Are all rings created equal? A single centre experience of fetal and paediatric vascular rings

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Abstract

Background: Vascular rings cause highly variable clinical presentations. This study assesses the impact of prenatal versus postnatal diagnosis on clinical outcomes. *Methods:* We conducted a single centre retrospective review of isolated vascular ring patients (without significant CHD) from 2011 to 2022 and compared clinical and operative data between patients with prenatal and postnatal diagnoses. *Results:* Of 177 patients, 45% (N = 80) had prenatal diagnosis. Between 2018 and 2022, 78% had prenatal diagnosis compared to 41% from 2013 to 2018 and 4% before 2013 ($p < 0.001$). 76.3% (N = 135) had a right aortic arch with left ligamentum arteriosum, 22.6% (N = 40) had a double aortic arch, and 1.1% (N = 2) had a left aortic arch with right ligamentum arteriosum. Postnatal diagnosis patients were more likely to have preoperative respiratory symptoms (55.7%), medications (34.0%), or admissions (24.7%) (versus 32.5%, 10.0%, and 11.3% of the prenatal diagnosis patients, $p < 0.05$) and require surgical repair (68.0% versus 38.8% of prenatal diagnosis patients, $p < 0.0001$). 54.8% of patients had surgical repair; prenatal diagnosis patients were younger at surgery, 7.5 (3-11) months compared to 16.0 (5-18) months in the postnatal diagnosis patients ($p = .0014$). Double aortic arch patients were more likely to require surgical repair (90.0%, compared to 44.5% with right aortic arch, $p < 1e^{-4}$). Postnatal diagnosis patients had more residual postoperative symptoms (40.9% versus 16.1% in prenatal diagnosis patients, $p = 0.01$). *Conclusion:* Prenatal diagnosis of vascular rings improves clinical surveillance, resulting in earlier surgical repair in symptomatic patients and diminished morbidity. Higher risk double aortic arch patients should have a tailored evaluation pathway.

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Introduction

A vascular ring is a congenital vascular anomaly in which blood vessels or ligaments completely encircle the trachea and oesophagus. Patients with vascular rings may have a wide range of clinical sequelae—some remain asymptomatic through adulthood while others may have aerodigestive issues in the neonatal period[1,2]. Severe disease burden may be associated with stridor, wheezing, respiratory distress, or pulmonary infections due to tracheobronchomalacia or dysphagia due to oesophageal compression. Conversely, patients may have mild, chronic respiratory or gastrointestinal symptoms that may have been wrongly attributed to another condition such as asthma or gastroesophageal reflux[3,4].

The true incidence of isolated vascular rings is unknown but estimated to account for approximately 1.5% of CHD[1,5–7] and 1 in 10,000 live births[5]. Vascular rings may occur in isolation or be associated with other forms of CHD[1]. Historically, vascular rings were diagnosed on postnatal imaging due to clinical suspicion or, less often, incidentally diagnosed by cardiothoracic imaging. Over the past 10 years, there has been a significant increase in prenatal diagnosis of CHD and specifically vascular rings[8–11], likely attributable to 2018 and 2019 guidelines from the American Institute of Ultrasound in Medicine on standard diagnostic obstetric as well as detailed perinatal ultrasound to include the three-vessel and trachea view[12,13].

Given the wide spectrum in the natural history of vascular rings, there is controversy amongst clinicians regarding timing of cross-sectional imaging, more invasive aerodigestive evaluation (such as esophagram, bronchoscopy, and/or endoscopy), and surgical intervention. There is consensus for surgical repair in symptomatic patients, but some centres advocate elective repair of all cases, while others advocate for clinical observation in asymptomatic patients[13]. Surgical repair of vascular rings involves division of the double aortic arch and/or ductus (or ligamentum) arteriosus via thoracotomy (or less common via minimally invasive thoracoscopy[14]); some surgeons may reimplant the aberrant subclavian artery and/or resect the diverticulum of Kommerell[3]. A recent meta-analysis of surgical outcomes for vascular rings concluded that further studies are needed to determine how prenatal diagnosis may impact outcomes and if earlier diagnosis and treatment may limit persistent symptoms[15].

This study reviews outcomes of fetal and paediatric patients with isolated vascular rings at a single paediatric centre and compares outcomes between prenatal and postnatal diagnosis. The primary outcome measure is age at surgical repair. Secondary outcome measures include frequency of associated respiratory and/or gastrointestinal symptoms before and after surgery, postoperative complications, and re-intervention. We evaluated whether fetal echocardiogram measurements could prognosticate patient symptoms and surgical repair. We hypothesise that patients with prenatal diagnosis would undergo earlier surgical repair in addition to decreased time living with disease, respiratory and/or gastrointestinal symptoms, and less need for re-intervention.

Materials and methods

We conducted a single paediatric centre retrospective review of patients with isolated vascular rings from January 2011 to December 2022. Inclusion criteria included fetuses and children up to 21 years of age at the time of diagnosis of a vascular ring (double aortic arch, right aortic arch with a left ductus (or ligamentum) arteriosus or left aortic arch with right ductus (or ligamentum) arteriosus). Eligible patients were identified from SyngoDynamics echocardiogram database, Society of Thoracic Surgeons – Congenital Heart Surgery Database, and key words from EPIC electronic medical record. Vascular ring type was based on surgical inspection as the gold standard (if repaired) or cross-sectional/echocardiography imaging (if unrepaired). Exclusion criteria included patients with additional CHD that required surgical intervention at the time or within one year of vascular ring repair. Vascular anomalies not resulting in a ring ("incomplete vascular rings" such as isolated aberrant subclavian arteries, right aortic arches without left patent ductus arteriosus or ligamentum arteriosum, and pulmonary artery slings) were excluded.

For patients with prenatal diagnosis, fetal demographics, echocardiogram, and clinical information were obtained from mother's chart, when available. Han et al published angle measurement between the right and left aortic arch or between the right aortic arch and its first branch to distinguish a double from right aortic arch[16]. Extrapolating on this theory, we evaluated if the angle of the arteries may prognosticate which patients are symptomatic and need repair. The fetal descending aorta position was noted, as a midline descending aorta has been shown to predict symptoms and likelihood of vascular ring surgical repair[17]. Postnatal demographic, clinical, and operative data were extracted from medical records. Postoperative mortality was defined as 30 days. Follow-up time frame was calculated from the most recent visit with cardiology, gastroenterology, otolaryngology, pulmonology, or primary care physician.

We represent our data through descriptive statistics, which are presented as median [min, max] for continuous data and n (%) for categorical data. Upon visual exploration of our continuous variables of interest, we found them to be non-normally distributed. Due to the non-normality, we implemented non-parametric Mann–Whitney U statistical tests to assess for statistical differences within our continuous variables. For our categorical data, we implemented chi-squared tests to determine whether there were associations between our variables of interest. P-values <0.05 were considered statistically significant at the 5% level. All analyses were performed on Version 1.4.1106-5 in RStudio Server Pro. This study was approved by the University of California San Diego Institutional Review Board (#801855).

Results

579 patients were initially identified using database search criteria. 177 patients met study criteria and were included. 402 patients were excluded: 325 had significant CHD, 62 had right aortic arch without vascular ring, and 15 had a left aortic arch without vascular ring (Fig 1).

All patients

Of the 177 patients included in the study, the patient population was varied without statistically significant differences between the prenatal and postnatal diagnosis patients regarding sex, race, and ethnicity (Supplemental Table 1). 76.3% (N = 135) had a right aortic arch with left ligamentum arteriosum and aberrant left subclavian artery, 22.6% (N = 40) had a double aortic arch, and 1.1% (N = 2) had a left aortic arch with a right ligamentum arteriosum. 154 (87.0%) of patients underwent advanced aero-digestive or imaging studies (barium swallow or esophagram, bronchoscopy, CT, or MRI). Several patients had multiple additional studies; 35 (22.7%) had barium swallow/esophagram, 63 (40.9%) bronchoscopy, 106 (68.8%) CT, and 56 (36.4%) had MRI imaging. Eighty (45.2%) patients had preoperative airway symptoms, for which 41 (23.2%) were prescribed medications, and 33 (18.6%) had admission(s) for asthma or reactive airway disease. Sixty-three (35.6%) patients had preoperative dysphagia symptoms, of which 12 (6.8%) were prescribed medications (Table 1).

Seventy-seven patients (43.5%) had either prenatal and/or postnatal genetic testing. 13.6% (N = 24) patients had a genetic anomaly identified and, within this group, DiGeorge syndrome was the most common anomaly affecting 4.5% (N = 8) of patients. Other genetic diagnoses included Trisomy 21 (N = 5), mutations in CHD7 gene (N = 3), neurofibromatosis (N = 2), and 1 patient each with Alagille syndrome, Williams syndrome, Klippel-Feil Syndrome, 2q11 deletion, 2q12 deletion, 4q22 deletion, 9q22 deletion, CDH7 mutation, chromosome 6 homozygosity, and mutation in CATSPER2/STRC. The median length of follow-up for all patients was 4.3 (1.6-8.4) years.

Prenatal diagnosis

Eighty patients (45.2% of study subjects) had a prenatal diagnosis of vascular ring, with a mean gestational age of 26 weeks at diagnosis. 77.5% (N = 62) had prenatal diagnosis in those born between 2018 and 2022, 41.3% (N = 33) from 2013 to 2018 and 3.8% (N = 3) before 2013 (p < 0.001). The most common indication for fetal echocardiogram was an abnormal 3 vessel view (85%, N = 68). Prenatal diagnosis was 97.5% accurate in delineating vascular ring type. Two patients had discrepant diagnoses between prenatal diagnosis versus postnatal imaging (confirmed intraoperatively). One patient born before 2013 had prenatal diagnosis of double aortic arch with dominant right arch and postnatally found to have a right aortic arch with left ligamentum arteriosum. One patient born between 2014 and 2018 had prenatal diagnosis at an outside institution of right aortic arch and postnatally found to have a double aortic arch with dominant right arch. The majority of prenatal diagnosis patients, 89% (N = 71) had right aortic arch, while only 11% (N = 9) had double aortic arch (Fig 2). Of the fetal echocardiograms available for review (N = 64), 43.8% (N = 28) had a midline descending aorta and 56.3% (N = 36) had a right descending aorta. There was no statistical difference in whether a vascular ring repair was
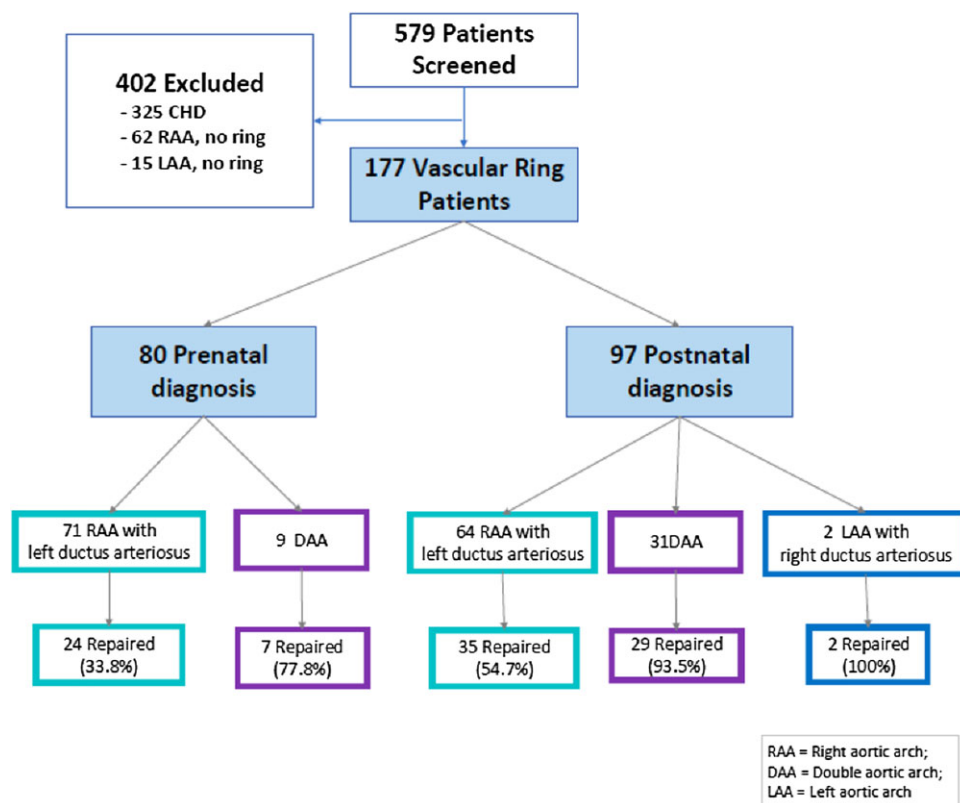
Figure 1. Schematic detailing patients included in study and breakdown by timing of diagnosis, type of vascular ring, and whether or not surgery was completed.

completed (p = 0.97) associated with the descending aorta position or the angle of arches (p = 0.42) (Supplemental Table 2).

Thirty-nine percent (N = 31) of prenatal diagnosis patients underwent surgical repair, with median age at repair of 7.5 (3-11) months which was significantly earlier compared to postnatal diagnosis patients with median age at repair of 16.0 (5-81) months (p = 0.0014). The median length of follow-up for prenatally diagnosed patients was 2.3 (0.9-4.1) years (Table 1).

Sixty-one percent (49/80) of the prenatally diagnosed patients were unrepaired at the time of data analysis, with a median follow-up of 19.6 months (9.7 months – 8.3 years). Most (95%, 47/49) of these patients had a right aortic arch with left ligamentum arteriosum. One patient with double aortic arch was referred at 6 months for advanced cardiac imaging and aerodigestive evaluation but has been lost to follow-up. Another patient with double aortic arch with dominant right and small left aortic arch had no airway compression on CT imaging, remained asymptomatic at 7 years, and has to date elected not to have surgical repair.

Postnatal diagnosis

Ninety-seven patients (54.8% of study subjects) had a postnatal diagnosis of vascular ring, with a median age at diagnosis of 12.4 (0.8-86) months. Two patients were noted to have had a fetal echo in the earliest birth era, which did not detect the vascular ring. A higher portion of postnatal diagnosis patients, 32% (N = 31), had double aortic arch compared to the prenatal diagnosis group. Of note, two patients diagnosed postnatally with right aortic arch and aberrant left subclavian artery were found to have a double aortic arch with an atretic left arch at the time of surgery. Postnatal diagnosis patients were more likely to have preoperative respiratory symptoms (55.7%), medications (34.0%), or admissions (24.7%), compared to the prenatal diagnosis patients with

32.5%, 10.0%, and 11.3%, respectively (p < 0.05) (Table 1). There was no significant difference in the preoperative need for dysphagia or reflux medications between the prenatal or postnatal groups (Table 1). The median length of follow-up for postnatal diagnosis patients was 7.2 (3.9-13.6) years.

Surgical patients

Ninety-seven (54.8%) of all patients underwent surgical repair. Of these patients, 59 (60.8%) had a right aortic arch with left ligamentum arteriosum and aberrant left subclavian artery, 36 (37.1%) had a double aortic arch and 2 (2.1%) had a left aortic arch with right ligamentum arteriosum. Eight (4.5%) of all patients required neonatal repair due to respiratory insufficiency, half of whom had double aortic arch. Patients with postnatal diagnosis were more likely to have surgical repair at 68.0% versus 38.8% of prenatal diagnosis patients (p < 0.0001) (Table 2). Patients with a double aortic arch were more likely to require surgical repair (89.5%) as compared to either a right or left aortic arch with contralateral ligamentum arteriosum (44.5%, p < 0.0001), with no significant difference in age at repair or preoperative respiratory symptoms for double aortic arch versus other vascular ring surgical patients (Supplemental Table 3a & 3b).

Of the double aortic arch repairs, 4 patients (11.1%) included resection of the diverticulum in addition to division of the double arch and ligamentum arteriosum. Of the right aortic arch repairs, 18 patients (30.5%) included resection of the diverticulum in addition to patent ductus arteriosus/ligamentum arteriosum division.

There was no significant difference in postoperative length of intubation or length of stay in the prenatal versus postnatal diagnosis patients (Table 2). Nine total patients required reoperation. Reoperation rates were similar in the prenatal

Table 1. Comparing prenatal and postnatal diagnosis preoperative and postoperative outcomes

	Prenatal (N = 80)	Postnatal (N = 97)	p-value
Postnatal vascular ring diagnosis			
Double aortic arch	9 (11.3%)	31 (31.9%)	0.0015
Left aortic arch with right ductus arteriosus	0 (0%)	2 (2.1%)	
Right aortic arch with left ductus arteriosus	71 (88.8%)	64 (66.0%)	
Vascular ring repair done			
No	49 (61.3%)	31 (32.0%)	< 1e-04
Yes	31 (38.8%)	66 (68.0%)	
Preoperative history of airway symptoms			
No	53 (66.3%)	43 (44.3%)	0.00256
Yes	26 (32.5%)	54 (55.7%)	
Preoperative hospital admission for asthma or reactive airway disease			
No	70 (87.5%)	73 (75.3%)	0.02402
Yes	9 (11.3%)	24 (24.7%)	
Preoperative number of hospital admissions for asthma or reactive airway disease			
Not admitted	71 (88.8%)	73 (75.3%)	0.02395
One admission	9 (11.3%)	18 (18.6%)	
Multiple admissions	0 (0%)	6 (6.2%)	
Preoperative respiratory medication			
No	71 (88.8%)	64 (66.0%)	0.00019
Yes	8 (10.0%)	33 (34.0%)	
Preoperative history of dysphagia			
No	54 (67.5%)	58 (59.8%)	0.19611
Yes	24 (30.0%)	39 (40.2%)	
Preoperative reflux medication			
No	74 (92.5%)	88 (90.7%)	0.78765
Yes	5 (6.3%)	7 (7.2%)	
Postnatal genetic testing			
No	53 (66.3%)	72 (74.2%)	0.24623
Yes	27 (33.8%)	25 (25.8%)	
Postnatal genetic diagnosis			
All diagnoses	67 (83.8%)	88 (90.7%)	0.16176
Normal	13 (16.3%)	9 (9.3%)	
Extracardiac lesions			
No	51 (63.8%)	54 (55.7%)	0.27612
Yes	29 (36.3%)	43 (44.3%)	

diagnosis (4.1%, N = 4, of surgical patients) versus postnatal diagnosis (5.1%, N = 5, of surgical patients) patients (p = 0.408). Patients who underwent reoperation were more likely to have respiratory symptoms (7/9) than dysphagia symptoms (2/9). Reoperation included aortopexy alone (N = 5), slide tracheoplasty (N = 1), tonsillectomy (N = 1), tracheostomy (N = 1), and LeCompte procedure with pulmonary artery reconstruction and aortopexy (N = 1). Postnatal diagnosis patients were more likely to have residual symptoms (mostly respiratory) after repair (41% vs.

16% in prenatal diagnosis patients, $p = 0.01$). There were no postoperative mortalities in our study cohort. The median (interquartile range) length of follow-up for patients who underwent surgical repair was 2.5 (1.0-4.4) years.

Discussion

The incidence and types of isolated vascular ring varies among reports, and some studies include vascular anomalies that are not
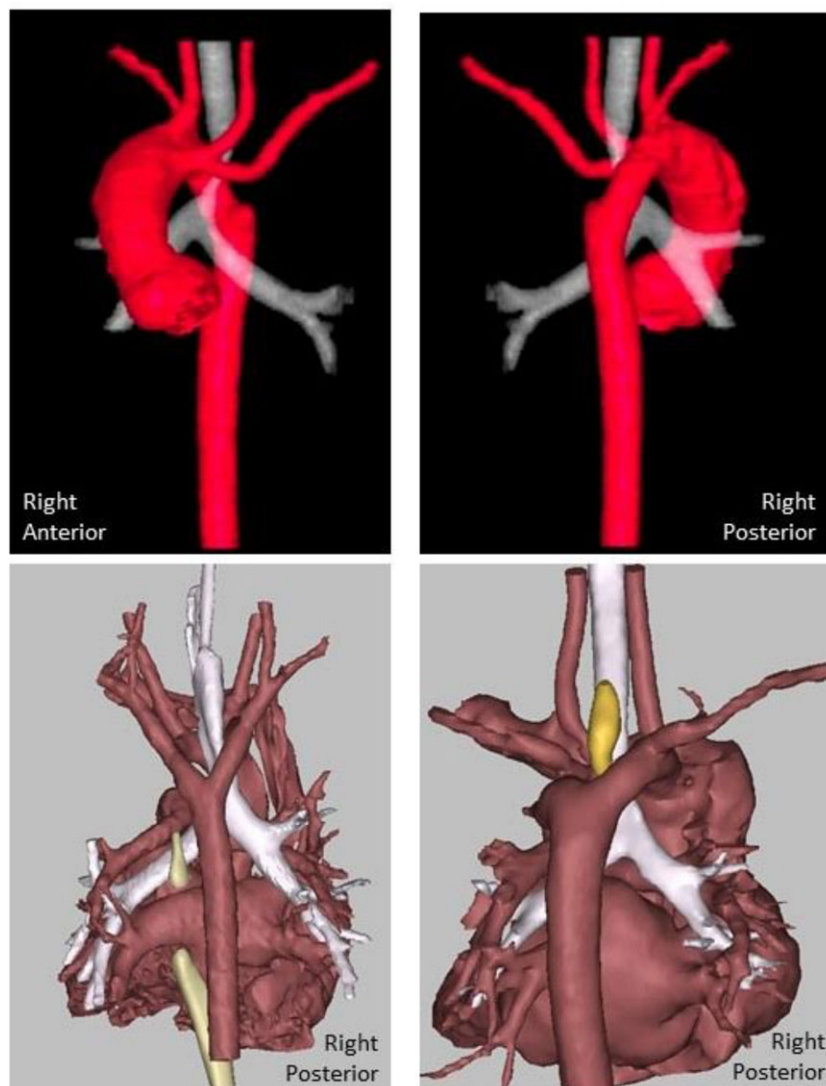
Figure 2. Three-dimensional reconstruction cardiac CT images in a patient with double aortic arch causing significant tracheal and esophageal compression. Vessels and cardiac structures shown in red, airway shown in white, and parts of the esophagus can be seen in yellow.

true (or "incomplete") vascular rings (such as left pulmonary artery sling, right aortic arch with mirror image branching, or left aortic arch with aberrant right subclavian artery)[3]. In our study, right aortic arch with left ligamentum was most common (76%) followed by double aortic arch (22%). We hypothesise that as prenatal, and therefore incidental, detection of vascular ring increases, right aortic arch with left ligamentum/ductus arteriosus will be the dominant type as compared to historical series in which double aortic arches made up a larger portion due to bias towards symptomatic and surgical patients[15]. In contrast, another contemporary single centre study in 2022 noted a higher proportion of double aortic arches, which accounted for 58% of cases[18]; this may be due to a smaller proportion of prenatally diagnosed patients (29%) in their study cohort.

Patients with double aortic arch anatomy are more likely to have severe symptoms, leading to earlier diagnosis and increased rate of repair as compared to other vascular rings[19,20]. Nearly 90% of patients with double aortic arch in our study required surgery (regardless of timing of diagnosis) as compared to roughly 45% of other vascular rings. Half of neonatal vascular ring repair patients had a double aortic arch. Although double aortic arch diagnoses

have historically been grouped with right aortic arch vascular rings, our study supports a tailored clinical management pathway for this higher risk group of vascular ring patients.

Vascular rings are typically a different clinical entity from congenital high airway obstruction syndrome, although rare cases of double aortic arch causing congenital high airway obstruction have been reported[21,22]. Some institutions recommend fetuses with double aortic arches be delivered at an institution equipped with neonatal cardiac intervention due to higher risk of respiratory compromise[8]. In contrast, fetuses with right aortic arch vascular rings are rarely symptomatic at birth and can be delivered per the obstetrician/patient family preference[8].

In our study, we considered cross-sectional imaging/echocardiography to be the gold standard for diagnosis in unrepaired patients and surgical inspection in those with repair. There were few discrepancies with this approach, though there were two patients diagnosed with a right aortic arch and aberrant left subclavian artery postnatally who ultimately had a double aortic arch with an atretic left arch at time of surgery. It is worth noting that the ligamentum arteriosum may not be as clearly seen on postnatal cross-sectional or echocardiographic imaging as the

Table 2. Surgical outcomes comparing prenatal and postnatal diagnosis patients

	Prenatal Diagnosis	Postnatal Diagnosis	p value
	(N = 31)	**(N = 66)**	
Age at surgical repair (days)			
Mean (SD)	242 (205)	1460 (1870)	0.0014
Median [Min, Max]	224 [3.00, 761]	480 [3.00, 6390]	
Type of procedure			
Diverticulum resection	7 (22.6%)	15 (22.7%)	0.45567
Divide the double aortic arch	8 (25.8%)	27 (40.9%)	
PDA division	28 (90.3%)	56 (84.8%)	
Reimplantation aberrant subclavian artery	4 (12.9%)	4 (6.1%)	
Reason for surgery			
Imaging Finding	24 (77.4%)	44 (66.7%)	0.45019
Parental preference	0 (0%)	1 (1.5%)	
Symptoms	23 (74.2%)	50 (75.8%)	
Preoperative history of airway symptoms			
No	13 (41.9%)	20 (30.3%)	0.25948
Yes	18 (58.1%)	46 (69.7%)	
Preoperative hospital admission for respiratory symptoms			
No	24 (77.4%)	45 (68.2%)	0.34915
Yes	7 (22.6%)	21 (31.8%)	
Preoperative number of hospital admissions for respiratory symptoms			
Not admitted	24 (77.4%)	45 (68.2%)	0.269
One admission	7 (22.6%)	16 (24.2%)	
Multiple admissions	0 (0%)	5 (7.6%)	
Preoperative respiratory medications			
No	27 (87.1%)	38 (57.6%)	0.00393
Yes	4 (12.9%)	28 (42.4%)	
Preoperative history of dysphagia			
No	14 (45.2%)	31 (47.0%)	0.86773
Yes	17 (54.8%)	35 (53.0%)	
Preoperative reflux medication			
No	28 (90.3%)	58 (87.9%)	0.86993
Yes	3 (9.7%)	7 (10.6%)	
Intubated pre-surgery			
No	28 (90.3%)	61 (92.4%)	0.72568
Yes	3 (9.7%)	5 (7.6%)	
Length of intubation (days)			
Median [Min, Max]	0 [0, 11.0]	0 [0, 30.0]	0.73119
Length of stay postoperatively (days)			
Median [Min, Max]	4.00 [2.00, 77.0]	3.00 [2.00, 106]	0.32237
Mortality			
No	30 (96.8%)	66 (100%)	0.14246

(Continued)

Table 2. (*Continued*)

	Prenatal Diagnosis	Postnatal Diagnosis	p value
Postoperative complications			
No	18 (58.1%)	49 (74.2%)	0.12632
Yes	12 (38.7%)	16 (24.2%)	
Long-term follow-up residual symptoms			
No	19 (61.3%)	37 (56.1%)	0.07311
Yes	3 (9.7%)	19 (28.8%)	
Residual symptoms			
No	24 (77.4%)	33 (50.0%)	0.01054
Yes	5 (16.1%)	27 (40.9%)	
Types of residual symptoms (requiring medications)			
Dysphagia	1 (3.2%)	8 (12.1%)	0.54862
Respiratory	5 (16.1%)	20 (30.3%)	
Need for reoperation			
No	25 (80.6%)	56 (84.8%)	0.40821
Yes	4 (12.9%)	5 (7.6%)	

ductus arteriosum in prenatal imaging. This, theoretically, could lead to more accurate diagnoses from prenatal fetal cardiac imaging.

Our study found that postnatal diagnosis patients underwent vascular ring repair more frequently than prenatal diagnosis patients, similar to other published studies[11,18]. There are likely people with undiagnosed vascular rings who do not have significant symptoms or anatomic compression requiring surgery. Those who are diagnosed postnatally are more often discovered during work-up for significant aerodigestive symptoms and thus have clinical indications for surgical repair. Patients with a prenatal diagnosis of vascular ring may more often be asymptomatic due to incidental diagnosis and be less likely to require surgical repair. As incidental prenatal diagnosis of isolated vascular rings increases, future studies should evaluate whether there is a shift in prevalence of surgical repair in these patients. Isolated vascular ring repair results in good surgical outcomes with low mortality, complication, and re-intervention rates[15]. Specifically, this recent meta-analysis of 19 studies only included two studies that reported the prenatal diagnosis rate, further emphasising the importance of distinguishing between prenatal and postnatal diagnosis groups and increased surveillance on long-term outcomes.

An association with DiGeorge/22q11 deletion syndrome has been described in 10-20% of patients with vascular rings[23,24]. We recommend genetic counselling and testing consideration in all patients with vascular rings; genetic testing variation in our study is likely due to practice differences among obstetric and paediatric providers. When vascular rings are diagnosed in isolation without additional congenital anomalies, provider counselling emphasis on potential genetic associations may be variable and influence familial decision-making to pursue genetic testing. Our study found 31% of those obtaining genetic testing identified a genetic anomaly, with DiGeorge/22q11 deletion syndrome comprised a smaller percentage (4.5%) in our study cohort. With increased incidental/prenatal diagnosis, the true prevalence of

DiGeorge/22q11 deletion syndrome in isolated vascular ring patients may be lower than historically quoted, but other genetic anomalies may be identified with more widespread genetic testing.

To our knowledge, this is the largest studied prenatal cohort of patients with isolated vascular rings. We aimed to evaluate a homogenous population of isolated vascular rings, in contrast to other studies that included patients with vascular rings associated with CHD (0 to 50%, Supplemental Table 4)[15]. The prenatal diagnosis rate of vascular rings is increasing as utilisation of the three-vessel tracheal view has become more prevalent in obstetrical ultrasound. Recent population studies suggest a higher incidence of isolated vascular rings than historically recognised; a contemporary study in Nevada found 7 per 10,000 live births are affected with isolated vascular rings[25]. In the recent era within our study, over 75% of patients with isolated vascular rings had a prenatal diagnosis. With increasing prenatal diagnoses, we are likely uncovering a larger cohort of patients that may have previously gone undiagnosed without experiencing clinical sequelae. Studies have shown a lack of consistent approach to vascular rings even among fetal cardiology experts regarding postnatal work-up, management, and indications for surgical repair[38]. As clinicians, we should continue to assess whether the risk of surgery, even if minimal, outweighs the risk of clinical monitoring. It is important to follow this growing population over time to define the optimal timing for surgical repair.

Prenatal diagnosis allows for clinical surveillance in the neonatal period and results in earlier surgical repair compared to postnatal diagnosis[8,18]. While multiple studies demonstrate earlier surgical repair in prenatal diagnosis patients, the timing is highly variable. Prenatal diagnosis patients were repaired at a median of 4.8 (interquartile range 0.5-24) months in one 2022 study[18], compared to 7.5 (interquartile range 3-11) months in our study and 13.1 months in yet another study[8]. The timing of vascular ring repair is likely multifactorial and includes consideration of patient features, family or surgeon preferences in

addition to institutional practice variation. Some centres and surgeons opt for early elective repair in infancy in all (including asymptomatic) patients to prevent long-term sequelae[8,26]. Other centres, such as ours, tend towards repair when clinically indicated with symptoms or notable oesophageal or tracheal compression on imaging. Prenatal diagnosis allows for proactive clinical surveillance, multi-modality evaluation of the aerodigestive tracts in asymptomatic patients, and earlier management of developing symptoms related to the vascular ring. Patients with postnatal diagnosis have more preoperative respiratory morbidity as compared to prenatal diagnosis patients. These patients often have a delay identifying the vascular ring as the underlying cause for respiratory and/or gastrointestinal symptoms. Residual postoperative respiratory symptoms were more often reported in patients with postnatal diagnosis (41%) as compared to prenatal diagnosis patients (16%), which has been shown in similar studies[18]. These findings emphasise the importance of early vascular ring detection to guide aerodigestive evaluation and optimal timing of surgical repair. Patients at our institution are now followed serially by a multidisciplinary vascular ring team (including cardiology, gastroenterology, otolaryngology, pulmonary, feeding therapists, and speech-language pathologists). Shorter time living with disease may result in earlier resolution of tracheobronchial compression/malacia secondary to the vascular ring constriction.

Our study represents a single centre experience, which may be influenced by institutional practice and surgeon preferences, but to our knowledge is the largest homogenous cohort of prenatal patients with vascular rings published to date. Selection bias exists as the study could not identify/include undiagnosed asymptomatic vascular ring patients. Our fetal/paediatric cardiologists rely on obstetrical providers to screen and refer patients either at risk for cardiac anomalies or with abnormal screening views on obstetrical ultrasounds; our fetal echocardiogram protocol was unchanged over the study period. Improved prenatal diagnosis in our institution is likely due to changes in obstetrical screening policies and referral patterns, which may not be generalisable to different healthcare systems. We acknowledge inherent limitations of retrospective studies, such as potential recall and recording biases, which have inferior level of evidence compared to prospective studies.

Increasing prenatal diagnosis of vascular rings may improve clinical surveillance leading to earlier surgical repair in symptomatic patients to diminish pre- and postoperative respiratory morbidity. Higher risk double aortic arch patients should have a tailored evaluation pathway. As isolated vascular rings are more often diagnosed incidentally, additional studies should be pursued to demonstrate whether early surgical repair would be beneficial in all cases, including patients who are asymptomatic. Our institution evaluates and manages vascular ring patients with a multidisciplinary clinic with collaboration from cardiology, pulmonology, otolaryngology, gastroenterology, and feeding specialists. This approach helps to determine the clinical impact of the vascular ring on the aerodigestive tract and determine indications for and timing of vascular ring repair. Future long-term studies are needed in this growing cohort of prenatally diagnosed patients to determine whether all vascular ring patients should undergo surgical repair and the optimal timing to minimise operative risk.

References

1. Humphrey C, Duncan K, Fletcher S. Decade of experience with vascular rings at a single institution. Pediatrics 2006; 117 (5): e903–e908. DOI: 10.1542/peds.2005-1674.
2. Naimo PS, Fricke TA, Donald JS, et al. Long-term outcomes of complete vascular ring division in children: a 36-year experience from a single institution. Interact Cardiovasc Thorac Surg. 2017; 24 (2): 234–239. DOI: 10.1093/icvts/ivw344.
3. Worhunsky DJ, Levy BE, Stephens EH, Backer CL. Vascular rings. Semin Pediatr Surg. 2021; 30 (6): 151128. DOI: 10.1016/j.sempedsurg.2021.151128.
4. Zhou Y, Zhou Y, Yu T, Li W, Zhang J, Zhang C. Vascular ring: prenatal diagnosis and prognostic management based on sequential cross-sectional scanning by ultrasound. BMC Pregnancy Childbirth. 2023; 23 (1): 308. DOI: 10.1186/s12884-023-05637-y.
5. Bjornard K, Riehle-Colarusso T, Gilboa SM, Correa A. Patterns in the prevalence of congenital heart defects, metropolitan Atlanta&comma. Birth Defects Res A Clin Mol Teratol. 2013; 97 (2): 87–94. DOI: 10.1002/bdra.23111 2013.
6. Hoffman JIE, Kaplan S. The incidence of congenital heart disease. (2002).
7. Mitchell SC, Korones SB, Berendes HW. Congenital heart disease in 56,109 births incidence and natural History 1971, http://ahajournals.org.
8. Stephens EH, Eltayeb O, Kennedy C, et al. Influence of fetal diagnosis on management of vascular rings. Ann Thorac Surg. 2022; 113 (2): 630–636. DOI: 10.1016/j.athoracsur.2021.01.025.
9. Bravo-valenzuela NJ, Peixoto AB, Araujo Júnior E. Prenatal diagnosis of congenital heart disease: a review of current knowledge. Indian Heart J. 2018; 70 (1): 150–164. DOI: 10.1016/j.ihj.2017.12.005.
10. Evans WN, Acherman RJ, Ciccolo ML, et al. Vascular ring diagnosis and management: notable trends Over 25 Years. World J Pediatr Congenit Heart Surg. 2016; 7 (6): 717–720. DOI: 10.1177/2150135116661279.
11. Young AA, Hornberger LK, Haberer K, et al. Prenatal detection, comorbidities, and management of vascular rings. Am J Cardiol. 2019; 123 (10): 1703–1708. DOI: 10.1016/j.amjcard.2019.02.030.
12. J Ultrasound Med. AIUM practice parameter for the performance of detailed second- and third-trimester diagnostic obstetric ultrasound examinations. J Ultrasound Med. 2019; 38 (12): 3093–3100. DOI: 10.1002/jum.15163.
13. J Ultrasound Med. AIUM-ACR–ACOG-SMFM–SRU practice parameter for the performance of standard diagnostic obstetric ultrasound examinations. J Ultrasound Med. 2018; 37 (11): E13–24. DOI: 10.1002/jum.14831.
14. Kogon BE, Forbess JM, Wulkan ML, Kirshbom PM, Kanter KR. Video-assisted thoracoscopic surgery: Is it a superior technique for the division of vascular rings in children? Congenit Heart Dis. 2007; 2 (2): 130–133. DOI: 10.1111/j.1747-0803.2007.00086.x.
15. Rato J, Zidere V, François K, et al. Post-operative outcomes for vascular rings: a systematic review and meta-analysis. J Pediatr Surg. Published online September 2023; 58 (9): 1744–1753. DOI: 10.1016/j.jpedsurg.2023.02.058.
16. Han J, Zhang Y, Gu X, et al. The differential diagnosis of double aortic arch and right aortic arch with mirror-image branches in the fetus: a potential novel method. Pediatr Cardiol. 2021; 42 (6): 1405–1409. DOI: 10.1007/s00246-021-02625-x.
17. Trivedi M, Sheth S, Nguyen M, et al. Position of the thoracic descending aorta in fetuses diagnosed with vascular ring is associated with postnatal symptoms. J Am Soc Echocardiogr. 2022: Abstract P2-43. https://www.onlinejase.com/pb-assets/Health%20Advance/journals/ymje/YMJE_2022_ASE_Abstracts-1654699807693.pdf

18. Aly S, Papneja K, Mawad W, Seed M, Jaeggi E, Yoo SJ. Prenatal diagnosis of vascular ring: evaluation of fetal diagnosis and postnatal outcomes. J Am Soc Echocardiog. 2022; 35 *(3)*: 312–321. DOI: 10.1016/j.echo.2021.09.010.

19. Hernanz-Schulman M. Vascular rings: a practical approach to imaging diagnosis. Pediatr Radiol. 2005; 35 *(10)*: 961–979. DOI: 10.1007/s00247-005-1529-0.

20. Yu JM, Liao CP, Ge S, et al. The prevalence and clinical impact of pulmonary artery sling on school-aged children: a large-scale screening study. Pediatr Pulmonol. 2008; 43 *(7)*: 656–661. DOI: 10.1002/ppul.20823.

21. Naidu DP, Wohlmuth C, Gardiner HM. Prenatal diagnosis of double aortic arch: can we predict airway obstruction (pseudo-CHAOS) and need for airway EXIT? Ultrasound in Obstetrics and Gynecology 2017; 49 *(5)*: 660–661. DOI: 10.1002/uog.17212.

22. Shum DJ, Clifton MS, Coakley FV, et al. Prenatal tracheal obstruction due to double aortic arch: a potential mimic of congenital high airway obstruction syndrome. AJR Am J Roentgenol. 2007; 188 *(1)*: W82–W85. DOI: 10.2214/AJR.05.0356.

23. Mcelhinney DB, Clark BJ, Weinberg PM, et al. *Association of chromosome 22q11 deletion with isolated Anomalies of aortic arch laterality and Branching.*; 2001).

24. Momma K, Matsuoka R, Takao A. Aortic arch Anomalies associated with chromosome 22q11 deletion (CATCH 22). 1999.

25. Evans WN, Acherman RJ, Ciccolo ML, et al. Isolated vascular rings are common cardiovascular malformations. World J Pediatr Congenit Heart Surg. 2023; 14 *(1)*: 21–23. DOI: 10.1177/21501351221122972.

26. Dodge-Khatami A. Commentary: if you know about it, why not just fix it? Planning surgical repair on asymptomatic patients with vascular rings in the new era of prenatal diagnosis. Semin Thorac Cardiovasc Surg. 2021; 33 *(2)*: 503–504. DOI: 10.1053/j.semtcvs.2020.09.013.