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REVIEW

Childhood hypertension: what does the radiologist contribute?

Derek Roebuck

Introduction

Elevated systemic blood pressure (BP) is an increasingly important problem in paediatric public health [1]. Childhood hypertension is defined by reference to published standards for age, sex and height [2, 3]. The diagnosis can be based on three clinic BP measurements above the 95th centile, in order to minimise the phenomenon of white coat hypertension [2, 4]. Twenty-four-hour ambulatory blood pressure measurement (ABPM), which allows assessment of nocturnal BP dynamics, is a better method of assessment [5].

Hypertension may be essential (primary) or secondary to a variety of causes (Table 1). The most important risk factors for essential hypertension are obesity and a family history of high BP [4, 6–8], but there are also associations with sleep apnoea, low birth weight and prematurity. The most important cause of secondary hypertension in childhood is chronic renal disease [9].

Imaging

Diagnostic imaging may help to determine the cause of hypertension, to evaluate its complications and to direct further management. The clinical utility of imaging is, however, fairly limited.

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D. Roebuck (✉)
Radiology Department,
Great Ormond Street Hospital for Children NHS Trust,
Great Ormond Street,
London WC1N 3JH, UK
e-mail: roebud@gosh.nhs.uk

In the first decade of life, essential hypertension is relatively uncommon and is, therefore, a diagnosis of exclusion. Conversely, essential hypertension is the dominant type (about 90%) in adolescence. Clinical investigations, including blood and urine tests, may point to a renal or non-renal cause for the elevated BP. Abdominal US is performed to evaluate the kidneys, aorta and renal arteries (Figs. 1 and 2), and to look for rare causes of hypertension such as tumours (Fig. 3).

Imaging assessment of the complications of hypertension may be clinically indicated; for example, various forms of brain imaging for neurovascular complications (Fig. 4) or echocardiography for left ventricular hypertrophy (Fig. 2) [10–12]. Ultrasonography and MRI can be used in a research context to look for vascular changes associated with hypertension, such as increased arterial intima-media thickness [12, 13] and abnormal arterial distensibility [13].

The use of non-invasive imaging to evaluate renovascular disease is controversial [14]. In principle, various ultrasound, nuclear medicine, CT and MRI techniques can be used for this purpose, and each of these is briefly discussed below. In practice, however, it is unclear which patients should undergo what form of imaging. This is because it is difficult to perform good quality research in a field where there are few patients and imaging technology is rapidly evolving. There is currently no non-invasive technique that is capable of excluding renovascular disease in children, although this may well change in the next few years.

For the time being, a reasonable compromise is to try to identify groups of patients who have a high probability of renovascular disease (Table 2). These children should undergo angiography (and renal vein renin sampling if appropriate) with a view to endovascular treatment. Non-invasive imaging in children who will definitely

Table 1 Classification of hypertension in childhood

Primary (essential) hypertension		
Chronic renal disease		
Disease of the aorta and/or renal arteries	Aortic coarctation	
	Fibromuscular dysplasia	
	Neurofibromatosis type 1	
	Takayasu aorto-arteritis	
	Williams syndrome	
	Radiation vasculopathy	
	Thrombosis	Iatrogenic
		Procoagulable state
	Transplant renal artery stenosis	
Renal vein thrombosis		
Endocrine disease		
Tumours	Neuroblastoma	
	Wilms tumour	
	Phaeochromocytoma	
	Adrenal cortical tumour	
Iatrogenic	Corticosteroids	
	Cyclosporine	

require angiography has no significant benefit, and may lead to a delay in treatment. There may, however, be a role for CT angiography (CTA), MR angiography (MRA) or angiotensin-converting enzyme inhibitor (ACEi)-primed scintigraphy when the probability of renovascular disease is only moderate. It is probably best to select one technique, based on institutional preference, and to proceed to angiography if this study suggests the presence of vascular disease. Non-invasive imaging may also direct management in a few patients by identifying an indication for nephrectomy.

Ultrasound

The abdominal aorta can been seen and measured with US (Fig. 1), although the renal arteries are not reliably visualised. For this reason, various Doppler parameters have been used as indirect indicators of renal artery stenosis [14, 15]. These include peak systolic velocity (PSV), acceleration time and resistive index. PSV may be either increased or decreased distal to a stenosis of the main renal artery or one of its branches. A combination of increased acceleration time and decreased PSV, the tardus-parvus phenomenon (Fig. 2), is a good indicator of renal artery stenosis. The role of US is limited by its poor detection of stenosis of small branches or accessory or multiple renal arteries, which are not uncommon in children with renovascular disease.

Nuclear medicine

Renal scintigraphy can be performed with ^{99m}Tc-dimercaptosuccinic acid (DMSA) or ^{99m}Tc-mercaptoacetyltriglycine (MAG3), before and after the administration of an ACEi such as captopril. In theory, this is an extremely elegant idea, but in practice the results have probably not been good enough to exclude treatable renovascular disease [16]. This technique is particularly unhelpful if there is aortic or bilateral renal artery stenosis, neither of which is rare in children with hypertension. In children with suspected phaeochromocytoma, ^{123}I-metaiodobenzylguanidine (MIBG) scintigraphy may be helpful to localise the lesion and assess the extent of disease (Fig. 3).

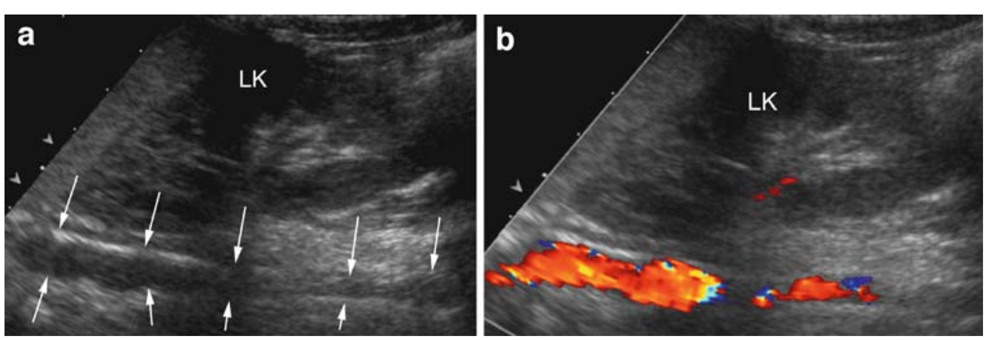


Fig. 1 A 30-month-old boy with congenital mid-aortic syndrome. Coronal **a** grey-scale and **b** colour Doppler US images show irregular stenosis of the abdominal aorta (*arrows*). This was confirmed at angiography

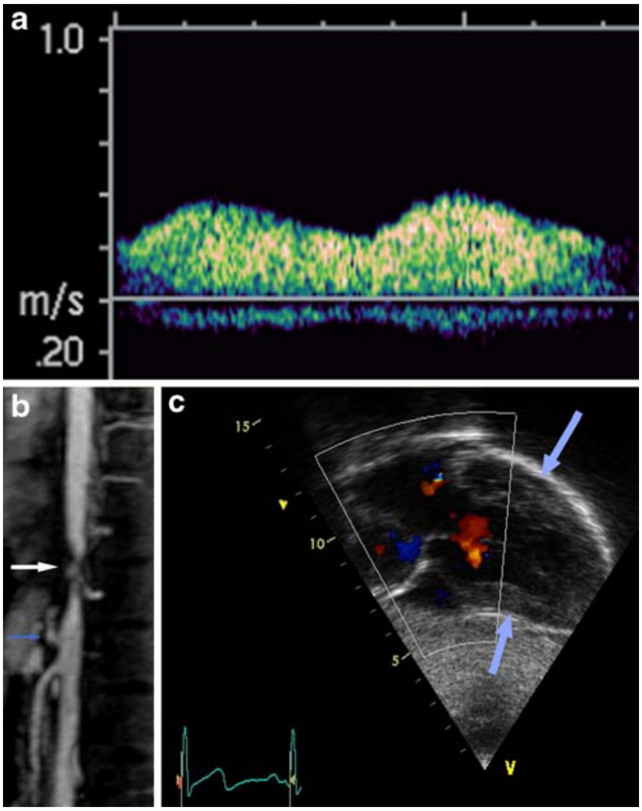


Fig. 2 A 4-year-old boy with idiopathic stenosis of the supracoeliac abdominal aorta. **a** Pulsed-wave Doppler trace from the left renal artery shows a low peak systolic velocity (about 0.4 m/s) and increased acceleration time, the so-called tardus-parvus pattern. The resistive index was 0.35. **b** Contrast MR angiography shows a stenosis of the aorta (*white arrow*) above the level of the coeliac trunk (*blue arrow*). Prominent collateral vessels are present. **c** Echocardiography (subcostal long-axis view) shows marked left ventricular hypertrophy (*arrows*). On a parasternal long axis view (not shown) the left ventricular posterior wall width in diastole was 8.0 mm, giving a *z*-score of +4.4 based on body surface area

CT angiography

CTA is clearly adequate for diagnostic evaluation of most aortic pathology (Fig. 4). Its role in the main renal arteries and their branches is currently unproven in children. Although there are still some problems (Figs. 4 and 5), recent technical developments may make this a more useful technique.

MR angiography

MRA is currently capable of accurate depiction of the aorta in children [17], but even in the main renal arteries image quality is not always adequate (Fig. 4). This may change as spatial and temporal resolution improves. It is possible that perfusion techniques [18] will permit the indirect detection of abnormalities of segmental renal arteries.

Invasive diagnosis and treatment

Although there is always some reluctance to subject children to invasive procedures, these are, without doubt, much more useful than non-invasive imaging in selected patients.

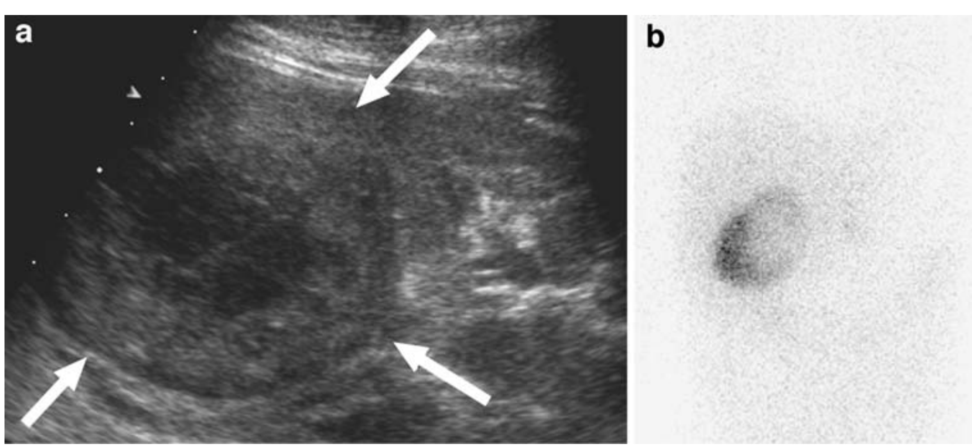
Renal vein renin sampling

Renal vein renin (RVR) sampling is usually performed at the same time as diagnostic angiography, using a femoral vein approach [19]. Shaped catheters (or coaxial micro-catheters) are used to take samples from the infrarenal inferior vena cava, the main renal veins and their intrarenal tributaries. RVR assay may then lateralise the ischaemic focus, or even localise it to a small area of one kidney [20].

Diagnostic angiography

Catheter-based digital subtraction angiography (DSA) is the most accurate technique for the evaluation of suspected renovascular disease in children. DSA can be performed with sedation or local anaesthesia alone, but in younger

Fig. 3 A 14-year-old boy with phaeochromocytoma. **a** Longitudinal US image shows a large mass with a hypoechoic central region, lying superior to the right kidney (*arrows*). **b** ^{123}I-MIBG scintigraphy (*anterior view*) shows avid uptake in the non-central parts of the mass. No metastatic disease was detected



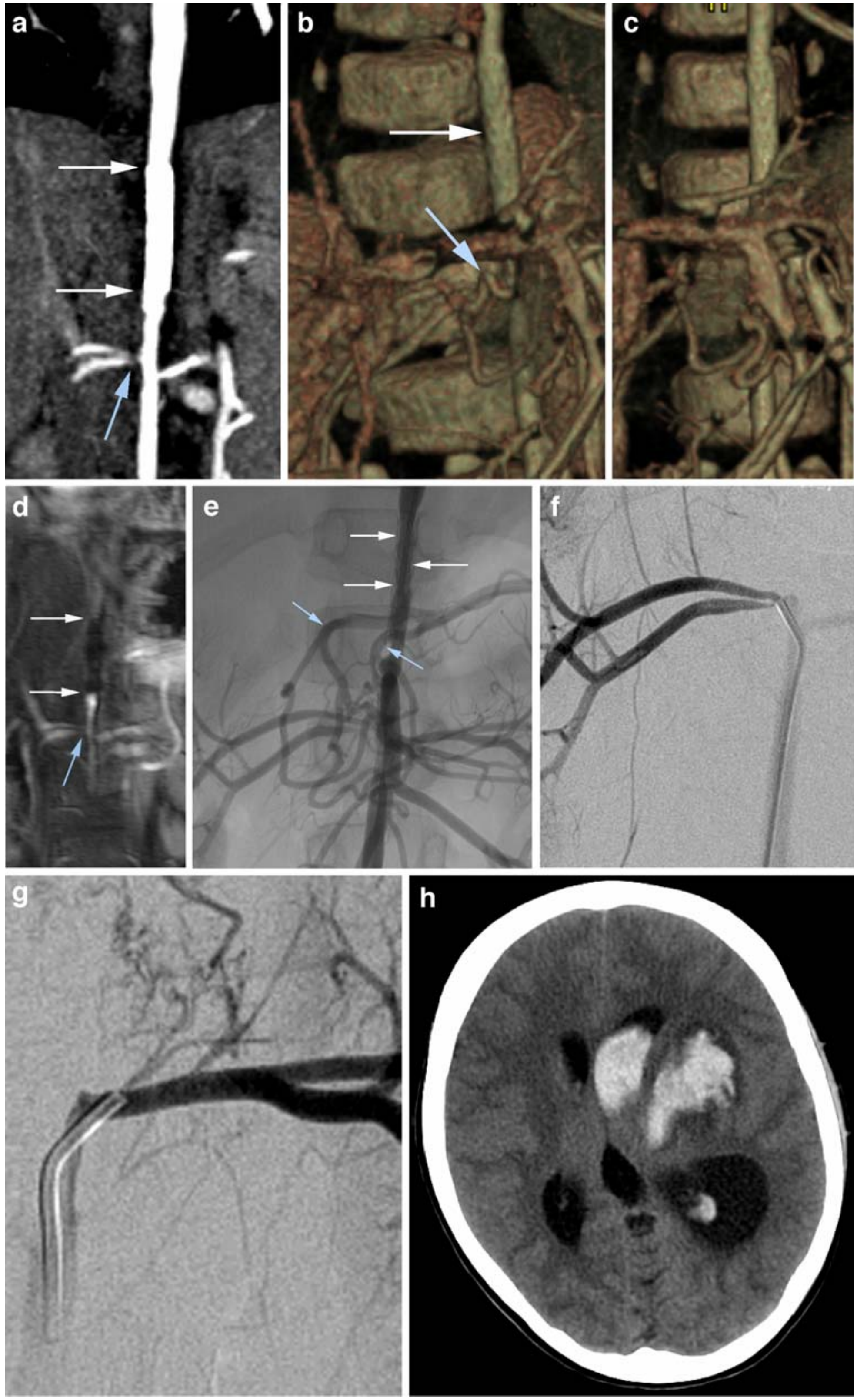


Fig. 4 A 10-year-old boy with mid-aortic syndrome due to neurofibromatosis type 1. A balloon-expandable stent had previously been implanted in the abdominal aorta. **a** 16-slice multidetector CTA shows the stent (*white arrows*). The right renal artery (*blue arrow*) bifurcates early and appears stenotic. It is difficult to exclude a stenosis of the left renal artery. **b** On this volume-rendered image the right renal artery is obscured by a collateral vessel (*blue arrow*). The stent itself is well seen (*white arrow*). **c** Even after optimising rotation and excising the data from unwanted vessels, the artery is not well seen. **d** MR angiography shows signal loss in the position of the stent (*white arrows*). Appearances of the right renal artery (*blue arrow*) resemble those seen at CTA. **e** Aortography shows occlusion of the celiac trunk. The splenic artery fills through collateral pathways from the superior mesenteric artery (*blue arrows*). Note that there is significant in-stent restenosis, not seen on CT or MRA. **f** Selective angiography of the right renal artery confirms the stenosis of the right renal artery and its bifurcation. **g** Selective angiography shows that the left renal artery is narrow but has no focal stenosis. **h** The patient's blood pressure remained difficult to control despite seven antihypertensive medications. CT shows a hypertensive haemorrhage involving the left lentiform nucleus and thalamus, with rupture into the left lateral ventricle and obstructive hydrocephalus. There is cerebral oedema and mild midline shift

Table 2 Potential indications for angiography in hypertensive children

Severe (stage 2) hypertension	
Poor response to antihypertensive medication (one or two drugs)	
Young age	
Complications of hypertension	Cardiac failure Cerebrovascular symptoms
Vasculitis or a syndrome associated with renovascular disease (see Table 1)	
Previous vascular insult	Radiotherapy Trauma Catheterisation
Renal transplant	
Abdominal bruit	
Elevated peripheral plasma renin	
Suspicion of renovascular disease on non-invasive imaging	

children it is best carried out under general anaesthesia. After US-guided puncture of a common femoral artery, and insertion of a valved sheath, catheters of various shapes are used to perform aortography and selective angiography (Fig. 4). It is not sufficient to obtain images of the renal arteries. In order to plan therapy it is always necessary to image the entire abdominal aorta and all of its branches. Depending on clinical considerations, it may also be appropriate to image the thoracic aorta and/or cerebral arteries [14, 21].

Recent technical developments include rotational angiography with three-dimensional reconstructions. This can be particularly helpful in children with complex stenoses or aneurysms. Intravascular US [21] and optical coherence tomography are investigational, but can potentially contribute information about the arterial wall that is not evident at angiography.

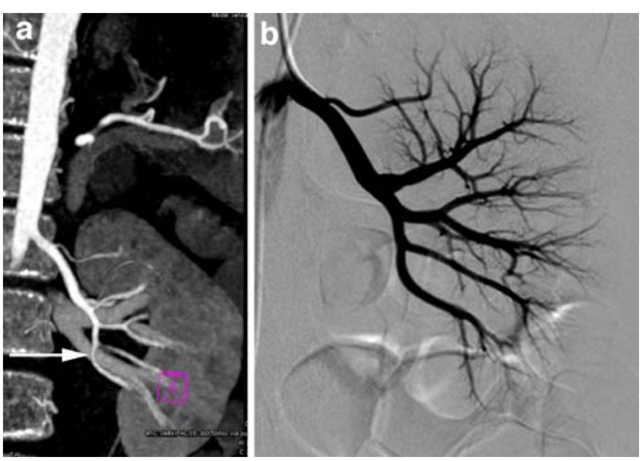


Fig. 5 A 10-year-old girl with vasculitis. **a** 16-slice multidetector CTA was interpreted as showing stenosis of a lower pole branch of the left renal artery (*arrow*). **b** This was not confirmed at angiography

Renal angioplasty

Angioplasty is usually the best first treatment in children with renal artery stenosis [14]. The procedure is usually performed via the common femoral artery, using either a long vascular sheath or a guiding catheter [22]. Various types of angioplasty catheters are available, but there is an increasing tendency to use devices originally designed for adult coronary arteries [22]. These monorail catheters are inserted over a 0.36-mm (0.014-in.) guidewire, and are ideal for the renal arteries of small children, and, in particular, for branch artery stenoses. The diameter of the inflated balloon is selected to be approximately equal to that of the artery proximal to the stenosis. When inflation does not abolish the waist of a standard angioplasty balloon, a cutting balloon may be used [23]. Significant post-angioplasty recoil is common and is consistent with a good clinical response (Fig. 6). Stent insertion is not necessary if the residual diameter stenosis is less than about 50% [14].

Most complications of renal angioplasty are technical, and can be treated immediately. Arterial spasm is usually self-limiting, but if persistent may be treated with glyceryl trinitrate. Some degree of intimal injury is inevitable with angioplasty, but flow-limiting dissection is uncommon, and can often be treated by reinflation of the angioplasty balloon. Stent insertion is occasionally required to ensure arterial patency. Arterial rupture, as shown by extravasation of contrast medium on post-angioplasty angiography, is very uncommon. Haemostasis can usually be achieved by reinflation of the angioplasty balloon for a few minutes. It is sensible to have an experienced vascular surgeon available in case there are irrecoverable complications of angioplasty [14].

The results of angioplasty depend strongly on patient selection [14, 24]. Overall, most children show worthwhile clinical improvement.

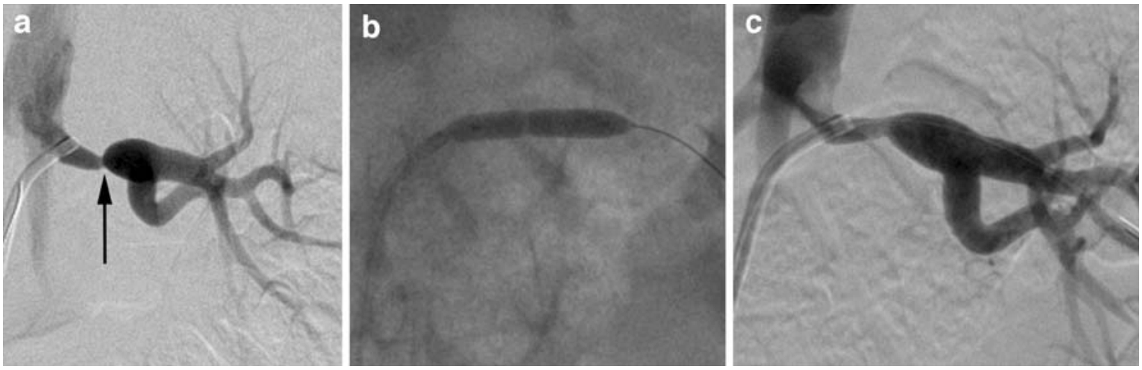


Fig. 6 An 11-year-old boy with poor blood pressure control on two antihypertensive medications. **a** There is an isolated tight stenosis near the bifurcation of the left renal artery (*arrow*). **b** Angioplasty was performed with a 4-mm coronary artery balloon. **c** There was an incomplete response to angioplasty, with partial recoil of the stenotic segment. The residual diameter stenosis is less than 50%, and no stent was inserted. The patient is now normotensive on no treatment

Renal artery stenting

The role of renal artery stenting in childhood is controversial. Reasonable indications for stenting include immediate recoil following angioplasty with >50% diameter stenosis, recanalisation of an occluded renal artery [25], and early recurrence of stenosis after clinically successful angioplasty [14]. The main limitation of stenting is the tendency for children to develop early and often severe in-stent restenosis (Fig. 4). Although this can usually be successfully treated by repeat angioplasty, stents should in most cases be regarded as a bridge to future surgery, which should be performed, if possible, when the child is almost fully grown.

Other endovascular techniques

Angioplasty of the aorta in children with mid-aortic syndrome tends to be followed by immediate recoil to the pre-angioplasty configuration. Despite this, endovascular treatment may be appropriate to delay the need for surgery for as long as possible [26–29]. The aorta should be dilated using a balloon with an inflated diameter somewhat smaller than the expected normal aortic diameter for the patient's age [14].

Many children with renovascular hypertension have segmental branch stenoses. These lesions may be difficult or impossible to angioplasty, depending on the size of the arteries involved. In selected children, segmental trans-arterial ethanol ablation may be appropriate [20, 30]. Renal artery aneurysms may also cause hypertension, and these can also be treated by endovascular techniques.

References

1. Din-Dzietham R, Liu Y, Bielo MV et al (2007) High blood pressure trends in children and adolescents in national surveys, 1963 to 2002. Circulation 116:1488–1496
2. National High Blood Pressure Education Program Working Group on High Blood Pressure in Children and Adolescents (2004) The fourth report on the diagnosis, evaluation, and treatment of high blood pressure in children and adolescents. Pediatrics 114: 555–576
3. Jackson LV, Thalange NK, Cole TJ (2007) Blood pressure centiles for Great Britain. Arch Dis Child 92:298–303
4. Chiolero A, Cachat F, Burnier M et al (2007) Prevalence of hypertension in schoolchildren based on repeated measurements and association with overweight. J Hypertens 25:2209–2217
5. Stabouli S, Kotsis V, Zakopoulos N (2007) Ambulatory blood pressure monitoring and target organ damage in pediatrics. J Hypertens 25:1979–1986
6. Kuschnir MC, Mendonca GA (2007) Risk factors associated with arterial hypertension in adolescents. J Pediatr (Rio J) 83:335–342
7. Lee WW (2007) An overview of pediatric obesity. Pediatr Diabetes 9(8 Suppl):76–87
8. Savitha MR, Krishnamurthy B, Fatthepur SS et al (2007) Essential hypertension in early and mid-adolescence. Indian J Pediatr 74:1007–1011
9. Hadtstein C, Schaefer F (2008) Hypertension in children with chronic kidney disease: pathophysiology and management. Pediatr Nephrol 23:363–371
10. Brady TM, Fivush B, Flynn JT et al (2008) Ability of blood pressure to predict left ventricular hypertrophy in children with primary hypertension. J Pediatr 152:73–78, 78 e71
11. Nguyen M, Mitsnefes M (2007) Evaluation of hypertension by the general pediatrician. Curr Opin Pediatr 19:165–169
12. Sinha MD, Reid CJ (2007) Evaluation of blood pressure in children. Curr Opin Nephrol Hypertens 16:577–584
13. Jourdan C, Wuhl E, Litwin M et al (2005) Normative values for intima-media thickness and distensibility of large arteries in healthy adolescents. J Hypertens 23:1707–1715
14. Tullus K, Brennan E, Hamilton G et al (2008) Renovascular hypertension in children. Lancet (in press)

15. Brun P, Kchouk H, Mouchet B et al (1997) Value of Doppler ultrasound for the diagnosis of renal artery stenosis in children. Pediatr Nephrol 11:27–30
16. Ng CS, de Bruyn R, Gordon I (1997) The investigation of renovascular hypertension in children: the accuracy of radio-isotopes in detecting renovascular disease. Nucl Med Commun 18:1017–1028
17. Prakken FJ, Kitslaar PJ, van de Kar N et al (2006) Diagnosis of abdominal aortic hypoplasia by state-of-the-art MR angiography. Pediatr Radiol 36:57–60
18. Michaely HJ, Schoenberg SO, Oesingmann N et al (2006) Renal artery stenosis: functional assessment with dynamic MR perfusion measurements—feasibility study. Radiology 238:586–596
19. Goonasekera CD, Shah V, Wade AM et al (2002) The usefulness of renal vein renin studies in hypertensive children: a 25-year experience. Pediatr Nephrol 17:943–949
20. Teigen CL, Mitchell SE, Venbrux AC et al (1992) Segmental renal artery embolization for treatment of pediatric renovascular hypertension. J Vasc Interv Radiol 3:111–117
21. McLaren C, Roebuck D (2008) Interventional radiology of renovascular hypertension. In: Slovis T (ed) Caffey' pediatric diagnostic imaging. Mosby Elsevier, Philadelphia, pp 3208–3213
22. McLaren CA, Roebuck DJ (2003) Interventional radiology for renovascular hypertension in children. Techn Vasc Interv Radiol 6:150–157
23. Towbin RB, Pelchovitz DJ, Cahill AM et al (2007) Cutting balloon angioplasty in children with resistant renal artery stenosis. J Vasc Interv Radiol 18:663–669
24. Shroff R, Roebuck DJ, Gordon I et al (2006) Angioplasty for renovascular hypertension in children: 20-year experience. Pediatrics 118:268–275
25. Liang CD, Wu CJ, Fang CY et al (2002) Endovascular stent placement for management of total renal artery occlusion in a child. J Invasive Cardiol 14:32–35
26. Adwani S, De Giovanni JV (1996) Percutaneous transluminal balloon angioplasty of abdominal aortic coarctation in an infant. Pediatr Cardiol 17:346–348
27. Lewis VD 3rd, Meranze SG, McLean GK et al (1988) The midaortic syndrome: diagnosis and treatment. Radiology 167: 111–113
28. Mickley V, Fleiter T (1998) Coarctations of descending and abdominal aorta: long-term results of surgical therapy. J Vasc Surg 28:206–214
29. Roques X, Bourdeaud'ui A, Choussat A et al (1988) Coarctation of the abdominal aorta. Ann Vasc Surg 2:138–144
30. Ishijima H, Ishizaka H, Sakurai M et al (1997) Partial renal embolization for pediatric renovascular hypertension secondary to fibromuscular dysplasia. Cardiovasc Intervent Radiol 20:383–386