The tracheal sweep: novel use of tracheal landmark in echocardiography to determine aortic arch sidedness

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Abstract

Objective: Diagnosis of Aortic arch (AoA) anatomy is critical for planning cardiac surgery/intervention and in diagnosing associated congenital heart defects. AoA sidedness is traditionally diagnosed with echocardiography as being contralateral to the direction of the first brachiocephalic artery in suprasternal view, but this method can be challenged by numerous anatomic variants and clinical conditions. The objective of this study was to assess feasibility of trachea visualization with echocardiography in pediatric patients, and using this landmark to identify AoA sidedness and potential for double aortic arch (DAA). Methods: A prospective study was performed on patients $<$18 years old who were undergoing Chest CT/MRI to serve as gold standard for confirming AoA anatomy. A right-to-left echocardiographic sagittal sweep was performed from the suprasternal notch and used to categorize 1) Left AoA = right SVC-trachea-AoA, 2) Right AoA= SVC-AoA-trachea, 3) DAA = SVC-AoA-trachea-AoA. The proportion of successful sweeps and diagnostic accuracy were calculated. Results: 100 consecutive patients were scanned (44% female; median age of 8.8 yr, range 2d–17.9 yr; median BSA 1.14 m^2, range 0.2–2.7; right AOA in 4%). Diagnosis of AoA sidedness was possible in 97% (95% CI: 94–100%, $p < 0.01$) and correct in 100% when the trachea was seen. Conclusion: Tracheal imaging with echo is reliable, easy, and reproducible method in patients of various sizes and levels of acuity to define AoA sidedness.

TITLE PAGE

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ABSTRACT

Objective: Diagnosis of Aortic arch (AoA) anatomy is critical for planning cardiac surgery/intervention and in diagnosing associated congenital heart defects. AoA sidedness is traditionally diagnosed with echocardiography as being contralateral to the direction of the first brachiocephalic artery in suprasternal view, but this method can be challenged by numerous anatomic variants and clinical conditions. The objective of this study was to assess feasibility of trachea visualization with echocardiography in pediatric patients, and using this landmark to identify AoA sidedness and potential for double aortic arch (DAA).

Methods: A prospective study was performed on patients <18 years old who were undergoing Chest CT/MRI to serve as gold standard for confirming AoA anatomy. A right-to-left echocardiographic sagittal sweep was performed from the suprasternal notch and used to categorize 1) Left AoA = right SVC-trachea-AoA, 2) Right AoA= SVC-AoA-trachea, 3) DAA = SVC-AoA-trachea-AoA. The proportion of successful sweeps and diagnostic accuracy were calculated.

Results: 100 consecutive patients were scanned (44% female; median age of 8.8 yr, range 2d–17.9 yr; median BSA 1.14 m^2, range 0.2–2.7; right AOA in 4%). Diagnosis of AoA sidedness was possible in 97% (95% CI: 94–100%, $p < 0.01$) and correct in 100% when the trachea was seen.

Conclusion: Tracheal imaging with echo is reliable, easy, and reproducible method in patients of various sizes and levels of acuity to define AoA sidedness.

Keywords

Congenital heart disease, aortic arch sidedness, aortic arch anomaly, vascular ring, trachea

Abbreviations

AoA: aortic arch; CHD: congenital heart defect; DAA: double aortic arch;

PA: pulmonary artery; SVC: superior vena cava

Introduction

Accurate diagnosis of Aortic arch (AoA) anatomy is critical in the care of patients with congenital heart disease for planning cardiac surgery/intervention, diagnosing associated congenital heart defects (CHD), and evaluating possible compression of the esophagus or airway.[1] Arch sidedness has been shown to influence the surgical incision, cardiopulmonary bypass cannulation, and interventional approach.[2,3] Arch anomalies can increase the technical difficulty of endovascular treatment including carotid stent procedures and the risk of neurologic complications, and correct identification of arch anomalies helps avoid potential complications.[4,5] Notably, patients with right aortic arch and mirror image branching have been reported to have additional CHD in up to 98% of cases.[6]

Determination of AoA sidedness is traditionally completed with echocardiography as being contralateral to the direction of the first brachiocephalic artery in suprasternal view.[7] However, this method is challenged by poor acoustic windows, and can be technically difficult in small neonates for whom neck extension may not be feasible, the critically ill, or patients with aberrant subclavian artery. This method may also miss a double aortic arch (DAA). Given these challenges, the need for additional advanced imaging with CT or MRI for diagnosis has been reported in up to 28% of patients with AoA anomalies.[8]

In fetal echocardiography, imaging of the trachea is used routinely in the 3-vessel trachea view as a part of standard protocols to determine AoA sidedness and evaluate for AoA anomalies or pulmonary artery (PA) sling.[9,10] In pediatric or adult echocardiography, however, tracheal imaging is not routine. Despite this, the tracheal rings can be identified with transthoracic echocardiography by the classic echogenic shadow they produce. While imaging the trachea in echocardiography is not novel, we have found no published literature about its use or feasibility. The objective of this study was to evaluate the feasibility of imaging the trachea with echocardiography and bring attention to this often-forgotten technique. We hypothesize that visualization of the trachea with echocardiography can be accomplished in most pediatric patients, and that the technique of a tracheal sweep can identify AoA sidedness or double aortic arch.

Methods

A prospective study was performed on 100 consecutive patients less than 18 years old who were undergoing either CT or MRI of the chest for any indication. These advanced imaging studies served as gold standard for diagnosis of AoA anatomy. A priori power analysis was completed assuming null proportion of successful tracheal imaging of 85% and demonstrated power > 0.95 with a sample size of 100 when proportion was 97%. If a more conservative null proportion of 90% was used, power remained significant at > 0.80 with when proportion was 97%.

Four total echocardiographic clips in two separate planes were obtained for each patient in 2D and color Doppler with Phillips IE33 or Phillips EPIQ echocardiography machines (Philips Electronics, Washington, USA). In all patients, a right-to-left sagittal sweep was performed with echocardiography from the suprasternal notch or high right parasternal view and used to categorize 1) Left AoA = right superior vena cava (SVC)-trachea-AoA, Figure 1, Video 1; 2) Right AoA = SVC-AoA-trachea, Video 2; 3) DAA = SVC-AoA-trachea-AoA, Video 3. A parasternal short-axis view at the base of the heart showing the PA bifurcation straddling the trachea was used to rule out PA sling, Video 4. No additional echocardiography images were obtained as a part of this study. Study approval was granted by the University of Iowa institutional review board. Age appropriate consent/assent was obtained on the day of advanced imaging to participate in additional research-only echocardiographic images completed either directly before or after CT/MRI.

Patient acuity, use of sedation or anesthesia, imager experience, and subjective ease of obtaining echo were collected. Independent review for AoA sidedness, DAA, and absence of PA sling was performed by 2 advanced-imaging pediatric cardiologists for all echocardiography images and advanced imaging scans. Those obtaining echo images and those reading images were blinded to any previous diagnoses. Kappa coefficient was calculated to determine inter-reader reliability with independent read, and then in cases of initial disagreement, consensus was attained by joint review. Continuous variables were reported as median and range. Categorical variables were reported as percent. The proportion of successful imaging of the trachea and diagnostic accuracy with tracheal sweep were calculated as mean percent values with 95% confidence interval (CI). A one-tailed z-test was used to assess for statistical significance. These calculations were repeated for successful imaging of tracheal-PA bifurcation relationship for both the entire cohort and then again excluding patients who had previous surgical intervention on their PA (ie: Glenn/Fontan, RV-to-PA conduit, LeCompte).

Results

This study enrolled 100 consecutive patients at time of undergoing CT or MRI of chest as a part of their medical care. Participant characteristics are described in Table 1. 88% of studies were completed by an imager with less than 1 year of experience. 2% of study subjects had sedation or anesthesia prior to echocardiogram, and 6% of study echocardiograms were reported as challenging or not possible due to limited acoustic windows.

Successful imaging of the trachea by tracheal sweep was possible in 97% (95% CI 95 – 100), $p < 0.01$.

Right aortic arch was present in 4% of patients. There were no diagnoses of double aortic arch. There were no missed diagnoses of aortic arch anomalies, and the correct diagnosis of AoA sidedness and absence of DAA was 100% when the trachea was seen. Right aortic arch was correctly diagnosed in every patient where present. Kappa coefficient was 0.9. There were 3 tracheal sweeps that were non-diagnostic with poor acoustic windows: one patient had a BSA > 2.5 m^2 and BMI greater than 40, a second patient had chronic lung disease and tracheostomy dependence, and the third had a progressive mediastinal mass. 2 of 3 non-diagnostic echocardiograms for arch sidedness were performed by an imager with less than 1 year of experience. Tracheal imaging was possible in patients with various non-cardiac pathologies including chronic lung disease, cystic fibrosis, mediastinal masses, and pectus excavatum. It was also possible in patients with complex cardiac disease including heterotaxy with hypoplastic left heart syndrome, transposition of the great arteries, truncus arteriosus, tetralogy of Fallot, complete atrioventricular canal, absent pulmonary valve, and other concerns for aortopathy.

Successful imaging of trachea-to-PA relationship could rule out PA sling in 91% (95% CI 85 – 97), $p = 0.12$. Excluding 6 patients who had previous surgical PA intervention, success rate was 97% (95% CI 93-100), $p = 0.04$. There were no missed diagnoses of PA sling with correct identification of PA anatomy was made 100% of the time when the trachea was seen. Kappa coefficient was 1.0. After exclusion of patients with previous PA surgery, there were 3 studies where tracheal-PA relationship was non-diagnostic with poor acoustic windows: one patient was status-post surgical repair of interrupted aortic arch, a second patient had chronic lung disease, and the third had a progressive mediastinal mass. All non-diagnostic studies for assessing PA sling were performed by an imager with less than 1 year of experience.

Discussion

Tracheal sweep offers a reliable, easy, and reproducible method in patients of various sizes and levels of acuity to define aortic arch sidedness and may aid in ruling out double aortic arch, complementing the existing American Society of Echocardiography (ASE) protocol as a potentially helpful adjunct in challenging cases.

The importance of accurate diagnosis of aortic arch sidedness and other aortic anomalies has been well established, and current ASE protocol for diagnosis with echocardiography is known to be a reliable and consistent method.[11] Despite this long history of experience, however, it has been reported that additional advanced imaging is often needed for correct diagnosis in up to 28% of patients with aortic arch anomalies.[8] Madry et al demonstrated that echocardiographic diagnosis was particularly challenging in patients with left aortic arch and aberrant right subclavian artery, and in patients with double aortic arch. Clinical experience has also shown that determining arch anatomy with echocardiography can also be difficult in low-birthweight neonates and other patients who are critically unstable with limited ability for neck extension. The tracheal sweep method utilized in this study provides a complimentary technique that is easy to attain and can reliably establish arch anatomy without the need for advanced imaging. This technique is also able to diagnose arch anatomy in cases of aberrant subclavian arteries as it does not depend on a normal aortic arch branching pattern and may also improve the sensitivity of diagnosing double aortic arch.

Specific use of imaging the trachea with echocardiography has been described in limited fashion but is often considered to be difficult and has very limited evidence of its use as a reliable diagnostic method for aortic arch sidedness or presence of double aortic arch.[6,7,12] This cohort demonstrated that, despite being air-filled, the trachea can be recognized by the classic echogenic appearance of the tracheal rings in a suprasternal (or high parasternal) parasagittal view. The trachea was seen in patients of all ages, sizes, and clinical conditions ranging from newborns with a BSA of 0.2 m^2 to 17.9-year-old adolescents with BSA well above 2.0 m^2. While a majority of the patients were imaged in the outpatient setting, the tracheal sweep method was shown to be successful in critically ill patients who were intubated in the neonatal and pediatric intensive care units with the endotracheal tube creating excellent contrast and serving as a surrogate for the trachea. This study was also able to demonstrate the feasibility of imaging the trachea in a wide variety of complex cardiac and non-cardiac pathologies. Visualization of the relationship between the trachea and aortic arch was even able to successfully diagnose arch sidedness in a patient without a right-SVC. With successful imaging of the trachea in 97% of time, the diagnosis of aortic arch sidedness was accurate every time the trachea was seen and there were no missed diagnoses of aortic arch anomalies. Excluding patients who had previous surgical intervention on their PAs, tracheal imaging was also able to successfully rule-out PA sling in nearly all patients.

The relative ease of this method is supported by the high rate of success achieved by an imager with very limited experience, in that nearly 90% of scans were completed by a cardiology fellow in their first year of fellowship with no prior echocardiographic experience. These images were also obtained without other standard echocardiographic views that can help orient an inexperienced sonographer, and nearly all studies were completed without the assistance of sedation or anesthesia. The notable limitations of tracheal imaging with echocardiography were in patients with particularly challenging acoustic windows that would have also limited standard echocardiographic methods.

It should be noted that this study primarily focused on the ability to reliably image the trachea and its relationship to the aortic arch and pulmonary artery bifurcation with echocardiography. This study was adequately powered to show significant success with this technique, and was not meant to compare superiority or non-inferiority to current methods in standard echo protocols as recommended by the ASE. In otherwise challenging cases, however, the tracheal sweep can be a helpful adjunct method to aid in making the correct diagnosis without needing to expose the patient to additional radiation via CT or sedation/anesthesia as is often needed for MRI. The percentage of patients with right aortic arch in this study is similar to previously reports population rates and all arch variants in this patient cohort were correctly diagnosed by tracheal sweep. Further study is needed to assess the success of the tracheal sweep method in diagnosing arch anomalies in cohorts with larger numbers of patients who have anomalous aortic arch anatomy or pulmonary artery sling. These techniques were also successfully utilized in many critically ill patients. However, it would also be beneficial to demonstrate this technique in larger numbers of critically ill patients.

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Patient Characteristics	
Sex (female)	44%
Age (years)	8.8 (0.01 – 17.9)
Body Surface Area (m^2)	1.14 (0.2 – 2.7)
Previously Diagnosed Cardiac Anomaly	46%
Clinical Status (outpatient)	86%

Table 1: Characteristics of study subjects (numerical data shown with mean and range)

Figure Legends

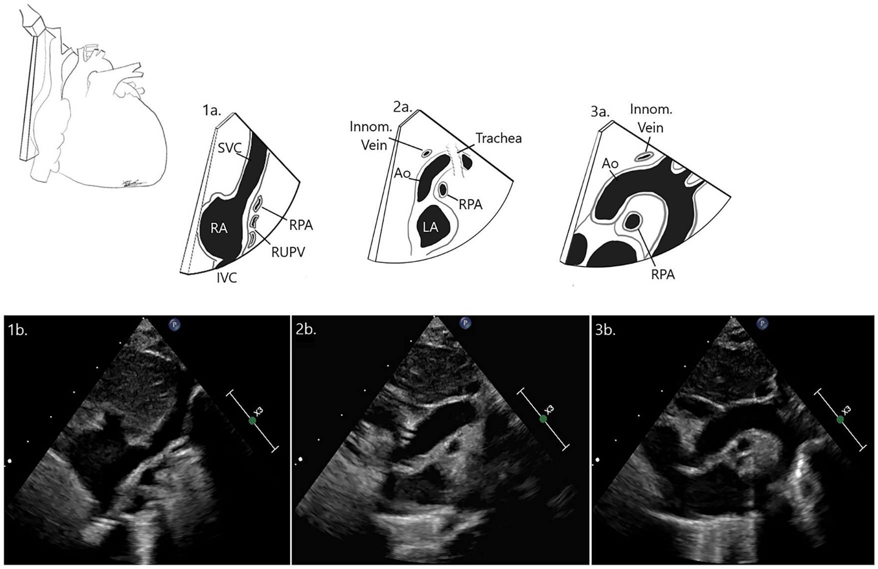
Figure 1. Tracheal Sweep: right-to-left sweep from suprasternal notch view of left aortic arch. 1a & 1b: Starting from patient's right the superior vena cava (SVC), inferior vena cava (IVC), and right atrium (RA) are demonstrated with the right pulmonary artery (RPA) and right upper pulmonary vein (RUPV) crossing behind SVC. 2a & 2b: The echo-bright trachea comes into view with the ascending aorta (Ao), the innominate vein (Inom) is anterior, and the RPA is seen in cross section behind the ascending Ao. 3a & 3b: The transverse Ao comes into view completing the right-to-left sweep.

Video 1. Left aortic arch shown with right-to-left sagittal sweep from suprasternal notch view.

Video 2. Right aortic arch with mirror image branching shown with right-to-left sagittal sweep from suprasternal notch view.

Video 3. Double aortic arch shown with right-to-left sagittal sweep from suprasternal notch view.

Video 4. Normal pulmonary artery bifurcation around trachea shown from parasternal short axis view at base of the heart.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