Pediatr Nephrol (2009) 24:2225–2232
DOI 10.1007/s00467-009-1242-6

ORIGINAL ARTICLE

# Mid-aortic syndrome: long-term outcome of 36 children

**Albina Tummolo · Stephen D. Marks · Marike Stadermann · Derek J. Roebuck · Clare A. McLaren · George Hamilton · Michael J. Dillon · Kjell Tullus**

Received: 1 April 2009 / Revised: 30 May 2009 / Accepted: 3 June 2009 / Published online: 15 July 2009


**Abstract** The clinical characteristics and outcomes of children with mid-aortic syndrome (MAS) and the effectiveness of different therapeutic approaches in reducing hypertension are still debated. We conducted a single-centre retrospective review of the records of children with MAS over 30 years. Children with angiographic evidence of a narrowed abdominal aorta were included. Therapeutic approaches included medical management, percutaneous transluminal angioplasty and/or surgical intervention. Thirty-six children had presented at a median age of 2.7 years (10 days–10 years). Thirteen (36%) patients had associated syndromes, and 44% had been diagnosed with cerebrovascular disease. All patients had involvement of multiple arteries. The mortality rate was 8% after a median follow-up period of 4.5 (range 1.1–19.7) years. Among the children who survived, 90% had obtained a reduction in their blood pressure (BP). Of the patients, 76% had had a normal estimated glomerular filtration rate (eGFR) at the last follow-up examination. Seventeen percent (six of 36) had renal dysfunction at presentation. Although MAS is a severe and widespread disease, in most cases it can be effectively treated with a combination of medical, angioplasty and surgical interventions.

**Keywords** Renovascular hypertension · Renal artery stenosis · Cerebrovascular disease · Percutaneous transluminal angioplasty · Surgical intervention

**Abbreviations**

| | |
|---|---|
| MAS | mid-aortic syndrome |
| BP | blood pressure |
| eGFR | estimated glomerular filtration rate |
| HTN | hypertension |
| NF-1 | neurofibromatosis type 1 |
| PTA | percutaneous transluminal angioplasty |
| DMSA | dimercaptosuccinic acid |
| RVH | renovascular hypertension |
| CVA | cerebrovascular accident |
| CKD | chronic kidney disease |

A. Tummolo (✉)
Department of Paediatric Nephrology,
University of Bari, Bari, Italy
e-mail: albinatummolo@yahoo.it

S. D. Marks · M. Stadermann · M. J. Dillon · K. Tullus
Department of Paediatric Nephrology,
Great Ormond Street Hospital for Children NHS Trust,
London, UK

D. J. Roebuck · C. A. McLaren
Department of Paediatric Radiology,
Great Ormond Street Hospital for Children,
London, UK

G. Hamilton
Department of Surgery, Royal Free Hospital,
London, UK

## Introduction

Mid-aortic syndrome (MAS) is a rare condition presenting with severe hypertension (HTN) and characterized by severe narrowing of the abdominal aorta, usually involving the renal arteries and visceral branches [1]. The clinical characteristics of MAS were first described in 1963 [2], with the narrowing of the subisthmal aorta (unlike the typical Takayasu-type changes of the aortic arch and Leriche-type of aortic bifurcation obliterative disease) [3].

MAS has subsequently emerged as its own clinical entity and specific cause of renovascular hypertension (RVH) in

childhood and young adulthood. Previously, MAS was termed coarctation [4–7], hypoplasia or mesenchymal disease of the abdominal aorta [8, 9], but the term MAS is the most recent preferred terminology as it provides an anatomical and clinical definition (as opposed to aetiopathogenetic disease entities) [10]. In most cases MAS is associated with renovascular disease, although, in previous studies among a total of 196 children with renovascular disease, 51 (26%) had MAS [11–14].

The aetiology of MAS is still unknown, and its pathophysiology remains elusive, although many mechanisms have been advocated. It has been described as a congenital disorder when diagnosed in neonates and associated with congenital syndromes [15–18]. However, Indian and Asian authors have described MAS as an acquired disorder [19, 20] when detected in adolescent and young adults with signs of perivascular and intravascular inflammation in conjunction with elevation of serum inflammatory markers. This form was described as an aorto-arteritis due to Takayasu disease.

MAS has been treated with increasing frequency over the past two decades, although many aspects of this syndrome still need to be clarified. Therefore, we conducted a retrospective review of the records of patients with hypertension related to MAS who have been followed in our centre. We describe the clinical syndrome, its multidisciplinary management, the response to our therapeutic approaches and the occurrence of renal dysfunction.

## Materials and methods

### Patients

Thirty-six children with hypertension and suspected renovascular disease who were found to have MAS with angiographic evidence of narrowing of the abdominal aorta were included in the study. They had been treated at Great Ormond Street Hospital for Children NHS Trust from November 1976 to July 2008. All children were diagnosed by digital subtraction angiography, which was considered the gold standard for suspected RVH [21]. A full medical examination, biochemical analysis and abdominal ultrasonography were performed as first approach in all the children. Less invasive imaging techniques were carried out on selected patients for whom the need for angiography was uncertain [21]. Two patients underwent computed tomography angiography, and another two children had magnetic resonance angiography. Abdominal-vessel Doppler ultrasound was not routinely performed because it was considered unhelpful in detecting stenosis of the smaller arteries [22]. All children were treated with anti-hypertensive agents as first attempt. Usually, they required a combination of different types of medications: beta-blockers, vasodilators, alpha and beta blockers. The angiotensin-converting-enzyme inhibitors and the angiotensin receptor-blockers were used as second choice, when other options failed to control blood pressure (BP), with close monitoring of the renal function.

The hospital records were reviewed, and data on initial presentation, treatment and follow-up were obtained and recorded.

The BP response to treatment was evaluated as:

(A) cure: normalization of BP to below the 95th centile for age, gender and height centile without any anti-hypertensive medication
(B) improvement: reduction but not normalization of BP centile (> 95th centile) while on drug therapy, with or without previous intervention
(C) unchanged: same BP centile with the same or increased drug therapy, with or without previous intervention
(D) failure: technical failure of intervention [23].

The renal function was assessed as estimated glomerular filtration rate (eGFR) with the Schwartz formula [24]. Renal dysfunction was present in patients with eGFR < 90 ml/min per 1.73 $m^2$ body surface area.

## Results

Of 36 patients with MAS, 64% were male and 77% were Caucasian. Age at presentation with HTN varied from 10 days to 10 years, with a median age of 2.7 years. The median age of referral to our centre was 4 years (range 1 month–13 years). The median time from onset of symptoms to referral to our unit was nearly 3 months (range 3 days–5.7 years).

### Presenting features

BP at presentation was above the 99th centile for age, gender and height centile in all children [median systolic BP of 160 (range 117–250) mmHg]. Hypertension was incidentally found in 25% (nine) of patients at a routine medical examination or during investigations for other pathological conditions, whereas another 25% (nine) presented with symptoms of congestive cardiac failure and 17% (6) with hypertensive encephalopathy. Hypertension was detected in eight children (22%) at screening, due to known or suspected genetic syndromes. Other modes of presentation included claudication and failure to thrive. No patients had a history suggesting chronic inflammation and/or elevated levels of inflammatory markers. Physical signs of vascular abnormality could be detected in 50% (18) of patients: 14% (five) had a heart murmur, 19% (seven) an abdominal bruit, 6% (two) children demonstrated decreased

or absent femoral pulses, and 11% (four) of patients presented with two or three of the above signs. Because of the difficulty of obtaining BP in the legs, especially for small children, the differential in the BP between the upper and the lower extremities was not routinely achieved.

Left ventricular hypertrophy was diagnosed in 80% (26/32) of children, and hypertensive retinopathy in 21% (5/24). Renal involvement at onset was investigated in all patients, with renal dysfunction (eGFR below 90 ml/min per 1.73 $m^2$) found in 17% (six) of children: median eGFR 103 (range 53–161) ml/min per 1.73 $m^2$. Technetium-99 m-dimercaptosuccinic acid (DMSA) scintigraphy detected pathological differential up-take of radionuclide below 45% in one kidney in 59% of patients.

## Associated findings

Genetic conditions were present in 36% (13) of patients. Neurofibromatosis type I (NF-1) was the most common associated genetic syndrome (19%). Of the children with NF-1, 8% (three) were also affected by neoplastic disease (Table 1). The presence of a neoplasm was demonstrated in one patient with Feuerstein–Mims syndrome and in 8% (three) of children without a defined genetic condition. In these cases a large abdominal malignant tumour was the cause of the vascular disease, with compression of the aorta and its visceral branches. In all cases the mass had been removed, but the children remained severely hypertensive.

Scoliosis was detected in 14% (five) of patients, and altered skin pigmentation (hyperpigmentation or hypopigmentation) in 22% (eight). Neurodevelopmental delay, convulsive episodes, impaired visual or hearing function were present in 28% (ten) of patients, related to their underlying diagnosis and/or cerebrovascular disease, and/or degree of hypertension.

## Extent of disease

All patients had narrowing of the abdominal aorta at various segments, associated with other vascular abnormalities. Renal artery stenosis (RAS) was present in 86% (31) of children, and bilateral RAS in 50% (18). Intrarenal vascular involvement was detected in 31% (11) of patients, all of whom also had main RAS, which was bilateral in eight cases.

Intestinal arterial involvement was found in 67% (24) of children. There was a simultaneous narrowing of two or three branches in 19% (seven) of cases and of the iliac arteries in 8% (three). However, none of them was symptomatic of mesenteric ischaemia. Cerebrovascular disease was diagnosed by cerebral perfusion studies: technetium (Tc)-99 m HMPAO (single-photon emission computed tomography with hexamethyl-propylene amine oxide-labelled with technetium-99), cerebral computed tomography and magnetic resonance angiography. Of the patients, 44% (16) demonstrated abnormal head or neck arteries, with narrowing of either the carotid or subclavian artery in 14% (five) of children, one or several abnormal intracranial arteries in 31% (11), and 11% (four) with cerebral infarctions.

## Outcome

Over a median follow-up period of 4.5 (range 1–19.7) years, patients underwent multiple therapeutic interventions. Anti-hypertensive medications represented the first-line treatment for all patients, with a median number of drugs of 4 (range 2–7).

### *Medical therapy*

Six children received medical treatment only (16%); three patients did not need further treatment because good BP control was achieved with anti-hypertensive agents alone (Table 2). In two children the high complexity and widespread nature of the arterial disease excluded the possibility of a curative angioplasty or surgical intervention, and, in one case, the study of the arterial tree was not clear enough to allow invasive treatment (renal arteries not identified on angiography performed in 1991).

The three children who had initially responded well to drug therapy, obtained good BP control and required fewer anti-hypertensive agents. However, the other three children were felt not to be amenable to angioplasty or surgery and had had a more severe outcome. One child with widespread

**Table 1** Associated findings

| Associated syndromes | Number (%) of cases | Number (%) of patients with neoplastic lesions |
|---|---|---|
| Neurofibromatosis 1 | 7 (19) | 3 (43) (Optic nerve glioma, pilicytic astrocytoma, neurofibroma) |
| William's syndrome | 3 (8) | 0 (0) |
| Hypomelanosis of Ito | 1 (3) | 0 (0) |
| Feuerstein–Mims syndrome | 1 (3) | 1 (100) (Dermolipoma) |
| Chromosome 10 abnormality | 1 (3) | 0 (0) |
| Non-syndromic children | 23 (64) | 3 (13) (Neuroblastoma, congenital infantile fibrosarcoma, retroperitoneal teratoma) |

**Table 2** Long-term outcome. BP response to treatment was evaluated as (*A*) cure—normalization of BP; (*B*) improvement—reduction in BP centile while on drug therapy, with or without previous intervention; (*C*) unchanged; (*D*) failure—technical failure of intervention (*PTA* percutaneous transluminal angioplasty)

| Treatment | No. of patients | Mean follow-up period (years) | Mean number of drugs at follow-up | Mean eGFR | Outcome (A, B, C, D) | No. of deaths |
|---|---|---|---|---|---|---|
| Medical therapy | 3[a] | 12. | 2 | 116.5 | B 3 | 0 |
| | 3[b] | 11 | 1.6 | 53.5 | B 3 | 1 |
| PTA | 13 | 4.3 | 3.4 | 139 | A 1<br>B 9<br>C 3 | 1 |
| PTA + surgery | 7 | 7.2 | 1.5 | 102 | A 2<br>B 2<br>C 2<br>D 1 | 1 |
| Surgery | 10 | 5.6 | 0.4 | 99.4 | A 6<br>B 4 | 0 |

[a] Patients not needing invasive procedures

[b] Patients not amenable to invasive procedures

vascular disease died from a cerebrovascular accident (CVA), another developed claudication and worsening renovascular disease. The BP of the third patient was less than the 95th centile, with evidence of decreased perfusion on a single-photon emission computed tomography (SPECT) cerebral scan.

*Percutaneous transluminal angioplasty*

Of the patients, 36% (13) underwent percutaneous transluminal angioplasty (PTA) at a median age of 8.6 (range 0.3–15.6) years (Table 2). PTA was performed more than once in six patients, with a mean of 1.6 interventions. Five patients underwent PTA for unilateral or bilateral RAS with stenting in all but one patient. Five children had dilatation of the aorta, which was also stented in three of them. PTA of both renal arteries and aorta (in two cases also stented) was performed in three children.

Nine patients achieved better BP control, and one child was normotensive without anti-hypertensive medications. Three patients did not obtain any improvement of their HTN: one patient where no distal renal arteries could be detected on renal angiography, one patient with a re-stenosis of the aorta after angioplasty, and one child who had undergone two attempts of PTA that did not lead to improved BP. For this patient, the parents refused surgical intervention.

*PTA plus surgical treatment*

Among patients treated with PTA for the narrowing of their arteries, seven subsequently also needed surgical treatment (Table 2). The median age at PTA was 6.5 (0.8–10.1) years, whereas the median age for the surgical intervention was 7.6 (1.8–10.3) years. For all patients, the reason for further surgery was failure of angioplasty to improve BP control and, in three children, also worsening renal function.

PTA for either unilateral or bilateral RAS was performed in three children, with stenting in one case. Three patients underwent balloon dilatation of the aorta. In one case the hypertension was treated through dilatation and stenting of both renal arteries and aorta.

Surgical procedures included autologous surgery with renal revascularization (one), synthetic graft interposition for renal revascularization (two) and aortic reconstruction (two) and nephrectomy (two). Owing to persistent severe HTN, a following PTA was necessary for three patients.

At the end of the follow-up period, 28% (2/7) of patients were normotensive without the use of anti-hypertensive agents; two children had improved BP on anti-hypertensive medications. In two patients HTN continued, and one child died from complications of the intervention.

*Surgical treatment*

In 28% (ten) of patients surgery was the only therapeutic approach for the treatment of MAS, after a first attempt with medical treatment (Table 2). The median age at surgery was 4.7 (0.9–10.5) years. The indication for surgery was severe HTN (systolic BP up to 300 mmHg) which was associated with renal dysfunction in five patients. In one case the high complexity of vascular disease was the main reason for surgery; in another three children the surgery represented the only possible approach (therapeutic strategy performed more than 20 years ago). The surgical interventions included autologous surgery for aortic reconstruction (one) and renal

revascularization (three), synthetic graft interposition for renal revascularization (one) and aortic reconstruction (one), and nephrectomy (four). Only one patient was treated with angioplasty after the surgical intervention, and only one needed a second surgical procedure.

At the end of the follow-up period, six patients were off anti-hypertension therapy, five with good BP control (median BP centile: 65th, range 50th–90th ) and one with gradually increasing BP due to a new vascular stenosis, needing a further intervention.

*Long-term outcome of all patients*

The mortality rate was 8% (3/36 patients). One patient with severe bilateral RAS, intrarenal disease and complex vasculopathy managed in the early 1980s was judged not to be amenable to surgery and died after a CVA. The second patient was diagnosed with severe HTN (systolic BP 190 mmHg) at the age of 3 years and cerebrovascular disease and died after two CVAs before the planned surgery could take place. The third death was a patient with bilateral RAS, intrarenal disease and cerebrovascular involvement.

At the end of the follow-up time, 25% (nine) of patients were off therapy (A), 58% (21) still required anti-hypertensive therapy with better BP control (B), 14% (five) of patients continued to have HTN, despite treatment (C), 3% (one) was hypertensive for a technically unsuccessful intervention (D) (Table 2).

Of 33 patients who had survived, 90% (30) obtained an improvement in their HTN, 27 with normal renal function. A total of eight patients (24%) had renal dysfunction at the end of the study (eGFR median value 71 ml/min per 1.73 $m^2$ body surface area, range 52–87 ml/min per 1.73 $m^2$). There was no significant difference between baseline and final eGFR ($P>0.1$).

In the three patients with persistent HTN, two had bilateral RAS and intrarenal disease. Two children had cerebrovascular involvement, one child had chronic kidney disease (CKD; eGFR 55 ml/min per 1.73 $m^2$). All these children underwent multiple invasive treatments during the study period.

## Discussion

This series of 36 children affected by MAS is the largest series to date. All children also suffered from abnormalities in other vascular beds, including 86% with RAS. The vasculature that was felt to be most important for the HTN was treated, and a successful outcome (defined as cured or improved BP) was demonstrated in 90% of patients, although 24% of patients had CKD at the end of a median follow-up time of 4.5 years.

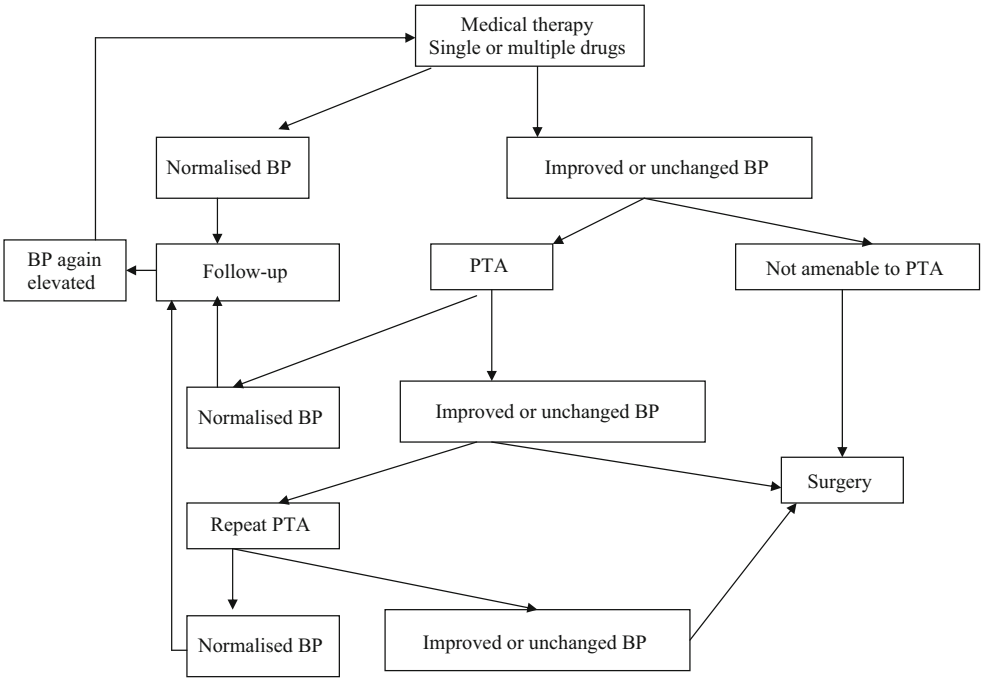
Several studies have documented the clinical features of MAS, thereby contributing to our knowledge of this condition (Table 3). Some of them referred only to idiopathic MAS [1, 25, 26], while other studies included cases of MAS of different aetiologies [10, 27, 28].

A new finding in our study was the low median age at presentation with HTN: 2.7 years, with 33% (12) of patients being diagnosed before they were 8 months old. Previous studies have reported MAS as a disease of late childhood or early adulthood [1, 29], but, more recently, a lower age at diagnosis has been reported, with a mean age of 4.5 years [25]. The trend towards diagnosis in younger children is likely to be the result of more severe cases from tertiary and

**Table 3** Review of the literature

| Author, year | No. of patients | Mean age at presentation | Mean follow-up period | Treatment | BP normalized | BP improved | Total (BP normalized/improved) |
|---|---|---|---|---|---|---|---|
| Messina et al., 1986 [27] | 10 | 19.5 years | 4.1 years | Surgery | 7 (77%) | 2 (23%) | 100% |
| Lewis et al., 1988 [1] | 11 | 9.7 years | 27.3 months | PTA<br>Surgery | 8 (73%) | 1 (9%) | 82% |
| O'Neill et al., 1995 [26] | 17 | 9.7 years | 48 months | PTA<br>Surgery | 12 (70%) | 5 (30%) | 100% |
| Panayiotopoulos et al., 1996 [10] | 13 | 7.1 years | 2.7 years | Medical<br>PTA<br>Surgery | 5 (38%) | 5 (38%) | 76% |
| Connolly et al., 2002 [28] | 8 | 17 years | 6.5 years | Surgery | 3 (37%) | 3 (37%) | 74% |
| Sethna et al., 2008 [25] | 6 | 4.5 years | 6.6 years | Medical<br>Surgery | 3 (50%) | 2 (33%) | 83% |
| This study | 36 | Median 2.7 years<br>Mean 5 years | 6.4 years | Medical<br>PTA<br>Surgery | 9 (27%) | 21 (63%) | 90% |

**Fig. 1** Therapeutic algorithm




quaternary referrals and improved diagnosis for earlier detection of this condition. It is also likely that children previously died before diagnosis and/or intervention.

In this series, MAS often presented with severe symptoms, although it was also diagnosed as an incidental finding in 25% of patients. Many children had involvement of the renal arteries as well as of other major visceral branches, although clinically evident mesenteric ischaemia was not detected in any child, presumably due to a rich collateral circulation. Almost 45% of our children had cerebrovascular disease [11–14], and, in two of the three children who died, the cause of death was due to CVA. Other studies have not reported such a widespread vascular involvement. Visceral arteries have almost invariably been shown to be abnormal [1, 10, 26, 27], but the presence of cerebrovascular disease was rarely recognized in previously reported children [30]. Our data show that it is important to look for cerebrovascular abnormalities in children affected by MAS.

Previous studies emphasized surgical therapy as the best approach for children affected by MAS [14], with early normalization of BP after open surgery in 94% of all cases [31]. This is similar to that for our single-centre patient cohort [32], where 86% of patients had surgery in conjunction with conservative therapy. The results of our study appear to confirm better outcomes for those patients whose MAS was felt to be amenable to surgery alone without PTA. However, this is only a case series, so there may be a selection bias between different treatment groups and changes over time with improvements in angioplasty techniques over the years.

In our study, PTA was a very successful treatment in a proportion of affected children, while, in most previous studies, it has failed to provide a lasting clinical and angiographic improvement [10, 27, 28]. In three children with MAS, PTA with stenting was proven to be effective, in the short to medium term (less then 1 year), by D'Souza et al. [33]. They suggested a possible therapeutic approach to obtain a prompt reduction of extremely high BP, in selected cases not involving renal and mesenteric arteries [34]. In a recent retrospective review at our centre [35], PTA was successful in reducing BP in 55% (18/33) of patients, using different technical approaches for angioplasty of renal arteries and/or aorta.

In our study described now, RVH was treated with PTA of renal arteries alone in eight children, aortoplasty in another eight, and with combined PTA for both renal arteries and abdominal aorta in four children. This approach was decided on the basis of which blood vessel was judged to be most important for causing HTN.

The possibility of medical therapy was reported by Panayiotopoulos et al. [10], who describe an initial moderate to good BP response in patients with MAS. Other authors claim that medical management of MAS with moderate arterial impairment can allow BP control and reduce the risk for complications [6, 7, 25, 34, 36]. In our study, medical therapy had an important role in the management of MAS. There was a small group of children with not too complex and widespread a vasculopathy where well-controlled BP seemed to be achieved with anti-hypertensive agents alone.

We propose a different stepwise treatment policy of MAS, which does not emphasize a single therapeutic option (PTA or surgery) as the best choices for these children, but includes all these treatments in a structured therapeutic

pathway based on the clinical characteristics of patients and validated by a long-lasting multi-disciplinary approach to this condition. Figure 1 suggests a therapeutic algorithm based on our current approach to children with MAS.

Our clinical preference is to delay surgical revascularization until the child is as developed as the clinical situation will allow, preferably to the stage of adolescence. This is because prosthetic conduits are preferable to the saphenous vein, which has a small but real risk of late aneurysmal degeneration. Obviously, prosthetic conduits have no growth potential, and their use in smaller younger children may require a further secondary surgical reconstruction at or after adolescence. Renal stent angioplasty, in our experience, carries a significant in-stent stenosis rate of up to 50%, but it has not compromised the potential for surgical reconstruction in any of the children of our experience. Our policy is, therefore, to use stents, even in younger children, accepting that many will need later re-intervention and eventual surgery but in a bigger child where prosthetic renal revascularization stands a better chance of being the definitive procedure for that individual's life span.

## Conclusions

We report a group of children with MAS that are younger and with more widespread disease then previously described in the literature. Individualized use of medical, interventional and surgical treatments managed to control or improve the BP in 90% of the children.

## References


1. Lewis VD, Meranze SG, McLean GK, Mclean K, O'Neill JA, Berkowitz HD, Burke DR (1988) The midaortic syndrome: diagnosis and treatment. Radiology 167:111–113
2. Sen PK, Kinare SG, Engineer SD, Parulkar GB (1963) The middle aortic syndrome. Br Heart J 25:610–618
3. Watson NA, Chalmers N, Naqvi N (1998) Supradiaphragmatic middle aorta syndrome—MR and angiographic imaging. Br J Radiol 71:213–216
4. Taketani T, Miyata T, Morota T, Takamoto S (2005) Surgical treatment of atypical aortic coarctation complicating Takayasu's arteritis: experience with 33 cases over 44 years. J Vasc Surg 41:597–601
5. De Bakey ME, Garrett HE, Howell JF, Morris GC Jr (1967) Coarctation of the abdominal aorta with renal arterial stenosis: surgical considerations. Ann Surg 165:830–843
6. Graham LM, Zelenock GB, Erlandson EE, Coran AG, Lindenauer SM, Stanley JC (1979) Abdominal aortic coarctation and segmental hypoplasia. Surgery 86:519–529
7. Hallett JW Jr, Brewster DC, Darling RC, O'Hara PJ (1980) Coarctation of the abdominal aorta: current options in surgical management. Ann Surg 191:430–437
8. Terramani TT, Salim A, Hood DB, Rowe VL, Weaver FA (2002) Hypoplasia of the descending thoracic and abdominal aorta: a report of two cases and review of the literature. J Vasc Surg 36:844–848
9. Rhodes AB, O'Donnell SD, Gillespie DL, Rasmussen TE, Johnson CA, Fox CJ, Burklow TR, Hagler DJ (2005) The endovascular management of recurrent aortic hypoplasia and coarctation in a 15-year-old male. J Vasc Surg 41:531–534
10. Panayiotopoulos YP, Tyrrell MR, Koffman G, Reidy JF, Haycock GB, Taylor PR (1996) Midaortic syndrome presenting in childhood. Br J Surg 83:235–240
11. Deal JE, Snell MF, Barratt TM, Dillon MJ (1992) Renovascular disease in childhood. J Pediatr 121:378–384
12. Estepa R, Galleg N, Orte L, Puras E, Aracil E, Ortuño J (2001) Renovascular hypertension in children. Scand J Urol Nephrol 35:388–393
13. Piercy KT, Hundley JC, Stafford JM, Craven TE, Nagaraj SK, Dean RH, Hansen KJ (2005) Renovascular disease in children and adolescents. Vasc Surg 41:973–982
14. Stanley JC, Criado E, Upchurch GR Jr, Brophy PD, Cho KJ, Rechtenwald JE, Michigan Pediatric Renovascular Group, Kershaw DB, Williams DM, Berguer R, Henke PK, Wakefield TW (2006) Pediatric renovascular hypertension: 132 primary and 30 secondary operations in 97 children. J Vasc Surg 441:1219–1228
15. Halpern M, Currarino G (1965) Vascular lesions causing hypertension in neurofibromatosis. N Engl J Med 273:248–252
16. Riemenschreider TA, Emmanouilides GC, Hirose F, Luide LM (1969) Coarctation of the abdominal aorta in children: report of the cases and review of the literature. Pediatrics 44:716–726
17. Siassi B, Klyman G, Emmanouilides GC (1970) Hypoplasia of the abdominal aorta associated with the rubella syndrome. Am J Dis Child 120:476–479
18. Flynn PM, Robinson MB, Stapelton FB, Roy S 3rd, Koh G, Tonkin IL (1984) Coarctation of the aorta and renal artery stenosis in tuberous sclerosis. Pediatr Radiol 14:337–339
19. Inada K, Shimizu J, Kobayashi T, Ishiai S, Kamamoto S (1962) Pulseless disease and atypical coarctation of the aorta. Arch Surg 84:306–311
20. Daimon S, Kitamura K (1964) Coarctation of the abdominal aorta. Jpn Heart J 5:562–573
21. Tullus K, Brennan E, Hamilton G, Lord R, McLaren CA, Marks SD, Roebuck DJ (2008) Renovascular hypertension in children. Lancet 371:1453–1463
22. Brun P, Kchouk H, Mouchet B, Baudouin V, Raynaud A, Loirat C, Azancot-Benisty A (1997) Value of Doppler ultrasound for the diagnosis of renal artery stenosis in children. Pediatr Nephrol 11:27–30
23. Ellis D, Shapiro R, Scantlebury VP, Simmons R, Towbin R (1995) Evaluation and management of bilateral renal artery stenosis in children: a case series and review. Pediatr Nephrol 9:259–267
24. Schwartz GJ, Haycock GB, Edelmann CM Jr, Spitzer A (1976) A simple estimate of glomerular filtration rate in children derived from body length and plasma creatinine. Pediatrics 58:259–263
25. Sethna CB, Kaplan BS, Cahill AM, Velazquez OC, Meyer KEC (2008) Idiopathic mid-aortic syndrome in children. Pediatr Nephrol 23:1135–1142
26. O'Neill JA Jr, Berkowitz H, Fellows KJ, Harmon CM (1995) Midaortic syndrome and hypertension in childhood. J Pediatr Surg 30:164–172
27. Messina LM, Goldstone J, Ferrell LD, Reilly LM, Ehrenfeld WK, Stoney RJ (1986) Middle aortic syndrome. Effectiveness and durability of complex arterial revascularization techniques. Ann Surg 204:331–339
28. Connolly JE, Wilson SE, Lawrence PL, Fujitani RM (2002) Middle aortic syndrome: distal thoracic and abdominal coarctation, a disorder with multiple etiologies. J Am Coll Surg 194:774–781
29. Bleacher J, Turner ME, Quivers E, Schwartz MZ (1997) Renal autotransplantation for renovascular hypertension caused by midaortic syndrome. J Pediatr Surg 32:248–250

30. Kuzeyli K, Cakir E, Dinc H, Sayin OC (2003) Midaortic syndrome and subarachnoid hemorrhage associated with ruptured middle cerebral artery aneurysm: case report and review of the literature. Neurosurgery 52:1460–1463, discussion 1463–1464
31. Delis KT, Gloviczki P (2005) Middle aortic syndrome: from presentation to contemporary open surgical and endovascular treatment. Perspect Vasc Surg Endovasc Ther 17:187–206
32. Stadermann M, Lord R, Hamilton G, Roebuck D, McLaren C, Dillon M, Marks S, Tullus K (2007) Surgical treatment for renovascular hypertension in children. Pediatr Nephrol 22: 1440–1447
33. D'Souza SJ, Tsai WS, Silver MM, Chait P, Benson LN, Silverman E, Hebért D, Balfe JW (1998) Diagnosis and management of stenotic aorto-arteriopathy in childhood. J Pediatr 132:1016–1022
34. Keith DS, Markey B, Schiedler M (2002) Successful longterm stenting of an atypical descending aortic coarctation. J Vasc Surg 35:166–167
35. Shroff R, Roebuck DJ, Gordon I, Davies R, Stephens S, Marks S, Chan M, Barkovics M, McLaren CA, Shah V, Dillon MJ, Tullus K (2006) Angioplasty for renovascular hypertension in children: 20-year experience. Pediatrics 118:268–275
36. Patman RD, Shutze WP (1995) Non-atherosclerotic vascular diseases and conditions. In: Dean RH, Yao JST, Brewster DC (eds) Current diagnosis and treatment in vascular surgery. Prentice Hall, London, pp 172–192