Introduction

Pediatric hypertension is considered a strong predictor for the development of hypertension in adults and if left untreated can predispose to various cardiovascular complications.\(^1\) Despite guidelines from various societies, there is inconsistent effort to regularly measure blood pressures (BP) in children and most cases of pediatric hypertension are diagnosed incidentally.\(^2\) By definition, the presence of systolic BP more than 95\(^{th}\) percentile for that age, sex, and height is considered as pediatric hypertension.\(^3\) Up to 10% of these cases are attributed to renovascular hypertension (RVH) that is due to any lesion reducing blood flow to part or one or both kidneys, with resulting alterations in the renin–angiotensin system.\(^4\) It is important to identify children with RVH, as many diseases causing RVH can be treated by endovascular, or surgical interventions, in addition to optimal medical management. Early identification and proper management can significantly improve the child’s long-term outcome.\(^3\)

Etiology

The most common etiology of RVH in developed countries is fibromuscular dysplasia (FMD) (\(\rightarrow\) Figs. 1A–B and 2), while in Asian and African countries, Takayasu arteritis (TA) (\(\rightarrow\) Fig. 3) is more common.\(^5\) Other uncommon causes of renal artery stenosis (RAS) in children can be either syndromic (neurofibromatosis-1 [NF-1], tuberous sclerosis, William’s syndrome, Marfan’s syndrome) or nonsyndromic (hypercoagulable states) (\(\rightarrow\) Fig. 4A and B) (\(\rightarrow\) Table 1). Most of the syndromic causes of RVH have bilateral RAS with concomitant involvement of other visceral arteries. Previous studies have shown that 24 to 78% of patients with RVH may have bilateral RAS.\(^5,6\) Focal stenosis of renal arteries was seen more commonly than diffuse or multifocal involvement. Stenotic lesions have been reported throughout the renovascular tree in the main renal arteries in 25% of patients, in second-order branches in 50% of patients, in 12.5% of patients in more distal “parenchymal”
branches, and in accessory renal arteries, respectively (►Fig. 5).6,7 In middle aortic syndrome (MAS), a syndromic cause of RVH, segmental narrowing of the abdominal, or distal descending thoracic aorta is seen, which usually involves the renal arteries in 60% of patients and other visceral branches, like intestinal, iliac, carotid, cerebral, and brachial arteries.3,5,6,8,9 MAS can be either congenital or acquired. In the congenital form, there is faulty development of the abdominal aorta around day 25, due to improper fusion of the two embryonic dorsal aortas to form a single vessel.3 The acquired forms of MAS are associated with inflammatory conditions of the aorta such as TA and NF-1.6,7

**Imaging in Pediatric Renovascular Hypertension**

No single screening imaging modality can accurately diagnose all children with RAS. All noninvasive imaging modalities have been used for diagnosing RAS in children, with digital subtraction angiography being considered the gold standard for diagnosis. ►Table 2 provides a summary of all the imaging modalities available for the evaluation of RVH.10–14

**Management**

Various treatment options for RVH include medical management, endovascular management, and surgery. The primary goal of all treatment modalities is to control hypertension, preserve renal function, and restore renal perfusion.15 The primary treatment modality is decided by a multidisciplinary approach including pediatric nephrologists, pediatric radiologists and interventional radiologists, and pediatric surgeons.

**Medical Management**

Initial management of children with raised BP is done with antihypertensives. The choice of the antihypertensives is based on the etiology. Angiotensin–converting enzyme inhibitors or angiotensin receptor blockers are preferably avoided in children with bilateral RAS.16 In addition, 24-hour
ambulatory BP monitoring is helpful to provide information about BP control.

Continuation of medical therapy is done in children, who are still being evaluated for RAS or those unfit to undergo procedures like angioplasty or surgical intervention; however, these children often require multiple antihypertensives of different classes for optimal BP control. Almost one in every two children who undergoes an interventional or surgical procedure requires medical treatment in the postoperative period. Careful monitoring of the child’s adherence and evaluation for side effects of drugs is also essential. In children with MAS and RAS, previous studies have shown that delay in intervention till puberty has a better outcome.

Angioplasty
Arterial stenosis in children with RVH is due to local intimal hyperplasia. Percutaneous balloon angioplasty is the most used technique for RAS in children, especially in children with lesions involving smaller lengths of renal arteries (Figs. 6 and 7). It is usually performed under general anesthesia using femoral or brachial artery access. The balloon diameter used for angioplasty varies with age and vessel size. Renal artery diameter, proximal to the stenosed segment, is used to guide the sizing of the angioplasty.
balloon, as poststenotic segment is often dilated. In unilateral disease, however, the normal contralateral artery diameter can also be used to guide the balloon size. The use of high-pressure balloons and drug-eluting balloons to supplement conventional angioplasty is uncommon in children. Children, who have an inadequate response to angioplasty, are more prone to develop worsening hypertension within a few months of the procedure. These children might require secondary procedures for control of their BP. Children may also show delayed clinical response after angioplasty. This is thought to be related to spasm resulting in a false impression of residual stenosis on postplasty angiograms or due to an increase in luminal diameter over time during healing by retraction of fibrous bands. Restenosis following angioplasty is seen in as high as 41% of cases and requires repeat angioplasty. Time to restenosis has been shown in different studies to range from as low as 2 weeks to 60 months. In the long term, the success for angioplasty for FMD in children is less than that reported for adults, while the ostial stenosis secondary to NF-1 has better treatment outcomes. Other reasons for a lower response in children may be higher rates of multiple stenoses, especially those with MAS who present with widespread disease, including bilateral RAS and intrarenal involvement. In such cases, in

<table>
<thead>
<tr>
<th>Modality</th>
<th>Diagnostic findings</th>
<th>Sensitivity and specificity (values mostly from adult studies)</th>
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<tbody>
<tr>
<td>Ultrasound</td>
<td>Parvus-et-tardus waveform, PSV &gt; 180 or 200 cm/s, AT &gt; 80 milliseconds, Renal artery aorta ratio &gt; 3, Difference in RI &gt; 0.05, Difference in kidney length ≥ 1 cm</td>
<td>73–85% and 71–92%</td>
</tr>
<tr>
<td>CEUS</td>
<td>Identification of perfusion defects useful for documenting postangioplasty increased perfusion</td>
<td>Not routinely used for diagnosis</td>
</tr>
<tr>
<td>MRA</td>
<td>Narrowing in main or the accessory renal artery, Presence of collateral vessels, For evaluation of aorta and other nonvascular causes of hypertension</td>
<td>64–93% and 72–97% in various studies</td>
</tr>
<tr>
<td>CTA</td>
<td>Similar to MRA</td>
<td>64–94% and 62–97%</td>
</tr>
<tr>
<td>Renal scintigraphy (99mTc-DMSA or 99mTc-MAG3)</td>
<td>Increase in time to peak activity in renogram curve, Delayed washout</td>
<td>52–93% and 63–92%</td>
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<tr>
<td>Renal vein renin sampling</td>
<td>Renin ratio of &gt; 1.5 between main renal veins, Ratio of &lt; 1.3 between the contralateral renal vein and IVC</td>
<td>56 and 94% (usually performed in bilateral cases)</td>
</tr>
<tr>
<td>Angiography</td>
<td>Direct visualization of a stenosed segment of the renal artery and its branches</td>
<td>Considered as gold standard for diagnosis of RAS</td>
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Abbreviations: 99mTc-DMSA, 99m technetium-dimercaptosuccinic acid; 99mTc-MAG3, 99m-Tc-mercaptoacetyltriglycine; AT, acceleration time; CEUS, contrast-enhanced ultrasound; CTA, computed tomography angiography; IVC, inferior vena cava; PSV, peak systemic velocity; MRA, magnetic resonance angiography; RAAS, renin angiotensin-aldosterone system; RAR, renal artery to aortic flow velocity ratio; RI, resistive index.
the presence of significant intrarenal disease, successful treatment of main artery stenoses might still fail to improve the BP.

Cutting balloon angioplasty is used for high-grade lesions and lesions resistant to treatment with conventional and high-pressure angioplasty. It is now recommended to limit the use of cutting balloons, only for the incisional phase with balloon diameter limited to no more than normal vessel diameter after which further dilatation should be done with a conventional balloon. This recommendation was made, as many studies showed complications like dissections and aneurysms developing after the use of cutting balloons in children. Additionally, imaging modalities like intravascular ultrasound can be used that can guide the safe placement of the balloon at the desired location.

Stenting

The use of stents is generally not preferred in children, as they can act as sites of stenosis when the child grows. Even in cases refractory to conventional balloon angioplasty, repeat angioplasty is more suitable as compared with stenting. Various published studies have shown that the rate of restenosis after stenting is significantly higher (close to 35%) as compared with only angioplasty which has a restenosis rate of approximately 17%. Currently, there are only a few indications for stenting in children, which include very severe or recurrent lesions, and managing iatrogenic dissections, which show significant elastic recoil or restenosis after angioplasty.

Ethanol Embolization

Ethanol embolization can be used when segmental arterial stenosis is detected as the cause of RVH (lesions that are not amenable to angioplasty or open surgery). Super selective embolization of segmental artery is done with ethanol causing coagulative necrosis and subtended parenchymal infarction.

Aortic Interventions

Aortic angioplasty with or without stenting is required in patients with combined MAS with associated RAS. These patients often have hypertension that is refractory to medical management, despite multiple classes of antihypertensives being used. Various studies have shown that there is a significant drop in systolic BP in these patients, when compared with patients with isolated RAS with angioplasty; however, long-term outcomes are variable.  

Complications of Endovascular Management

Various studies have reported complications ranging between 0 and 43%, following endovascular procedures for RVH in children. Procedural complications include arterial spasm, dissection or aneurysm formation, delayed pseudoaneurysm formation, and iatrogenic perforation. Focal renal ischemia or infarction can develop secondary to embolic phenomenon distal to angioplasty site or due to thrombosis of segmental vessels, after prolonged guidewire placement. Local site dissection can be expected at the site of balloon dilatation due to vascular remodeling. Such dissections are seen more frequently with cutting balloon angioplasty than conventional angioplasty, and may not be hemodynamically significant. Procedure-related mortality has previously been rarely reported. If an inadvertent arterial rupture occurs, balloon reinfusion or covered stent placement may be attempted, failing which urgent surgical consultation should be obtained. Postprocedural complications include accelerated or worsening hypertension that increase the risk of stroke in children therefore, preprocedural assessment of head and neck vessels should always be performed.

Surgery

Surgery is usually reserved for children with complicated RAS (i.e., long stenotic lesions >10 mm, multiple segment stenosis of large vessels, or bilateral RAS), due to technical challenges in small children. There is a paucity of surgical data in the pediatric population. Most of the surgeries are performed, when children attain adult-sized vasculature. Bridging this gap with endovascular treatment can lead to secondary fibrotic changes, necessitating alterations in the typical surgical approach from primary renal arterial reimplantation to aortorenal bypass. Due to the established safety and success of endovascular interventions, most institutions prefer endovascular treatment for RAS.

Conclusion

RVH is an important cause of secondary hypertension in children. Lack of prospective studies due to the heterogeneity of the population being affected is an important challenge in formulation of uniform guidelines for management. A multidisciplinary approach including pediatric radiologists and interventional radiologists, pediatric nephrologists, and
pediatric surgeons is vital for optimal clinical outcome. Endovascular therapy with angioplasty is generally preferred in appropriately selected children with good clinical outcomes.

Funding
None.

Conflict of Interest
None declared.

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