios (ORs) and 95% CIs for improvement in each of the 2 outcomes (BP or RF responder).

Points were assigned according to the regression coefficients of each independent variable in each of the 2 models to embrace the maximum score of 10 and proportionally to the OR values.

Step 4: score interpretation. The score was regarded as indicative of a low probability of favorable BP or RF response, if less than 30% of patients with this score presented with BP or RF improvement.

The score was considered as showing a medium probability of favorable BP or RF response, if 31% to 70% of patients with this score exhibited BP or RF improvement.

The score was regarded as indicative of a high probability of favorable BP or RF response, if more than 70% of patients with this score showed BP or RF improvement. These rules determined point limits in total scores, so they can be used for prediction purposes.

Statistical analyses were performed using the Statistica 13.0 software (StatSoft Polska, Kraków, Poland). A *P* value less than 0.05 was considered significant, unless otherwise stated.

RESULTS The detailed characteristics of the study patients and index lesions are shown in TABLE 2. Percutaneous transluminal angioplasty was performed for unilateral RAS in 137 patients (67.8%), bilateral RAS in 35 (17.3%), and RAS of a single functioning kidney in 30 (14.9%).

Following PTA, mean (SD) systolic and diastolic BP compared with the baseline values was 134.3 (17.8) mm Hg versus 150 (25) mm Hg ($P < 0.001$) and 75.5 (10.8) mm Hg vs 83 (13) mm Hg ($P < 0.001$), respectively. A systolic BP decrease of 20 mm Hg or greater and a diastolic BP decrease of 5 mm Hg or greater were observed in 122 patients (60.4%).

Furthermore, a significant increase in the mean (SD) eGFR compared with the baseline values, ie, 56 (23.4) mm Hg versus 52.3 (21.6) mm Hg ($P = 0.003$), was observed at 12-month follow-up. An eGFR increase greater than 11 ml/min/1.73 m² was noted in 56 patients (27.7%).

Univariable logistic regression analysis indicated several parameters that may have impact on the probability of BP and RF response (TABLE 1).

The model of favorable blood pressure response

A positive BP response, defined as systolic and diastolic BP decrease of at least 20 mm Hg and 5 mm Hg respectively, was associated with the following preprocedural parameters in univariable analysis: systolic BP ≥ 145 mm Hg (area under the curve [AUC], 0.792; $P < 0.001$), diastolic BP ≥ 83 mm Hg (AUC, 0.837; $P < 0.001$), PTA of a single functioning kidney (OR, 1.25; $P = 0.009$), and PTA for bilateral ARAS (OR, 1.13; $P = 0.05$), whereas a negative response was related to contralateral kidney length ≥ 122 mm (AUC, 0.398; $P = 0.007$).

Multivariable analysis identified 4 independent predictors of BP response: 1) baseline systolic BP ≥ 145 mm Hg (OR, 5.42; 95% CI, 2.64–11.1; $P < 0.001$); 2) baseline diastolic BP ≥ 83 mm Hg (OR, 6.63; 95% CI, 3.07–14.3; $P < 0.001$); 3) PTA of a single functioning kidney (OR, 3.09; 95% CI, 0.92–10.4; $P = 0.066$); and 4) PTA for bilateral ARAS (OR, 2.56; 95% CI, 1.2–5.49; $P = 0.015$).

The BP response score comprised 4 preprocedural variables (points): systolic BP ≥ 145 mm Hg (3 points) and diastolic BP ≥ 83 mm Hg (4 points), PTA of a single functioning kidney (2 points), and bilateral PTA (1 point).

The prevalence of responders was 93.3% (70 of 75 patients) in the high-probability category (≥ 6 points), 66.7% (32 of 48 patients) in the medium-probability category (3–5 points), and 25.3% (20 of 79 patients) in the low-probability category (0–2 points).

The model of favorable renal function response

A positive RF response, defined as an eGFR increase of at least 11 ml/min/1.73 m², was associated with the following preprocedural parameters in univariable analysis: serum creatinine level ≥ 122 μ mol/l (AUC, 0.601; $P = 0.016$), index kidney length > 98 mm (AUC, 0.609; $P = 0.007$), EDV > 1.1 m/s in the index renal artery (AUC, 0.61; $P = 0.009$), and index artery RI < 0.74 (AUC, 0.678; $P < 0.001$), whereas a negative response was associated with eGFR < 30 ml/min/1.73 m² (AUC, 0.43; $P = 0.09$).

TABLE 1 Univariable logistic regression analysis for blood pressure and renal function at 12 months following angioplasty for renal artery stenosis in treatment responders and nonresponders

Variable	SBP and DBP decrease of 20 mm Hg and 5 mm Hg or greater, respectively		eGFR increase of 11 ml/min/1.73 m ² or greater	
	OR (95% CI)	P value	OR (95% CI)	P value
Age (per 1 year)	0.92 (0.81–1.05)	0.21	1.14 (0.99–1.31)	0.07
Female sex	1.05 (0.92–1.19)	0.48	1.07 (0.93–1.23)	0.32
More than 3 blood-lowering drugs	1.08 (0.95–1.23)	0.89	0.7 (0.56–0.87)	0.001
Diabetes	1.02 (0.89–1.18)	0.75	1.07 (0.94–1.22)	0.31
Hyperlipidemia	1.06 (0.92–1.22)	0.41	0.97 (0.86–1.11)	0.7
Smoking status	1.01 (0.88–1.16)	0.91	1.12 (0.98–1.29)	0.11
BMI (per 1 kg/m ²)	0.88 (0.75–1.03)	0.1	1.04 (0.88–1.23)	0.67
Previous MI	1.12 (0.99–1.27)	0.07	1.18 (1.03–1.36)	0.017
Previous stroke	1 (0.86–1.15)	0.94	1.04 (0.91–1.2)	0.56
Prior flash pulmonary edema	0.94 (0.82–1.08)	0.37	1.02 (0.88–1.17)	0.82
Prior hypertensive crisis	1.06 (0.92–1.22)	0.43	1.03 (0.9–1.19)	0.66
LVEF <45%	1.03 (0.9–1.17)	0.68	0.99 (0.86–1.13)	0.87
Internal carotid artery stenosis	1.14 (1.01–1.3)	0.04	1 (0.87–1.16)	0.96
CAD	1.08 (0.95–1.23)	0.21	0.96 (0.84–1.11)	0.59
Lower extremity occlusive disease	1 (0.87–1.15)	0.66	1 (0.87–1.15)	0.98
Baseline SBP ≥145 mm Hg	1.53 (1.36–1.71)	<0.001	0.96 (0.85–1.1)	0.59
Baseline DBP ≥83 mm Hg	1.7 (1.52–1.89)	<0.001	1.04 (0.92–1.19)	0.54
Baseline creatinine >122 µmol/l	1.1 (0.97–1.25)	0.13	1.17 (1.03–1.32)	0.019
Baseline eGFR <30 ml/min/1.73 m ²	1.18 (0.94–1.34)	0.48	0.51 (0.32–0.83)	0.007
Angiographic and procedural data				
Bilateral vs unilateral PTA	1.13 (1–1.28)	0.05	1.1 (0.95–1.26)	0.19
PTA of a single functioning kidney	1.25 (1.09–1.44)	0.009	1.06 (0.93–1.22)	0.39
Degree of RAS (per 1%)	1.08 (0.95–1.23)	0.24	0.96 (0.84–1.09)	0.52
Stent diameter (per 1 mm)	1.17 (1.03–1.33)	0.015	1.23 (1.08–1.4)	0.002
Stent length (per 1 mm)	0.79 (0.61–1.1)	0.58	1.01 (0.89–1.15)	0.84
Predilation	0.9 (0.79–1.02)	0.1	0.94 (0.83–1.07)	0.38
Doppler ultrasonography parameters				
Peak systolic velocity in index RAS (per 0.1 m/s)	0.94 (0.83–1.07)	0.35	0.82 (0.61–1.1)	0.19
End-diastolic velocity in index RAS >1.1 m/s	0.98 (0.85–1.11)	0.72	1.23 (1.08–1.40)	0.002
Renal-aortic ratio in index RAS >5.1	1 (0.88–1.13)	0.95	1.09 (0.96–1.24)	0.2
Resistive index in index RAS <0.74	0.94 (0.83–1.07)	0.37	1.27 (1.12–1.44)	<0.001
Intrarenal resistive index in index RAS <0.7	0.95 (0.84–1.09)	0.47	1.24 (1.09–1.41)	0.001
Index kidney length >98 mm	1.02 (0.89–1.16)	0.82	1.23 (1.08–1.41)	0.002
Contralateral kidney length >122 mm	0.84 (0.74–0.95)	0.007	1.05 (0.91–1.2)	0.23

Abbreviations: BMI, body mass index; CAD, coronary artery disease; DBP, diastolic blood pressure; eGFR, estimated glomerular filtration rate; LVEF, left ventricular ejection fraction; MI, myocardial infarction; OR, odds ratio; PTA, percutaneous transluminal angioplasty; RAS, renal artery stenosis; SBP, systolic blood pressure

In multivariable logistic regression analysis, RF improvement was associated with the following findings: 1) preprocedural serum creatinine level >122 µmol/l and eGFR >30 ml/min/1.73 m² (OR, 3.71; 95% CI, 1.88–7.32; *P* <0.001); 2) index kidney length >98 mm (OR, 3.21; 95% CI, 1.63–6.32; *P* = 0.001); 3) EDV >1.1 m/s in the index renal artery (OR, 2.72; 95% CI, 1.35–5.48; *P* = 0.005); and 4) preprocedural index artery RI <0.74 (OR, 2.33; 95% CI, 1.19–4.56; *P* = 0.013).

The RF response score comprised the following variables (points): preprocedural serum creatinine

level >122 µmol/l and eGFR >30 ml/min/1.73 m² (3 points), index kidney length >98 mm (3 points), EDV in ARAS >1.1 m/s (2 points), and renal artery RI <0.74 (2 points).

The prevalence of responders was 77.3% (17 of 22 patients) in the high-probability category (≥8 points), 33% (29 of 88 patients) in the medium-probability category (4–7 points), and 10.9% (10 of 92 patients) in the low-probability category (0–3 points).

DISCUSSION The key finding of this study is the development of simple preprocedural,

TABLE 2 Baseline characteristics of 202 study participants with atherosclerotic renal artery stenosis based on clinical, renal Doppler ultrasonography, and angiographic data

Parameter	Value
Men, n (%)	111 (54.9)
Age, y, median (IQR)	67 (60–74)
Blood pressure–lowering drugs, n, median (IQR)	3 (3–4)
Patients taking ≥ 4 blood pressure–lowering drugs	115 (57)
Hypertension	202 (100)
Hypercholesterolemia	194 (96)
Diabetes	68 (33.7)
Current smoking status	96 (47.5)
BMI, kg/m ² , mean (SD)	27.5 (6.1)
Prior IS	22 (10.9)
Prior MI	33 (16.3)
LVEF $\leq 45\%$	17 (8.4)
Prior flash pulmonary edema	11 (5.4)
Prior hypertension crisis	95 (47)
Coexistent atherosclerotic lesions $> 50\%$	
CAD	139 (68.8)
Internal carotid artery disease	77 (38.1)
Peripheral athero-occlusive disease	69 (34.1)
Baseline blood pressure and renal function parameters	
SBP, mm Hg, median (IQR)	145 (134–164)
DBP, mm Hg, median (IQR)	80 (74–90)
Serum creatinine, $\mu\text{mol/l}$, median (IQR)	114 (94–155)
eGFR, ml/min/1.73 m ² , median (IQR)	48.6 (35.7–67.6)
eGFR > 30 ml/min/1.73 m ²	168 (83.2)
Angiographic and procedural parameters	
Degree of renal artery lumen stenosis, %, mean (SD)	74 (14)
PTA of unilateral RAS	137 (67.8)
PTA of bilateral RAS	35 (17.3)
PTA of a single functioning kidney	30 (14.9)
Stent implantation	202 (100)
Stent diameter, mm, mean (SD)	5.74 (0.95)
Stent length, mm, mean (SD)	16.3 (4.2)
Ultrasonographic parameters	
Aortic systolic velocity, m/s, mean (SD)	0.86 (0.19)
Peak systolic velocity in the index renal artery, m/s, mean (SD)	3.9 (1.23)
End-diastolic velocity in the index renal artery, m/s, mean (SD)	1 (0.46)
Renal-aortic ratio for index renal artery, mean (SD)	4.73 (1.75)
Resistive index in the index renal artery, mean (SD)	0.74 (0.06)
Intrarenal resistive index in the index kidney, mean (SD)	0.64 (0.09)
Acceleration time in the index kidney, ms, mean (SD)	122 (45)
Index kidney length, mm, mean (SD)	99.4 (11.7)
Contralateral kidney length, mm, mean (SD)	102.4 (16.9)

Data are presented as number (percentage) of patients unless otherwise indicated.

Abbreviations: IS, ischemic stroke; others, see [TABLE 1](#)

parameter-based scores of the favorable BP and RF response to ARAS revascularization in patients who meet both the angiographic and duplex ultrasound criteria of stenosis severity exceeding 60% lumen reduction.

We propose 2 simple prediction scores, separately for BP and RF improvement ([TABLE 3](#)), which are based on preprocedural systolic and diastolic BP values that remain increased regardless of maximized blood pressure–lowering medication, preprocedural serum creatinine levels and eGFR, as well as ARAS parameters on renal ultrasonography.

There has been an increasing understanding of the fact that ARAS-PTA is an option neither for (nearly) “all” patients with ARAS (like in the inclusion criteria of randomized studies) nor for “none” of these patients (like, seemingly, in the outcomes of these randomized studies), but the field lacks clinically applicable tools for the prediction of a favorable clinical response.^{15,18-20}

The scores developed in this study are clinically relevant, as they are based on simple parameters ([TABLE 3](#)), which are routinely examined in everyday clinical practice for the evaluation of patients with ARAS, and our thresholds for responses labeled as favorable have been shown to be associated with a reduced risk of cardiovascular events and cardiovascular death.^{16,21,22} As previously reported, lowering systolic BP by 20 mm Hg was associated with a significantly lower risk of death from stroke (hazard ratio, 0.36–0.67) and ischemic heart disease (hazard ratio, 0.49–0.67), whereas diastolic BP levels within the reference range (70–79 mm Hg) confer the lowest risk of major vascular events and ischemic stroke.^{22,23}

The new scores ([TABLE 3](#)) are now open to prospective validation in larger patient cohorts, which may lead to some modifications.

Of note, the prevalence of resistant hypertension is independently associated with coronary artery disease, cardiovascular death, and RF impairment.²⁴ Renovascular disease has a relevant deleterious effect on BP and RF control and it affects long-term cardiovascular prognosis.^{15,18}

The role of baseline systolic BP or mean BP in response prediction has been addressed by other investigators using research tools different from those applied in this study.²⁵⁻²⁷ In general, the higher the systolic BP, the greater BP improvement after renal intervention. However, the predictive accuracy of such a simplified approach reaches approximately 50%.^{11,19,28} Adopting another approach, Modrall et al²⁷ have recently identified the following independent predictors of a positive BP response: requirement for 4 or more drugs (OR, 5.9; $P < 0.001$), preprocedural diastolic BP > 90 mm Hg (OR, 13.9; $P < 0.001$), and preprocedural clonidine use (OR, 4.52; $P = 0.008$), but they have not translated those into a prediction score. Beyond the number of antihypertensive drugs (presumably in optimized doses), others have reported a role of renal parenchymal thickness, bilateral renal artery disease, brain natriuretic peptide levels, renal fractional flow reserve, translesional pressure gradient, and renal flow frame count on a dynamic angiogram.²⁹⁻³¹ Some authors have reported an improved BP response when treating lesions with resting or hyperemic

TABLE 3 Multivariable logistic regression analysis and the prediction score for the probability of favorable blood pressure or renal function response

Variable	OR (95% CI)	P value	Points assigned
Favors blood pressure response			
Preprocedural systolic BP ≥ 145 mm Hg	5.42 (2.64–11.1)	<0.001	+3
Preprocedural diastolic BP ≥ 83 mm Hg	6.63 (3.07–14.3)	<0.001	+4
PTA of a single functioning kidney	3.09 (0.92–10.4)	0.07	+2
PTA of bilateral renal artery stenosis	2.56 (1.2–5.49)	0.02	+1
Probability of positive blood pressure response	Score		Prevalence of responders, %
Low	≤ 2 points		25.3
Medium	3–5 points		66.7
High	≥ 6 points		93.3
Favors renal function response			
Preprocedural serum creatinine level $> 122 \mu\text{mol/l}$ and eGFR $> 30 \text{ ml/min/1.73 m}^2$	3.71 (1.88–7.32)	<0.001	+3
Index kidney length > 98 mm	3.21 (1.63–6.32)	0.001	+3
End-diastolic velocity $> 1.1 \text{ m/s}$ in the renal artery	2.72 (1.35–5.48)	0.005	+2
Preprocedural index artery resistive index < 0.74	2.33 (1.19–4.56)	0.01	+2
Probability of positive renal function response	Score		Prevalence of responders, %
Low	≤ 3 points		10.9
Medium	4–7 points		33
High	≥ 8 points		77.3

Abbreviations: see [TABLE 1](#)

pressure gradients exceeding 20 mm Hg,^{29,30} but the physiological assessment of ARAS using the Pd/Pa ratio (pressure ratio, across stenosis) and papaverine-induced renal fractional flow reserve did not predict BP response after PTA in a more recent study.³⁰

Our study provided new data that reconcile several prior discrepancies. Our prediction score of BP improvement following ARAS-PTA includes preprocedural systolic BP of at least 145 mm Hg or higher (3 points) and diastolic BP of 83 mm Hg or higher (4 points) in medically treated patients, ARAS revascularization of a single functioning kidney (2 points), and bilateral PTA (1 point). Patients who scored 3 points or less had a low probability of BP improvement following PTA. Importantly, those with poorly controlled elevated systolic BP and with ARAS limited to one side (in the presence of a normal contralateral renal artery) had low probability ($< 25\%$) of BP improvement following PTA. Regardless whether ARAS involved a single functioning kidney or was bilateral, ARAS-PTA was similarly ineffective in well-controlled BP. On the other end of the spectrum, patients who obtained 6 points or more in the BP response prediction score ([TABLE 3](#)) had about 93% probability of positive BP response following ARAS-PTA. Our study confirmed the greatest benefit of PTA in patients with single functioning kidney or bilateral ARAS coexistent with elevated systolic and diastolic BP (9 or 8 points), or at least elevated above the thresholds systolic and diastolic BP in patients with unilateral ARAS (7 points) ([TABLE 3](#)).

Despite a general agreement on the role of baseline RF and kidney parameters in predicting RF response,^{13,15,30,32,33} the RF response to ARAS-PTA has been even more controversial than BP response. Kalra et al¹³ reported that ARAS revascularization in chronic kidney disease stages 3–5 was independently associated with improvement in RF at 1 year. In another small study that included only patients with baseline serum creatinine levels above 1.5 mg/dl yet below 4 mg/dl and bilateral RAS or a single functioning kidney in the context of ARAS, RF improved or stabilized in all patients after PTA.⁶ Several other factors have been indicated in association with a reduced likelihood of a favorable RF response, including age above 65 years, male sex, severe atherosclerotic disease, proteinuria $> 1 \text{ g/d}$, severely impaired RF (eGFR $< 40 \text{ ml/min/1.73 m}^2$), diabetes, and the RAS degree $< 70\%$.^{29,33,34} Our data are consistent with these findings, as (having recruited patients with significant ARAS assessed by angiography, which required confirmation of renal artery flow impairment on ultrasonography) we showed that eGFR below $30 \text{ ml/min/1.73 m}^2$ reduced the likelihood of favorable RF response ([TABLE 3](#)). Our RF response prediction model included preprocedural serum creatinine level $> 122 \mu\text{mol/l}$ and eGFR $> 30 \text{ ml/min/1.73 m}^2$ (3 points), and it also indicated the crucial role of parameters assessed by preprocedural renal ultrasonography, including index kidney length > 98 mm (3 points), index EDV $> 1.1 \text{ m/s}$ (2 points), and index artery RI < 0.74 (2 points). Thus, for a favorable RF response, preprocedural RF should be significantly decreased, while kidney size

preserved, in the presence of either high EDV or preserved index renal artery RI. Of note, pre-procedural EDV >1.1 m/s is an indicator of severe ARAS, while RI, of renal and intrarenal arterial stiffness.³²

Limitations Our findings were based on a retrospective, single-center study. As the approach to patients with ARAS referred for PTA is subject to change over time, the proposed prediction scores should be further validated in a prospective manner, preferably in a multicenter clinical study setting.

Conclusions In conclusion, as PTA for ARAS should be performed in patients who are likely to benefit in terms of a reduced risk of cardiovascular events (cardiac ischemia, stroke, and death), the proposed predictive models, although they require further validation, may advise clinicians on patient selection for PTA.

ARTICLE INFORMATION

CONFLICT OF INTEREST None declared.

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