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Systematic Review

Emerging approaches in secondary hypertension due to renal artery stenosis: evaluation and treatment - systematic review

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ABSTRACT

Hypertension, a global health concern, affects a staggering 1.28 billion people worldwide, as stated by the World Health Organization (WHO) however renal artery stenosis (RAS), a common cause of secondary hypertension, is characterized by the narrowing of renal arteries, leading to physiological changes such as arterial stiffening and elevated blood pressure. The major causes of RAS include atherosclerosis and fibromuscular dysplasia. Diagnosis involves clinical suspicion and imaging studies such as Doppler ultrasonography and angiography. Treatment strategies encompass lifestyle modifications, pharmacotherapy, interventional procedures like angioplasty with stenting, and emerging options such as renal denervation and gene therapy. Our aim is to provide a comprehensive examination of the pathophysiology, prevalence, risk factors, causes, diagnosis, and treatment modalities through a systematic search gathering qualitative and quantitative data. We address the challenges in diagnosis and treatment, emphasizing the need for tailored approaches considering patient-specific factors. We will review emerging approaches in evaluating and treating secondary hypertension due to RAS.

Keywords: Secondary hypertension, Renal artery stenosis, Treatment

INTRODUCTION

Hypertension, or high blood pressure, is a prevalent condition affecting millions worldwide. While primary or essential hypertension develops over time and has no identifiable cause, while secondary hypertension is caused by identifiable causes such as renal artery stenosis (RAS). RAS narrows down one or both renal arteries and ends up leading to secondary hypertension. Recent reports suggest that RAS could cause hypertension in 1% to 10% of the estimated 50 million people in the United States.[1]

RAS is caused by plaque building, atherosclerosis, or fibromuscular dysplasia, and these conditions reduce renal blood flow while increasing blood pressure as the body attempts to compensate. Causes of RAS include atherosclerosis, most frequently in men over 45 and often associated with the proximal sections of the renal arteries. Fibromuscular dysplasia mostly affects women under 50 and involves the middle and distal parts of the renal arteries. Risk factors for atherosclerosis include dyslipidemia, viral infections, cigarette smoking, immune injury, and elevated homocysteine levels. Less common risk factors are thromboembolic disease, arterial dissection, and vasculitis. Diagnosing renal artery stenosis (RAS) involves clinical suspicion and specific tests. Physicians' suspicion for RAS arises from severe, difficult-to-treat hypertension, especially if it appears suddenly to the patients or he/she lacks a family history. Further tests

to confirm RAS include checking kidney function and using imaging like duplex Doppler ultrasonography, computed tomography angiography (CTA), magnetic resonance angiography (MRA), and renal arteriography.

To treat RAS, physicians aim to restore blood flow to the kidneys and manage hypertension. They control symptoms with medications like angiotensin converting enzyme (ACE) inhibitors (despite their potential to exacerbate renal function in RAS patients) to more direct interventions such as angioplasty with or without stenting, and in severe cases, maybe surgery is prescribed. The choice of treatment is influenced by the underlying cause of RAS, its severity, and the patient's overall health status.[1] Importantly, the field of hypertension management is constantly evolving, with emerging options such as renal denervation and gene therapy showing promising results. These advancements in treatment offer hope and optimism for the future of managing secondary hypertension due to RAS, underscoring the potential for improved patient outcomes.

METHODS

Our search strategy was meticulous, and we selected electronic databases such as PubMed/MEDLINE, Scopus, Embase, and Web of Science. We employed a comprehensive set of keywords including: secondary hypertension, renal artery stenosis, evaluation, treatment, pathophysiology, prevalence, risk factors, causes, diagnosis, and management. To ensure the accuracy of our results, we used Boolean operators (AND, OR) to combine search terms appropriately. Our main MesH term was: ('Hypertension' AND 'Renal Artery Stenosis') AND ('Pathophysiology' OR 'Diagnosis' OR 'Treatment'). This rigorous approach allowed us to gather the most relevant and up-to-date information for our review.

Inclusion criteria and exclusion criteria

This review includes studies discussing the pathophysiology, prevalence, risk factors, causes, diagnosis, and treatment of secondary hypertension due to renal artery stenosis. This paper also includes primary research studies to get qualitative data from randomized controlled trials, cohort studies, case-control studies, systematic reviews, and meta-analyses. We also selected papers that provide insights into emerging treatments or advancements in managing renal artery stenosis-induced hypertension. No restrictions were applied based on the age or gender of study participants.

In exclusion, we discarded studies not focused on secondary hypertension due to renal artery stenosis. We excluded review articles lacking original data, editorials, letters, conference abstracts, grey literature, or unpublished paper were excluded. This paper only includes studies published in English or sufficient data to extract relevant information.

Data extraction, synthesis, and analysis

Four independent reviewers screen titles and abstracts of retrieved articles to identify potentially eligible studies. Full texts of potentially relevant articles were retrieved and assessed for eligibility strictly following inclusion and exclusion criteria and relevant studies. Data from included studies was extracted using a standardized form. We extracted data about study characteristics (author, year, study design), participants, the aim of the paper, methodology, limitations, outcomes assessed, key findings relevant, and reason for choosing the study and developed PRISMA flow diagram of all the process.

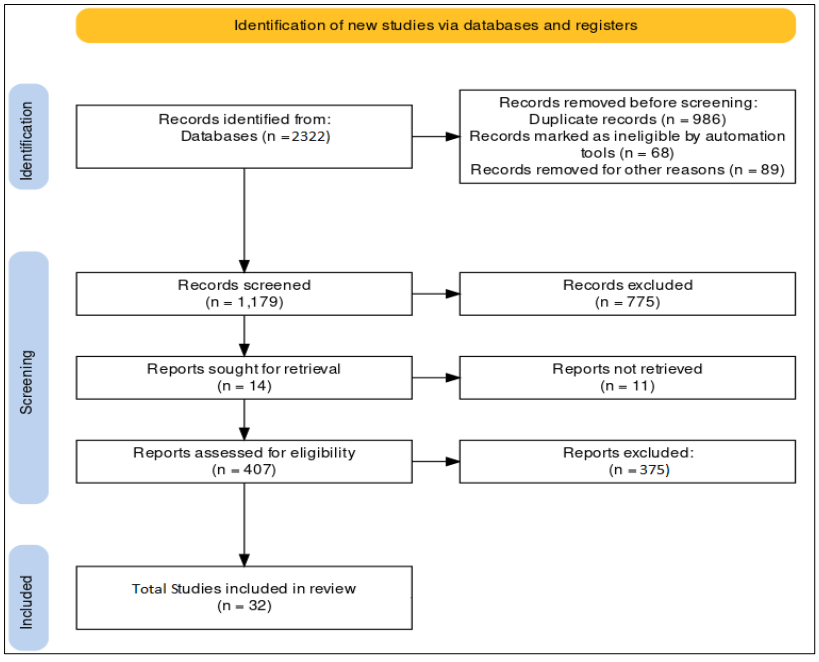

Figure 1: PRISMA flow diagram.

This PRISMA flow diagram outlines the systematic review process, detailing the identification, screening, and inclusion of studies. Initially, 2,322 citations were identified through citation searching. After removing 986 duplicates and records ineligible by automation tools, 1,179 records were screened, excluding 775 records. Following screening, reports were sought for retrieval, with 14 identified and 11 not retrieved. Four hundred-seven reports were assessed for eligibility, including 32 total studies in the review. No new studies were identified via databases, registers, websites, or organizations.

RESULTS

Previous evidences for management of hypertension secondary to renal artery stenosis

In Balk study, a comprehensive review was conducted on the effectiveness and safety of percutaneous transluminal renal angioplasty and stenting (PTRAS) compared to medical therapy and surgical revascularization for atherosclerotic renal artery stenosis (ARAS). They included 78 studies and 20 case reports encompassing various study designs such as RCTs, nonrandomized comparative studies, and cohorts. The review aimed to identify predictors of outcomes associated with different interventions. The findings indicated that there were no significant differences in mortality, renal replacement therapy, cardiovascular events, or blood pressure control between PTRAS and medical therapy in most RCTs. However, PTRAS showed potential in improving kidney function, and adverse events related to PTRAS were rare. Subset analysis suggested that certain patients, particularly those with acute decompensation, might benefit from revascularization. However, the study highlighted limitations such as the limited applicability of RCTs to specific patient groups and inadequate adjustment in nonrandomized trials. Additionally, there was a general lack of reporting on medication-related adverse events. Mohan and Bourke's study, which involved participants from the CORAL study, aimed to compare optimal medical therapy (OMT) alone versus OMT with renal artery angioplasty in hypertensive patients with renal artery stenosis. This multicenter randomized trial, involving 947 hypertensive individuals with renal dysfunction and diagnosed RAS, found that both treatment groups experienced a reduction in systolic blood pressure (SBP). However, there were no significant differences observed in glomerular filtration rate (GFR) and creatinine (Cr) levels between the two groups. Overall, OMT plus angioplasty did not demonstrate superior clinical outcomes compared to OMT alone. Limitations of the study included exclusion criteria such as recent major medical events and specific kidney characteristics. HERCULES trial aimed to assess the efficacy of the RX Herculink elite renal stent system in treating ARAS or uncontrolled hypertension (HTN). This prospective multicenter study enrolled 202 patients and found a significant reduction in blood pressure in patients with severe HTN, not experienced with optimal medical therapy alone. However, there was a lack of correlation between systolic blood pressure reduction and baseline brain natriuretic peptide (BNP) levels. Limitations included exclusion criteria such as impaired left ventricular ejection fraction, myocardial infarction, and stroke. The ASTRAL trial, conducted in 2009 with 806 participants, aimed to determine the optimal treatment approach for ARAS candidates, comparing optimal medical therapy alone versus revascularization plus optimal medical therapy. The trial concluded that revascularization did not provide clinical benefits in ARAS patients, as it did not significantly lower risks related to kidney function, renal/cardiovascular outcomes, mortality, or blood pressure changes. Courand study assessed the benefits of renal angioplasty on daytime ambulatory blood pressure (ABP) in patients with true resistant hypertension and atherosclerotic renal artery stenosis. This retrospective uncontrolled single-center study found that angioplasty significantly decreased daytime ABP and reduced the need for antihypertensive treatment without changing the estimated glomerular filtration rate. Predictors of systolic ABP changes included high baseline systolic ABP and a low body mass index.[3,4]

Table 1: Summary and findings.

Citation	Participants/no. of studies included	Purpose	Method design and limitations	Findings and summary	Applicability to our research
Balk et al[2]	Seventy-eight studies and 20 case reports, including 9 RCTs, 11 nonrandomized comparative studies, 67 cohorts of PTRAS, 20 cohorts of medical therapy alone, and 4 cohorts of surgery.	To compare the effectiveness and safety of PTRAS versus medical therapy and surgical revascularization in treating ARAS. Identify predictors of outcomes by intervention.	Review of studies up to March 16, 2016, including RCTs, nonrandomized comparative studies, cohorts, and case reports on ARAS management strategies. Limitations include limited applicability of	No significant differences in mortality, RRT, cardiovascular events, or BP control between PTRAS and medical therapy were found in most RCTs. Kidney function may improve with PTRAS. Adverse events related to PTRAS were rare. Evidence suggests that subsets of patients benefit from	This study's findings support the exploration of patient-specific factors and conditions that may indicate the benefit of revascularization over medical

Continued.

Citation	Participants/no. of studies included	Purpose	Method design and limitations	Findings and summary	Applicability to our research
			RCTs to certain patient groups, inadequate adjustment in nonrandomized trials, and a general lack of reporting on medication-related adverse events.	revascularization, particularly those with acute decompensation.	therapy alone in managing secondary Hypertension due to renal artery stenosis.
Mohan and Bourke (2015).[3]	The CORAL study involved 947 patients. Participants were hypertensive individuals who were already on antihypertensive Medication (s), had renal dysfunction and had renal artery stenosis (RAS) detected by angiography, Duplex, CTA, or MRA.	The study aimed to determine whether optimal medical therapy (OMT) alone or OMT with renal artery angioplasty would lead to improved renal function and different clinical outcomes in hypertensive patients with renal artery stenosis.	Conducted as a multicenter randomized trial, the study had limitations, including exclusion criteria such as recent major medical events and specific kidney characteristics.	Both treatment groups showed a reduction in systolic blood pressure (SBP), but no significant differences were observed in glomerular filtration rate (GFR) and creatinine (Cr) levels. Overall, OMT plus angioplasty did not demonstrate superior clinical outcomes compared to OMT alone.	These insights are valuable for guiding treatment decisions in hypertensive patients with renal artery stenosis and renal dysfunction.
HERCULES[3]	The HERCULES trial enrolled 202 patients with either significant atherosclerotic renal artery stenosis (ARAS) or uncontrolled Hypertension (HTN) despite maximal antihypertensive thera	It aimed to assess the efficacy of the RX Herculink Elite Renal Stent System in treating ARAS or uncontrolled HTN.	The trial was a prospective multicenter study conducted between August 2007 and September 2009. Exclusion criteria included patients with specific medical conditions such as impaired left ventricular ejection fraction, myocardial infarction, and stroke.	The trial assessed primary and secondary endpoints, including the 9-month binary restenosis rate, all-cause mortality, kidney damage, changes in renal function, and blood pressure reduction. Notably, patients with severe HTN demonstrated a significant reduction in blood pressure not experienced with optimal medical therapy (OMT). However, there was a lack of correlation between systolic blood pressure reduction and baseline brain natriuretic peptide (BNP) levels.	These findings offer insights into the efficacy of renal artery stenting in patients with ARAS or uncontrolled HTN, particularly those with severe hypertension.
ASTRAL[3]	The ASTRAL trial enrolled 806 candidates with confirmed atherosclerotic renal artery stenosis (ARAS) >50% who were uncertain	Conducted in 2009, it aimed to determine the optimal treatment approach for ARAS candidates, comparing optimal medical therapy (OMT)	Exclusion criteria included candidates eligible for surgical revascularizatio n, those likely to require revascularizatio	The major endpoint of glomerular filtration rate (GFR) was assessed over time using the mean reciprocal slope of serum creatinine. Secondary endpoints included changes in blood pressure (BP), time to	These findings contribute to understanding the effectiveness of revascularization versus OMT alone in ARAS patients, guiding treatment

Continued.

Citation	Participants/no. of studies included	Purpose	Method design and limitations	Findings and summary	Applicability to our research
	candidates for revascularization.	alone versus revascularization plus OMT.	n within six months, and those with nonatheromatous cardiovascular disease or prior renal artery stenting.	major renal and cardiovascular events, and mortality. The trial concluded that revascularization did not provide clinical benefits in ARAS patients, as it did not significantly lower risks related to kidney function, renal/cardiovascular outcomes, mortality, or BP changes.	decisions in this population.
STAR trial[3]	The STAR trial, conducted in 2009, enrolled 140 patients with a known creatinine clearance <80 mL/min, ostial atherosclerotic renal artery stenosis (ARAS) per nonDuplex imaging, and stabilized blood pressure.	It aimed to compare medical therapy alone with medical therapy plus stenting in patients with impaired renal function and ARAS.	Exclusion criteria included patients with renal size <8 cm, renal artery diameter <4 mm, estimated creatinine clearance <15 mL/min, diabetes mellitus with proteinuria >3 g/day, and malignant Hypertension.	The trial protocol defined the primary endpoint as comparing medical therapy alone versus medical therapy plus stenting. Secondary endpoints included changes in renal function, blood pressure stabilization, and clinical outcomes related to renal artery stenosis.	The STAR trial's findings provide insights into the effectiveness of stenting in combination with medical therapy compared to medical therapy alone in patients with impaired renal function and ARAS.
Courand et al.[4]	Seventy-two patients with resistant Hypertension and atherosclerotic renal artery stenosis were treated by angioplasty.	To assess the benefits of renal angioplasty on daytime ambulatory blood pressure (ABP) in patients with true resistant Hypertension and atherosclerotic renal artery stenosis.	Retrospective uncontrolled single-center study from 2000 to 2016. Limitations include its retrospective nature, missing data during follow-up, and potential modifications in antihypertensive treatment needing to be standardized across the cohort.	Angioplasty significantly decreased dABP and reduced the need for antihypertensive treatment without changing the estimated glomerular filtration rate. A high baseline systolic dABP and a low body mass index were independent predictors of systolic dABP changes.	These findings highlight the potential of angioplasty in effectively managing resistant Hypertension due to renal artery stenosis, suggesting a specific subgroup of patients may benefit from this intervention regarding blood pressure control.

DISCUSSION

Evaluation of RAS secondary to hypertension

Identifying the cause of hypertension in RAS as a trigger is a complicated process that includes clinical examination, imaging methods, and building biomarkers and genetic market.[9] The beginning of the assessment would be a detailed patient profile and physical examination revealing the possibility of RAS, especially in cases where patients show sudden severe hypertension and a history of risk factors, e.g., smoking.[10] Doctors can recognize renal artery narrowing or blocking using different types of imaging techniques, such as Doppler Ultrasound, CT angiography, magnetic resonance angiography, or the gold-standard renal arteriography.[11] The assessment process is also more sophisticated, where

biological markers (biomarkers) and genetic markers (genetic markers) are considered to develop a better conceptualization.[12] The biomarkers of concern are circulating renin and aldosterone levels; these markers are not specific to RAS but can signal a possible injury to the vascular walls or dysfunction. Gene markers, which are the subject of ongoing thorough research, encompass polymorphisms in the renin-angiotensin system genes, the genes related to endothelial function, and inflammatory genes, hence providing possible insights into individual susceptibility to the development of vascular diseases and RAS.[13]

Pathophysiology

The pathophysiology of renovascular hypertension is rooted in decreased kidney perfusion and the activation of the renin-angiotensin-aldosterone system (RAAS), a concept first elucidated by Goldblatt et al in the 1930s.[14] Their research, primarily conducted on dogs, demonstrated that ischemic kidneys contribute to sustained Hypertension and proposed the involvement of a pressor substance akin to a hormone, identified as renin. Renin, secreted by the kidney's juxtaglomerular cells, responds to diminished kidney perfusion, low sodium chloride levels sensed by the macula densa, and beta-adrenergic stimulation.[15] Prolonged ischemia induces "JG recruitment", augmenting renin-expressing cells.[16] Renin acts on angiotensinogen to form angiotensin I, further converted to angiotensin II by ACE.[17] Angiotensin II induces hypertension through vasoconstriction, sympathetic nervous system activation, aldosterone secretion, sodium retention, and tissue fibrosis.[18] While atherosclerotic renal artery stenosis (ARAS) and fibromuscular dysplasia (FMD) are common triggers, any condition reducing kidney blood flow can initiate this cascade, leading to hypertension. In RAS, understanding the deep pathophysiology involves a detailed examination of how each cellular component and mechanism contributes to the condition's progression.[19]

Plaque formation physiology involve process of atherosclerosis which is a consequence of endothelial dysfunction, and the influx of lipid and immune cells into the arterial wall. Endothelial cells are turned on and start to express adhesion molecules, they become more permeable, which allows the monocytes to enter the inflamed area. The monocytes differentiate into macrophages; they load products of oxidized LDL along the way and become foam cells afterward. Injury-related smooth muscle cells transcribe into Intima and proliferate with time while producing messy extracellular matrix components, further leading to plaque formation.[21] Blood is gradually obstructed with plaque buildup in the artery, resulting in renal underperfusion and ischemia because of the decrease in flow. When there is insufficient oxygen and nutrition for the renal tissue, hypoxia-inducible factors (HIFs) are activated, making renal cells adapt accordingly. HIFs clearly express genes related to angiogenesis, erythropoiesis, and glycolysis to minimize severe hypoxic conditions. A rise in juxtaglomerular cell renin secretion is provoked during low renal perfusion. The renin gets secreted and subsequently produces angiotensin I from the angiotensin genes of the liver. The ACE changes the angiotensin I into angiotensin II. Angiotensin II works via the angiotensin II receptors binding (AT1 and AT2) as its ligand. AT1R activation results in vasal constriction of the systemic blood vessels, especially in the heart, the kidneys, and the smooth muscle, and as a result, it causes increased peripheral resistance together with the development of arterial pressure. Additionally, angiotensin II stimulates sympathetic nervous system bias, thereby accounting for the release of norepinephrine, which manifests itself as having vasoconstricting properties. Likewise, angiotensin II is also a component responsible for aldosterone secretion from the adrenal cortex. Aldosterone works on the peripheral zones and the kidney's collecting ducts to increase sodium ions' absorption and the potassium ions' flow volume. On the other hand, the fluid volume of the extracellular matrix increases accordingly, which also increases blood pressure. RAAS will continuously remain activated, and hypertension will also get settled for a long time, which would lead to pathological tissue remodelling and renal fibrosis. Angiotensin II promotes the synthesis of extracellular matrix proteins, such as collagen types I and III, by activating fibroblasts. This thickens the vascular wall, myocardium, and renal interstitium, impairing organ function.[20]

Renal artery stenosis diagnosis

The ARAS diagnostic field is a complex landscape, and the practice is an area that needs multiple imaging techniques to ensure a precise and appropriate diagnosis and management.

Table 2: Principal diagnostic modalities.

Diagnostic modality	Key advantages	Specific limitations
Doppler ultrasound (DUS)	Directly visualizes ARAS and measures blood flow velocity. High diagnostic accuracy with a peak systolic velocity (PSV) >200 cm/s indicates 95% sensitivity and 90% specificity for >50% stenosis.	Efficacy is reduced in overweight patients due to suboptimal visualization and is heavily operator-dependent.
CTA	Offers high spatial resolution, with sensitivity and specificity of 94% and 93%, respectively, for detecting >50% stenosis.	Exposure to ionizing radiation and contrast, with a noted increase in nephrotoxic risk.

Continued.

Diagnostic modality	Key advantages	Specific limitations
MRA	Non-ionizing, capable of visualizing renal arteries and providing hemodynamic data, with a sensitivity of 96% and specificity of 92% for >50% stenosis.	Risk of nephrogenic systemic fibrosis in patients with severe renal insufficiency when using gadolinium-based contrast.
Catheter angiography	Considered the gold standard, it allows precise stenosis quantification and assessment of hemodynamic significance through translesional pressure gradients.	Invasive with inherent procedure-related risks, including radiation exposure and potential for contrast-induced nephropathy.
Blood oxygen level dependent (BOLD) MRI	Accurately assesses renal tissue oxygenation levels and correlates with the severity of blood flow reduction.	Presently limited to research settings, and its clinical application is under investigation.
Dynamic contrast-enhanced MRI	Provides detailed functional information about renal perfusion and glomerular filtration rate, aiding in assessing renal parenchymal damage.	Susceptible to artifacts from respiratory motion and carries risks associated with contrast in patients with chronic kidney disease.
Intravascular ultrasound (IVUS)	Enables detailed plaque characterization and assists in optimizing stent placement with lower quality and resolution compared to optical coherence tomography.	May need to provide more detail for certain applications, like distinguishing between stent struts and thrombus.
Renal frame count	Offers a unique method to assess kidney perfusion and predict response to percutaneous transluminal renal angioplasty (PTRAS) based on contrast perfusion timing.	Risks associated with contrast use, especially in patients with pre-existing renal impairment.

Treatment approaches

The treatment of hypertension-induced RAS is a multilayered approach ranging from lifestyle modifications, pharmacotherapy, interventional, and even sometimes surgical operations.[23] The first line of treatment involves modifying lifestyle, e.g., reducing salt intake and exercising regularly. Also, losing weight and quitting smoking. These techniques are very powerful in lowering blood pressure and providing cardiovascular safety. Primarily used medications are ACE inhibitors like captopril, enalapril, and lisinopril, for example, or angiotensin II receptor blockers (ARBs), e.g., candesartan, irbesartan, losartan, valsartan for treating high blood pressure by assisting in the relaxation of blood vessels.[25,26]

Nevertheless, endovascular aortic stent-grafting procedures may have limitations in bilateral RAS or RAS in a solitary kidney because acute kidney injury is a possible side effect. Some antihypertensives, such as amlodipine and diltiazem, may be prescribed, and diuretics (hydrochlorothiazide) can be used. For RAS, the medications prescribed are beta-blockers like atenolol and metoprolol, which aim to reduce the heart rate and blood pressure. Interventional procedures such as stanging and angioplasty are the next steps.[28]

Another treatment approach, PTRA with or without stenting is a minimally invasive procedure that removes RAS.[29] This process requires placing the catheter through the groin into the narrowed part of the artery where the blockage is located. The balloon is then used to open up the obstruction. The stent may be inserted to maintain the artery's open passageway. The procedure is performed for FMD and, in some cases, aortoiliac RAS. Renal artery stenting, identical to PTRA, involves a stent in the narrowed renal artery followed by angioplasty for sustained blood flow to the kidneys.[30] A regular combination of PTRA and stenting of renal arteries is a crucial part of the cure of difficult and critical cases where sole angioplasty is insufficient.[31] The RAS therapy involves atherectomy that removes the plaque with specialized catheters applied, drug-coated balloon angioplasty preventing the restenosis, and brachytherapy embedding radioactive seeds to the artery walls.[32] Treatment selection hinges on factors such as stenosis severity, patient health, and the physician's judgment, tailoring interventions for optimal outcomes. In cases where PTRA is unsuitable or has failed, surgical revascularization may be considered. Bypass grafting can be prescribed where a vein or synthetic material is used to bypass the narrowed segment of the artery, or another procedure, endarterectomy, which removes the inner lining of the artery causing the blockage. When the case is more critical, renal artery reconstruction is sometimes performed.

Research into the new therapeutic options for RAS arising from hypertension is ongoing and includes surgical and pharmacological innovations. The National Kidney Foundation states that ACE inhibitors (ACEIs), along with ARBs, are basic medications that are used to treat hypertension patients with renal issues. These medications can inhibit and block the angiotensin-2 (AT2) receptor, which means lowering blood pressure and kidney functions are protected. They are mainly used to manage hypertension, chronic kidney disease (CKD), glomerular diseases, albuminuria, and cardiovascular diseases (CVD). ACE inhibitors and ARBs have relative strength in reducing kidney damage and mitigating cardiovascular

risks. These medications may cause secondary side effects, including low blood pressure, dry cough, hyperkalemia, pregnancy termination, and acute kidney injury (AKI), when they are used together with other drugs or conditions. The critical factors for the right use and safety of ACE inhibitors and angiotensin receptor blockers (ACE/ARBs) are regular monitoring and communication with healthcare providers.

This innovation renal denervation or RDN (a procedure used to treat resistant hypertension by targeting the renal nerves) as stated by Marcusohrn et al offers a new frontier in hypertension management, with its ability to interfere with the renal nerve signals and lower blood pressure being a unique feature of this procedure. Technology has shown increased efficacy in decreasing RDN-induced systolic blood pressure by 4-6 mm Hg; it is more effective than traditional drugs. RDN is generally considered safe, and overcoming severe problems is seldom seen. Patients eligible for the trial are patients who are in tight control of hypertension with their optimal medication and shared decision-making. Along with the approvals and acceptance of RDN by the relevant regulatory bodies, its role in treating hypertension patients who are not responding to medication, intolerant to drugs, or unwilling to follow strict treatment plans can also become pivotal in managing this condition. Gene therapy is one area of medicine that focuses on manipulating the genetic pathways that directly contribute to the formation of RAS and hypertension. It is becoming promising research field, yet it remains unexplored.[8]

CONCLUSION

Secondary hypertension that is induced by renal artery stenosis is still a persistent challenge for physicians when it comes to diagnosis and management. While advancements in imaging techniques and treatment modalities offer promising avenues, individualized approaches are still needed according to patient-specific factors. Lifestyle modifications, pharmacotherapy, and interventional procedures like angioplasty with stenting continue to play pivotal roles in managing RAS-induced hypertension. Emerging treatments such as renal denervation and gene therapy hold potential but there are significant complications and gap that need to be bridged, so we warrant further research.

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