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Interventions in children with renovascular hypertension: A 27-year retrospective single-center experience

Hitesh Agrawal MD[1,2] | Douglas Moodie MD[1] | Athar M. Qureshi MD[1,2] | Alisa A. Acosta MD[3] | Jose A. Hernandez MD[4] | Michael C. Braun MD[3] | Henri Justino MD[1,2]

[1]Department of Pediatrics, Texas Children's Hospital and Baylor College of Medicine, Lillie Frank Abercrombie Section of Cardiology, Houston, Texas

[2]Texas Children's Hospital and Baylor College of Medicine, C. E. Mullins Cardiac Catheterization Laboratories, Houston, Texas

[3]Renal Section, Department of Pediatrics, Texas Children's Hospital and Baylor College of Medicine, Houston, Texas

[4]Interventional Radiology Section, Pediatric Radiology, Texas Children's Hospital and Baylor College of Medicine, Houston, Texas

Correspondence
Henri Justino, MD, Texas Children's Hospital, 6621 Fannin St., MC 19345-C, Houston, TX 77030.
Email: hjustino@bcm.edu

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Abstract

Background: Renovascular hypertension (RVH) can be caused by renal artery stenosis (RAS) and/or middle aortic syndrome (MAS).

Methods: Patients who received surgical or transcatheter treatment for RVH between 1/1991 and 11/2017 were retrospectively reviewed using age = adjusted blood pressure ratio (BPR).

Results: Fifty-three patients diagnosed with RVH at a median age of 4.5 (0–18) years were included. Vascular involvement ranged from MAS with RAS (20), RAS only (32), and MAS only (1). The first intervention was transcatheter in 47 patients (transcatheter group: angioplasty = 41, stenting = 5, and thrombectomy = 1), and surgical in 6 patients (surgical group), occurring at a median age of 6.2 (0.1–19.6) years. There was a change toward transcatheter interventions as the first procedure over the study period. First reinterventions in the transcatheter group (27 lesions in 18 patients) were repeat transcatheter (in 20 lesions) and surgery (7 lesions) at a median of 92 (2–2555) days; in the surgical group (5 lesions in 4 patients) first reinterventions were transcatheter (4 lesions) and repeat surgery (1) at a median of 2.2 (1.1–12.0) years. A total of 136 transcatheter and 30 surgical discrete interventions were performed. There was a significant decline in antihypertensive medications and BPR at 4–6 months after the first intervention and on last follow-up in patients initially treated by transcatheter means while the decline was not significant in the surgical group (limited by small sample size). Complications were significantly more common in the surgical group ($P < .01$), 11/27 (41%) vs 10/136 (7.4%). Four patients died (2 from each group): 2 with congenital renal artery atresia and MAS, 2 with MAS and RAS. The median follow-up interval was 3.6 (0.1-35.2) years.

Conclusion: Pediatric patients with RVH treated with transcatheter means as the first intervention had significant improvement in BPR, as well as decline in antihypertensive medications and were less likely to suffer major complications.

KEYWORDS
midaortic syndrome, middle aortic syndrome, renal artery stenosis, renovascular hypertension

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1 | INTRODUCTION

Hypertension is one of the most common chronic diseases in adulthood, but is rare in childhood with a prevalence of ~1%–2%.[1] Approximately two thirds of pediatric hypertension is from secondary causes,[2] with renal parenchymal and renovascular disease being the commonest causes.[3] Renovascular hypertension (RVH) can be caused by isolated renal artery stenosis (RAS) and/or obstruction within the suprarenal abdominal aorta known as middle aortic syndrome (MAS).[4,5] This leads to decrease in perfusion pressure in the renal arteries, activation of the renin-angiotensin system and subsequent blood pressure elevation.

There remains significant institutional variability in the way these patients are evaluated and managed. Doppler ultrasound is a common screening test for work-up of children with suspected RVH, and 2D renal ultrasound is useful to look for secondary causes of hypertension such as tumors and medical renal disease. Noninvasive imaging with computed tomographic angiography (CTA) or magnetic resonance angiography (MRA) can provide detailed evaluation of the abdominal vascular structures but in smaller children they can have limited success. When noninvasive tests are inconclusive, conventional transcatheter angiography is the next best step. Transcatheter angiography remains the gold standard for anatomic evaluation of children with suspected RVH. It offers the benefit of interventions during the same procedure and provides crucial data for surgical planning.[6–8]

RVH, when severe, is usually not responsive to medical therapy alone[9] and a variety of procedures such as balloon angioplasty, stent implantation, and surgery (such as patch augmentation, bypass graft, or renal autotransplantation) are used.[4,10–13] Traditionally, patients with RVH refractory to medical therapy underwent surgical intervention.[4,14,15] With the advancement in transcatheter techniques, it is now possible to perform angioplasty and/or stenting in smaller children that might not have been considered surgical candidates in the past. There are no contemporary studies to compare the outcomes between surgery and catheter-based interventions in children with RVH. We sought to retrospectively compare the outcomes of transcatheter interventional procedures vs surgery in patients with RVH at our institution.

2 | METHODS

A retrospective review of electronic records of patients who underwent transcatheter intervention or surgery for RVH between 1/1/91 and 11/25/17 at Texas Children's Hospital was performed. Paper records from prior to 1991 were not searched, but any available information regarding interventions prior to 1991 within the electronic record was included. Search for patients was performed using diagnostic codes for the following conditions: renal artery stenosis, renal hypertension, coarctation of abdominal aorta, abdominal aortic aneurysm, coarctation of aorta, congenital atresia and stenosis of aorta, stricture of artery, Neurofibromatosis, Williams syndrome, Alagille syndrome, and Takayasu arteritis. Only those patients with hypertension in the setting of renal artery stenosis or stenosis of the abdominal aorta were included. We excluded those that were managed with medical therapy alone and those that exclusively had interventions performed in the thoracic aorta. This study was approved with waiver of consent by the Institutional Review Board of Baylor College of Medicine.

Patients <21 years at the time of diagnosis of RVH and who had surgical or transcatheter intervention in the abdominal aorta, renal arteries, celiac, or superior or inferior mesenteric arteries were included. Abdominal aortic lesions were divided into (1) short segment (discrete narrowing < 1cm long), and (2) long segment (diffuse narrowing extending for >1 cm). Renal lesions were grouped into (1) proximal lesions involving the ostium or any part of the main renal artery, and (2) distal lesions involving intrarenal arteries at first or higher order divisions.

Selection for surgical vs transcatheter intervention was based on individual findings and a multidisciplinary discussion between the treating physicians. Patients were divided into two groups (Transcatheter vs Surgical) based on which intervention was performed first. Additional interventions on celiac, superior, or inferior mesenteric arteries via surgery or catheterization were performed in the presence of signs or symptoms of mesenteric ischemia.

Data including demographics, noninvasive imaging, angiograms, hemodynamic findings related to the vessel stenosis and surgical or transcatheter interventions were collected. To look for varying practice patterns, the time span of the study was divided into three eras based on the date of procedure: (1) 1981–1995, (2) 1996–2005, and (3) 2006–2017.

Blood pressure (BP) measurements were abstracted from patient charts at the following time points: within 2 weeks before the procedure and 4–6 months postprocedure; when multiple systolic and diastolic BP measurements were obtained from the same limb during a single encounter, the average of these was taken. To perform reliable comparison between various age groups, age-adjusted blood pressure ratio (BPR) was generated for both systolic and diastolic BP. For subjects aged 1–17 years, the average systolic (or diastolic) BP was divided by the 95th percentile systolic (or diastolic) BP for the individualized age-gender-height provided by the Fourth Report Working Group on High Blood Pressure in Children and Adolescents.[16] The 95th percentile BP for children <1 year was obtained from the second task force report[17] and for those ≥18 years, obtained from the JNC8 classification.[18] Total number of antihypertensive medications including angiotensin converting enzyme inhibitors, angiotensin receptor blockers, beta blockers, calcium channel blockers, diuretics, and alpha-2 receptor agonists were collected prior to the procedure, 4–6 months post intervention, and at last follow-up using intention-to-treat method. Individual drug dosages were not analyzed, but as a general rule, patients were started on additional agents only after demonstration of inadequate BP control with near maximal doses of initial agents.

2.1 | Technical considerations

All procedures were performed under general anesthesia. Transcatheter procedures were performed using fluoroscopy and patients were heparinized for the duration of the procedure. Use of balloons for angioplasty and placement of stents was individualized according to

the type of lesion under consideration and at the operator's discretion. For the purpose of analysis, catheter-based interventions (including angioplasty, stenting, and thrombectomy) were grouped together, and surgical therapies (including bypass grafts, patch augmentation, renal autotransplantation, and nephrectomy) were grouped together. Of note, these may not have been unique procedures (eg, a patient receiving stenting may have received preparatory angioplasties during the same procedure but were analyzed under the stenting group, while patients receiving angioplasty only were deemed to have a single angioplasty per lesion even if multiple balloon dilations were performed in each lesion). Complications were defined as untoward events requiring further reinterventions (eg, vessel tear, vessel occlusion, pseudoaneurysm) or those causing permanent sequelae, cardiac arrest, arrhythmia, or death. Intimal flaps, dissections, and any extravasation of contrast occurring during balloon angioplasty or stenting were grouped under vessel tears.

2.2 | Statistical analysis

Paired samples of BPR preintervention and postintervention were used to compare the change in median systolic and diastolic BP ratios and the number of antihypertensive medications. Paired *T*-test was used to compare normally distributed variables and the Wilcoxon signed-rank test was used for nonparametric variables. SAS software was used for statistical analysis. The data are expressed as n (%) and range (minimum-maximum).

3 | RESULTS

A total of 53 patients (26 males) met inclusion criteria. The patients included were diagnosed at a median age of 4.5 (0–18) years with abdominal vascular involvement ranging from MAS with RAS (20 patients), RAS only (32), and MAS only (1) (Table 1). These patients had an associated diagnosis of Williams syndrome (4 patients), neurofibromatosis (7), and Takayasu arteritis (2). Accounting for all vascular lesions (including extra-abdominal) in these patients, each patient had a median of 3 (1–13) lesions. Median age at initial intervention was similar among the transcatheter and the surgically treated patients: 6.2 (0.1–19.6) vs 5.6 (0.1–16.6) years, respectively ($P = .70$), Table 1.

Median follow-up interval from the time of diagnosis of RVH was 3.6 (0.1–35.2) years. There was a statistically significant increase in transcatheter intervention as the first procedure over the study period, $P < .01$ (Figure 1 and Table 2). Of the 53 patients, 47 (termed the transcatheter group) were initially treated with transcatheter means (angioplasty alone = 41, stenting ± angioplasty = 5, and thrombectomy alone = 1) with a total number of discrete lesions receiving intervention being 70 lesions, and each patient receiving treatment for a median of 1 (1–6) lesions at the initial catheterization. Six patients (termed surgical group) were treated via surgery initially, with a total of 12 discrete lesions treated (median of 2, range 1–3 lesions per patient).

Twenty-seven lesions out of seventy, 39% (in 18 patients, 38%) in the transcatheter group received the following second interventions: repeat transcatheter (20 lesions), surgery (7) at a median of 92 (2–2555) days after the first intervention. Five lesions out of twelve, 42% (in 4 patients, 67%) in the surgical group underwent a second intervention by transcatheter means (4 lesions) and repeat surgery (1) at a median of 2.2 (1.1–12.0) years. The difference in the proportion of second intervention was not significant, $P = .84$ for lesion-specific comparison and $P = .18$ for patient-level comparison.

Total transcatheter interventions during the entire study period (n = 136) included angioplasty in abdominal aorta (10), renal arteries (94), celiac artery (2); abdominal aortic stenting (9), renal artery stenting (18); stenting of abdominal aorta bypass graft (1), stenting of aorto-renal bypass graft (1), and thrombectomy in abdominal aorta (1).

TABLE 1 Demographic and baseline characteristics of patients and their native lesions

Total patients	**N = 53 (%)**
Sex	
Male n (%)	26 (49.1)
Race and Ethnicity n (%)	
White Hispanic	23 (43.4)
White non-Hispanic	27 (50.9)
African American	3 (5.7)
Median age at diagnosis of RVH, y (range)	4.5 (0–18)
Median age at first procedure, y (range)	6.2 (0.1–19.6)
Diagnosis n (%)	
MAS	1 (1.9)
RAS	32 (60.4)
MAS and RAS	20 (37.7)
Total native lesions intervened upon	**N = 106 (%)**
Abdominal aorta	
Short segment n (%)	10 (9.4)
Long segment	10 (9.4)
Renal	
Proximal n (%)	60 (56.6)
Intrarenal	21 (19.8)
Mesenteric	
Celiac artery n (%)	3 (2.8)
Superior mesenteric artery	2 (1.9)
Inferior mesenteric artery	0 (0)

Abbreviations: MAS, middle aortic syndrome; RAS, renal artery stenosis; RVH, renovascular hypertension.

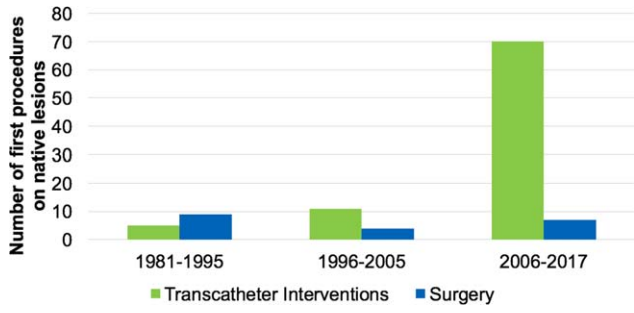

FIGURE 1 Distribution of type of first procedures over the study period. Each native vascular lesion is one unit

TABLE 2 Site of initial intervention

No. of lesions receiving interventions during first procedure	Transcatheter n = 70	Surgery n = 12
Abdominal aorta n (%)		
Short segment	7 (10.0)	1 (8.3)
Long segment	4 (5.7)	2 (16.7)
Renal n (%)		
Proximal	42 (60.0)	9 (75.0)
Distal	15 (21.4)	0
Mesenteric n (%)		
Celiac artery	2 (2.9)	0
Superior mesenteric artery	0	0
Inferior mesenteric artery	0	0

Surgical interventions during the entire study period (n = 27) included bypass grafts in abdominal aorta (4), renal artery (8), superior mesenteric artery (3); patch augmentation of abdominal aorta (1) and renal artery (5); autotransplantation of kidney (4); and nephrectomy (2). Total median number of unique lesions treated per patient during the entire study period were 1 (1–6), with number of reinterventions on the same lesion ranging from 0 to 10. (Figure 2).

Three patients in this series received drug eluting stents (DES) in renal arteries (unilateral in 2 patients and bilateral in 1 patient), 1 patient received a bioabsorbable stent in a renal artery (Absorb bioabsorbable vascular scaffold, Abbott, Abbott Park, Illinois) and 2 patients were treated with drug coated balloon (DCB) angioplasty. Out of these 6 patients, 1 stent was placed during the first procedure while the rest of the interventions (including DCB and bioabsorbable stent) were performed as a part of a reintervention. Hence, we have insufficient data to compare outcomes with use of DES, bioabsorbable stent and DCB vs conventional stents/balloons.

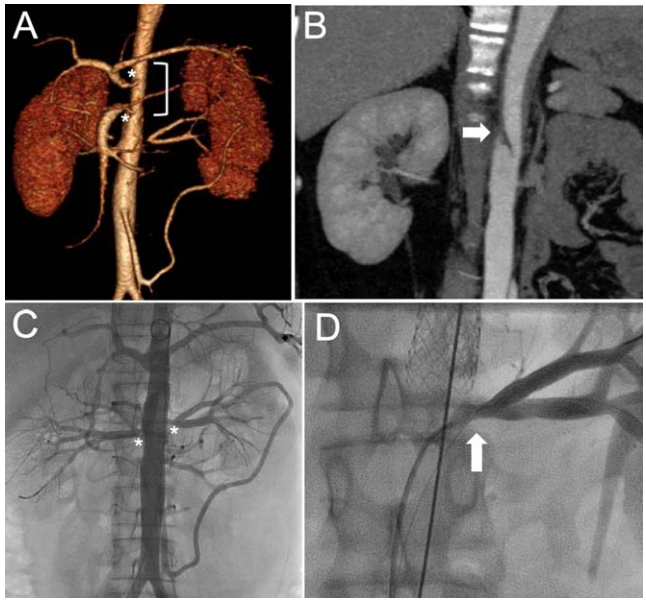

FIGURE 2 Thirteen-year-old female with Takayasu arteritis, long segment narrowing of abdominal aorta (open bracket), severe focal stenosis of celiac and superior mesenteric arteries (asterisks) and proximal stenosis of bilateral renal arteries, left more than right (A). There is spontaneous aortic dissection (B, white arrow). Angiogram after stenting of the abdominal aorta, and angioplasty of the celiac artery with improved caliber of the treated vessels. There is proximal stenosis of bilateral renal arteries (asterisks), more severe on the left (C). After angioplasty of bilateral renal arteries, selective angiogram of the left renal artery shows improved caliber of the ostium of the left renal artery with immediate bifurcation into upper and lower pole arteries (D)

In this series, recanalization of atretic renal arteries was possible in two children, a 10-week-old weighing 3.4 kg, and a 2-year-old weighing 11.7 kg (Figure 3). In the younger infant, femoral arterial approach provided limited access to the angulated renal arteries requiring conversion to a percutaneous carotid approach which provides a straight catheter course and has been shown to be a safe alternative.[19] The recanalized renal artery has remained patent, although requiring interval repeat angioplasties with gradually larger balloons.

Paired samples of BPRs (preintervention and 4–6 months postintervention) were used to compare patients that were initially treated with transcatheter means (47) and those treated surgically (6). This yielded 38 paired samples in the transcatheter and 3 in the surgical group (12 patients were excluded due to missing data for BP and/or antihypertensive medications). We found a significant decline in the number of antihypertensive medications, as well as systolic and diastolic BPRs in those patients who were initially treated by transcatheter means 4–6 months following the first procedure and at last follow-up. The decline was not significant in the surgical group (although with a limitation of only 3 paired samples in the surgical group) (Tables 3 and 4). During this study, some patients initially treated by transcatheter crossed over to receive surgical therapy, and vice versa. Hence, it is difficult to ascribe long term success of BP control to the initial type of intervention. We therefore divided the cohort into those exclusively treated by transcatheter means and those via surgery, excluding those that crossed over (n = 11), and repeated the analysis of BP control. There was again a statistically significant decline in the BPRs and antihypertension medications in the group exclusively treated by transcatheter means (n= 38, out of which data were available in 33 patients). There were insufficient numbers of patients exclusively treated by surgery (n= 4, out of which comparative data were available in two patients only) to allow a meaningful statistical comparison. However, an improving trend was noted in the BP and antihypertension medications in the two patients exclusively treated via surgery (Table 5).

Complications were assessed throughout the entire study duration (at the initial and at all subsequent interventions) and were found to be significantly more common in the surgical group ($P < .01$ for both types of comparisons below). When adverse event rates are calculated based on the total number of procedures (regardless of number of interventions performed in each procedure), the complication rate is 10/95 catheterization procedures (10.5%) vs 11/15 surgical procedures (73%). When calculated based on the total number of lesions treated, catheter-based interventions carried a total adverse event rate of 10 events per 136 lesions treated, or 7.4%, vs 11 events per 27 lesions, or 40.7% in the surgically treated lesions (Table 6).

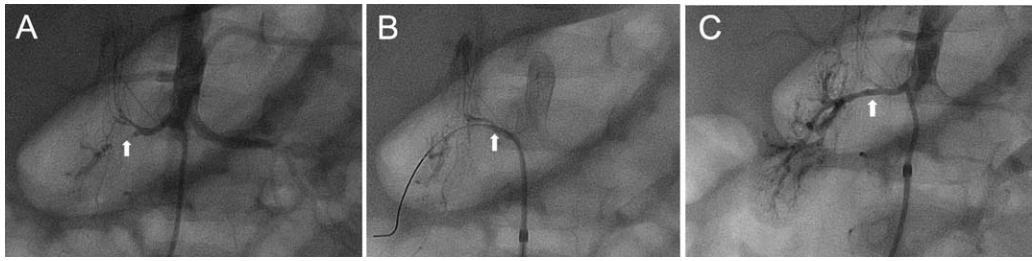

FIGURE 3 Two-year-old male with severe hypertension, complete occlusion of the right renal artery (white arrow, A) and atrophy of right kidney with collateral flow to the distal vessel. An 0.014″ wire was advanced through the occlusion (B) and the vessel was recanalized and angioplastied. After angioplasty, the angiogram shows improvement in caliber of the right renal artery (C)

TABLE 3 Comparison of the median difference in systolic and diastolic blood pressure ratio (BPR) and antihypertension medications before and 4–6 months after first intervention (transcatheter vs surgery)

Results of paired test						
Comparison	**Pairs**	**Before median (range)**	**After median (range)**	**Median difference (range)**	***P t****	***P s****
Transcatheter interventions						
Systolic BP ratio	38	1.31 (0.97–1.82)	1.05 (0.79–1.31)	−0.28 (−0.90, 0.08)	<.01	
Diastolic BP ratio	38	1.16 (0.82–2.23)	0.93 (0.62–1.24)	−0.26 (−1.26, 0.16)		<.01
Anti-HTN medications	38	3 (1–6)	2 (0–5)	−1 (−3, 1)		<.01
Surgery						
Systolic BP ratio	3	1.29 (1.09–1.31)	1.07 (1.04–1.29)	−0.08 (−0.14, −0.02)	.19	
Diastolic BP ratio	3	1.01 (0.67–1.01)	0.78 (0.66–1.00)	0.05 (−0.01, 0.11)	.87	
Anti-HTN medications	3	3 (1–5)	2 (0–4)	−0.500 (−1, 0)		.50

*P t value using paired t-test.
**P s value using Wilcoxon signed-rank test.

Five patients received unplanned interventions either during the same or subsequent catheterization procedure for correction of a known complication. All other procedures were planned interventions. The first patient, a 10-year-old female with MAS and RAS, developed a tear in the left renal artery following angioplasty with a cutting balloon that was successfully treated with a covered stent. The second patient, a 26-year-old female with Takayasu arteritis, underwent placement of a Palmaz P308 stent in the suprarenal abdominal aorta followed by post dilation, after which she developed a pseudoaneurysm and extravasation of contrast into the retroperitoneum that was sealed with four Gianturco coils (Cook Medical, Bloomington, Indiana). She ultimately died, and her course is described in the paragraph below. The third patient, a 9-year-old female with MAS and RAS, developed aortic dissection at the level of left renal artery following angioplasty of abdominal aorta and was treated with stenting of left renal artery and descending aorta. One week later she was treated for a left renal subcapsular hematoma by embolization of the bleeding branch with polyvinyl alcohol particles and coils. The fourth patient, a 19-year-old male with MAS, developed an intimal flap after angioplasty of the abdominal aorta requiring stenting. One week later, while engaging in strenuous activity, he developed a large pseudoaneurysm, requiring resection and reanastomosis of the abdominal aorta using a Gore-tex graft and

TABLE 4 Comparison of the median difference in systolic and diastolic blood pressure ratio (BPR) and antihypertension medications before any interventions and at last follow-up using intention-to-treat analysis (transcatheter vs surgery relates to the first procedure)

Results of paired test						
Comparison	**Pairs**	**Before median (range)**	**After median (range)**	**Median difference (range)**	***P t****	***P s****
Transcatheter interventions						
Systolic BP ratio	38	1.31 (0.97–1.82)	0.98 (0.72–1.33)	−0.28 (−0.92, 0.07)	<.01	
Diastolic BP ratio	38	1.16 (0.82–2.23)	0.86 (0.66–1.42)	−0.29 (−1.32, 0.18)		<.01
Anti-HTN medications	38	3 (1–6)	1 (0–5)	−1 (−5, 2)		<.01
Surgery						
Systolic BP ratio	4	1.29 (1.09–1.31)	0.96 (0.94–1.21)	−0.18 (−0.20, 0.01)	.06	
Diastolic BP ratio	3	1.01 (0.67–1.12)	0.71 (0.56–0.87)	−0.07 (−0.11, −0.02)	.22	
Anti-HTN medications	4	3 (1–5)	1 (0–4)	0 (−1, 0)		.50

*P t value using paired t-test.
**P s value using Wilcoxon signed-rank test.

TABLE 5 Comparison of the median difference in systolic and diastolic blood pressure ratio (BPR) and antihypertension medications before any interventions and at last follow excluding patients that crossed over to the other mode of therapy (transcatheter vs surgery relates to the first procedure)

Results of paired test						
Comparison	**Pairs**	**Before median (range)**	**After median (range)**	**Median difference (range)**	***P t****	***P s****
Transcatheter interventions					<.01	
Systolic BP ratio	33	1.31 (0.97–1.82)	0.98 (0.79–1.32)	−0.29 (−0.92, 0.07)		
Diastolic BP ratio	33	1.16 (0.82–2.23)	0.86 (0.66–1.42)	−0.28 (−1.32, 0.18)		<.01
Anti-HTN medications	33	3 (1–6)	1 (0–5)	−1 (−5, 2)		<.01
Surgery						
Systolic BP ratio	2	1.29 (1.29–1.31)	1.11 (1.11–1.12)	−0.19 (−0.20, −0.18)	.02	
Diastolic BP ratio	1	0.89 (0.89–1.12)	0.87	−0.02		–
Anti-HTN medications	2	3 (1–5)	1 (1–4)	−0.5 (−1, 0)	.50	

*P t value using paired t-test.
**P s value using Wilcoxon signed rank test.

reimplantation of the right renal artery. The fifth patient, a 10-year-old male with MAS and RAS, developed a vessel tear after angioplasty of right renal artery requiring placement of a covered stent. Within 24 hours, there was complete occlusion of the right renal artery and the patient required right nephrectomy.

Four patients died: 2 with congenital renal artery atresia and MAS, and 2 with MAS and RAS. Of these, two were initially treated with catheter-based interventions and two with surgery in the abdominal aorta and renal arteries. One patient from each category had crossover to the other modality of intervention/surgery. The first patient was found to have atresia of bilateral renal arteries, stenosis of the abdominal aorta below the celiac artery, and near atresia of the superior mesenteric artery. She underwent balloon angioplasty of the distal abdominal aorta at 6 weeks of age and was deemed to not be a candidate for recanalization or reperfusion of the kidneys. The cause of death was deemed to be atresia of the renal arteries. The second patient underwent balloon angioplasty of the descending thoracic and abdominal aorta and had stents placed in the abdominal aorta and left renal artery at 10 years of age. Due to progressive disease, a year later she underwent ascending to descending thoracic aortic bypass, right renal artery reimplantation, left nephrectomy and jump graft to bilateral common iliac arteries. The timing of death, although remote from the surgical intervention, is unclear from review of the medical records. The third patient had congenital abdominal aortic aneurysm, right renal artery atresia, stenosis of left renal artery arising from the aneurysmal segment and MAS. At 1 month, she underwent aneurysm resection and polytetrafluoroethylene (PTFE) graft placement from the proximal abdominal aorta to the common iliac arteries and left renal artery reimplantation. However, she became anuric overnight and developed complete occlusion of bilateral renal arteries. She was deemed to not be a candidate for further interventions and succumbed. The fourth patient had Takayasu arteritis and underwent right renal artery bypass grafting and auto-transplantation of the left kidney at 13 years. At 25 years, she underwent balloon angioplasty of abdominal coarctation and at 26 years she underwent stenting of the abdominal aorta proximal and distal to the renal arteries due to refractory hypertension. Extravasation of contrast was noted following postdilation of the stent above the renal arteries. A pseudoaneurysm was noted, and after placement of 4 Gianturco coils (Cook Medical), the extravasation stopped. She died 5 days later, and the cause of death could not be determined from review of the records, although it was considered a complication of the procedure.

TABLE 6 Complications during interventions

	Total number of procedures	
Complication types	**Transcatheter n = 136 (%)**	**Surgery n = 27 (%)**
Vessel tear	5 (3.7)	1 (3.7)
Vessel occlusion	1 (0.7)	6 (22.2)
Pseudoaneurysm	3 (2.2)	2 (7.4)
Cardiac arrest	0	1 (3.7)
Death related to procedure	1 (0.7)	1 (3.7)

4 | DISCUSSION

RVH in children has traditionally been treated with surgical therapy after failed pharmacologic management. However, recent advances have resulted in catheter-based interventions earning their place in the management of this disease. Previous studies looking at percutaneous angioplasty for pediatric RVH have reported varying success in BP control ranging from 54% to 94%.[10,11,13,20–24] Likewise, centers that have extensive surgical experience with this disease have reported excellent control of BP with cure rates ranging from 56%–70%, improvement in 23%–44%, and failure rates of 3%-32%.[4,14,15,25] Indeed, this variability can stem from multiple confounders including primary etiology of RVH (intrinsic stenosis of a renal artery vs thrombosis of an otherwise normal vessel), severity/location/number of lesions in each patient, aggressiveness of medical therapy, method of balloon angioplasty (eg, whether more aggressive techniques, such as high-pressure angioplasty and/or cutting balloons are used), if stenting was used, and whether BP was followed short-term vs long-term. Of note, nearly half of the patients in our study had severe disease manifesting both RAS and MAS and included patients with Williams syndrome and

neurofibromatosis which is drastically different from other series, especially those from the Asian subcontinent where inflammatory aortoarteritis is very common.[20,26]

Previous studies that looked at treatment of RVH in children have either focused on surgical management or transcatheter treatment and hence till date these cohorts have not been compared.[4,8,11,20,25] Our study spans 3 decades, and therefore, a variety of management strategies were in vogue during different eras of our study period. We have demonstrated a statistically significant increase in catheter-based interventions as the first procedure in recent years ($P < .01$) at our institution (Figure 1), and these interventions were performed either by interventional radiologists or interventional cardiologists. Although the criteria for intervention were not uniform between the surgical and transcatheter group, we saw a significantly higher rate of major adverse events in the surgically treated patients.

We found a significant decline in the number of antihypertensive medications, as well as systolic and diastolic BPRs after 4–6 months following first procedure and at last follow-up in patients initially treated by transcatheter means in contrast to those initially treated with surgery. The reason for lack of statistical significance in the surgical cohort is mainly due to a small sample size (Tables 3 and 4).

RVH is a potentially curable disease, although some patients can manifest recurrent arterial stenosis despite short term improvements in BP with percutaneous or surgical interventions. Despite the commonly held belief that surgical repair might be more definitive than a catheter-based intervention, our data show that the need for reintervention was almost indistinguishable between patients initially treated by catheter means and those initially treated by surgery. This was both true when analyzing total number of patients needing reintervention and total number of lesions needing reintervention. One important difference to consider is that only one specific type of intervention is clearly definitive, namely, surgical nephrectomy (ie, this is the only intervention for which the lesion cannot receive any reintervention). All other types of intervention, whether catheter-based or surgical, have the potential to result in recurrent or residual stenosis and therefore the need for reintervention.

Our study was able to confirm the superior results of catheterization vs surgery in terms of BP control and number of antihypertensive medications at first follow-up, and also confirmed that the reintervention rate is almost identical for both types of intervention. Additional studies will be needed to determine which specific types of intervention (eg, balloon angioplasty with conventional or cutting balloons vs stenting) and which surgical interventions (eg, patch angioplasties vs grafts) are associated with greater therapeutic benefit and lower reintervention rate.

5 | LIMITATIONS

This is a retrospective single institution review spanning many decades with varying practice patterns. Our study is limited by patient search using diagnostic codes and the limited availability of electronic records during the earlier portions of the study. The interventions performed were individualized and varied among the surgical and transcatheter groups. Data collection on long-term vessel patency is currently ongoing. Also, BP control can be confounded by other variables including drug dosage and type of medications utilized, age of patients, compliance, ethnicity, dietary regimen, and participation in physical exercise which were not accounted for in the comparisons. Finally, our groups were defined according to the type of initial intervention, whether catheter-based or surgical, hence, our subsequent analyses were performed according to an intention-to-treat analysis. While the BPRs and numbers of medications administered after the first intervention are an accurate reflection of the medium-term result of the first intervention, within each group there were many patients that crossed over to receive therapy of the other type during the course of follow-up (eg, a patient initially treated by catheter means may have received surgical treatment later on, and vice versa). This cross-over makes it very difficult to ascribe the long-term success or nonsuccess of a therapeutic strategy. Accordingly, the BPRs and numbers of medications administered at last follow-up may not reflect the success of the initial type of intervention (eg, a patient in the catheter group may have eventually received surgery, and the long-term successful control of BP may be due to the successful surgical intervention, and vice versa).

6 | CONCLUSION

Patients with RVH with multivessel involvement may be treated with medical therapy, catheter-based interventions and surgery. In recent years, these patients have been increasingly treated with transcatheter interventions at our institution when there is failure of medical therapy. Individuals treated with transcatheter means as the first intervention had significant improvement in BPRs, as well as decline in antihypertensive medications and were less likely to suffer major complications with clinical consequences, although limited by a shorter reintervention time interval between the first and second intervention compared to the surgical cohort.

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CONFLICT OF INTEREST

Dr Henri Justino is a consultant for the following companies: Abbott, Medtronic, Janssen Pharmaceutical, B-Braun Interventional Systems, and Edwards Lifesciences; none of these relationships are relevant to the topic of this manuscript. Dr Qureshi is a consultant for WL Gore and Associates. Other authors have no disclosures.

AUTHOR CONTRIBUTIONS

All the listed authors have made significant contribution in the preparation and review of the manuscript.

ORCID

Hitesh Agrawal MD http://orcid.org/0000-0001-9272-6949

Henri Justino MD http://orcid.org/0000-0002-5617-6932

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