

Tetralogy of Fallot with Absent Pulmonary Valve Syndrome

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Case Scenario

An 11-month-old boy weighing 7 kg presents for a scheduled direct laryngoscopy and bronchoscopy to evaluate moderate persistent wheezing. Pertinent medical history includes postnatal diagnosis of tetralogy of Fallot with absent pulmonary valve syndrome. He underwent cardiac repair at age 5 months, including ventricular septal defect repair, right ventricle to pulmonary artery valved conduit, and pulmonary artery plication. He is seen by a cardiologist every 6 months. He has a history of frequent respiratory infections requiring respiratory treatments, intravenous antibiotics, and admission. His current medications include albuterol, inhaled steroids, and a multivitamin.

Echocardiogram performed 3 months ago demonstrates:

- Small atrial left-to-right shunt with 3 mm Hg gradient
- No residual ventricular septal defect
- Normal biventricular function
- Mild right ventricular–pulmonary artery conduit regurgitation

Key Objectives

- Describe the anatomy of tetralogy of Fallot with absent pulmonary valve syndrome.
- Define the respiratory pathology in tetralogy of Fallot with absent pulmonary valve syndrome.
- Describe the intraoperative management for patients with repaired tetralogy of Fallot with absent pulmonary valve syndrome.
- Describe potential respiratory support in tetralogy of Fallot with absent pulmonary valve syndrome.

Pathophysiology

What are the anatomic features of tetralogy of Fallot with absent pulmonary valve?

Tetralogy of Fallot (TOF) is a spectrum, including multiple variants that differ in pulmonary artery and right ventricular

outflow tract (RVOT) characteristics. (See Chapters 7, 8, and 10.) Similar to other TOF variants, TOF with absent pulmonary valve syndrome (TOF/APVS) includes an anterior maligned ventricular septal defect (VSD), an aorta that “overrides” the septal defect, and a hypertrophied right ventricle. However, TOF/APVS is distinct in that there is an absent or rudimentary, incompetent pulmonary valve. The pulmonary valve, if present, may have some degree of stenosis but the dominant pathophysiology is pulmonary regurgitation.

Patients with TOF/APVS usually have unobstructed flow to the pulmonary arteries and therefore do not have the cyanosis or hypercyanotic “tet” spells associated with other TOF variants. The main and branch pulmonary arteries are generally dilated due to pulmonary regurgitation and excessive flow and can be large enough to cause a mass effect on surrounding structures, including the airways and lungs. (See Figures 9.1 and 9.2.)

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What is the respiratory pathology in TOF/APVS?

Tetralogy of Fallot/APVS commonly occurs with varying degrees of obstructive respiratory disease. Persistent pulmonary regurgitation causes abnormally large and tortuous pulmonary arteries that can cause fixed or dynamic mechanical airway obstruction, typically at the tracheobronchial level. Airway compression or collapse can cause symptoms that range from mild stridor with agitation to recurrent infections, and in severe cases, atelectasis, respiratory insufficiency, and long-term mechanical respiratory support. In the most severe cases, dilation occurs throughout the pulmonary vascular bed, impinging on gas movement within the entire respiratory tract.

Figure 9.1 Tetralogy of Fallot with absent pulmonary valve. Drawing by Ryan Moore, MD, and Matt Nelson.

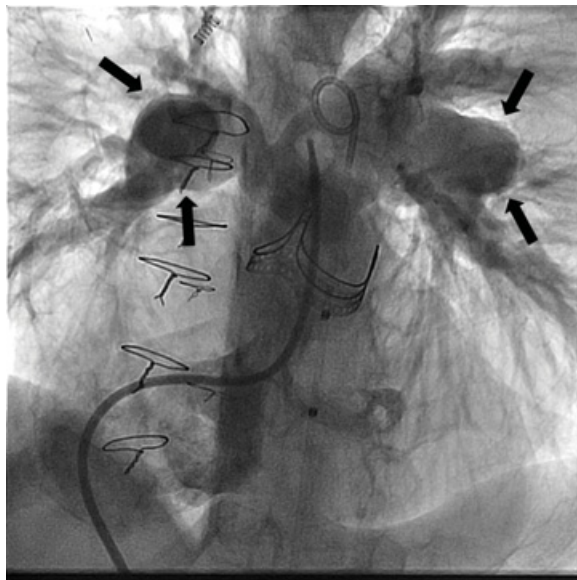
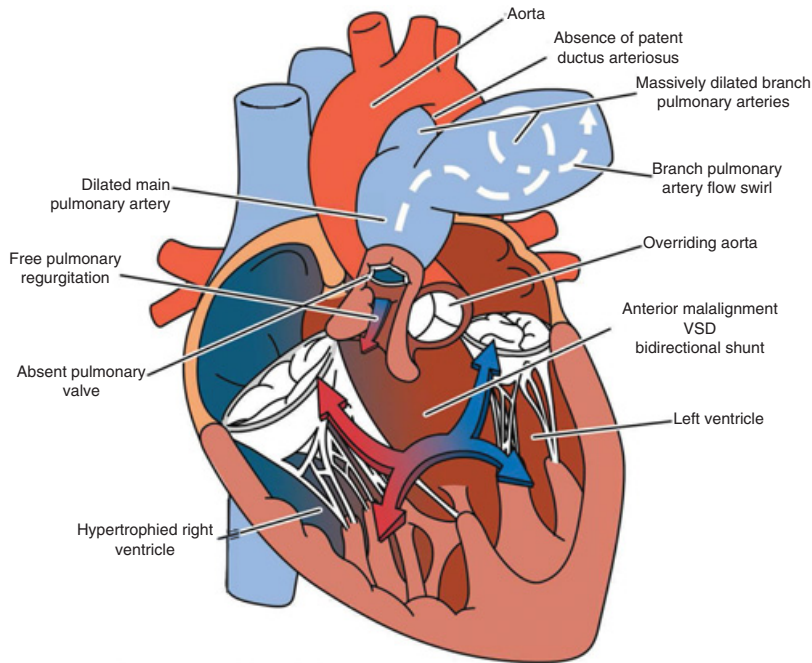


Figure 9.2 Dilated and aneurysmal branch pulmonary arteries post TOF/APVS repair. An angiogram is performed in the branch pulmonary arteries in the AP projection. The marked aneurysmal dilation of the proximal branch pulmonary arteries is noted (arrows). Courtesy of Russel Hirsch, MD.

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What is the role of the patent ductus arteriosus in TOF/APVS?

A patent ductus arteriosus (PDA) is typically *not* present in fetuses or neonates with TOF/APVS when significant pulmonary regurgitation is present. Absence of a PDA in TOF/APVS is associated with fetal survival.

Presence of a PDA in TOF/APVS physiology would create an unrestricted circular shunt of blood:

Aorta (via PDA) → pulmonary artery → regurgitation to RV → (via VSD) to LV → aorta

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Patients with TOF/APVS typically do not have a PDA as it would cause a circular shunt and is associated with fetal demise.

What symptomatology may be seen in unrepaired TOF/APVS?

Patients with unrepaired TOF/APVS have respiratory symptoms and cyanosis related to the degree of intracardiac shunting and airway compression. The presence of right-to-left (R-to-L) shunting at the ventricular level is dependent on relative right and left ventricular pressures and the amount of pulmonary regurgitation and stenosis

(if stenosis is present). Additionally, there may be respiratory symptoms or insufficiency when large pulmonary arteries cause tracheobronchial compression.

Respiratory symptoms are dictated by the amount of airway obstruction. Mechanical obstruction of large and small bronchi may present with a pattern of obstructive airway disease, similar to asthma. Milder cases may display only tachypnea or cough, while severe obstructive pulmonary disease may cause over-inflated lung fields with limited ventilation and areas of atelectasis.

For patients with airway compression or malacia requiring treatment, prone positioning or positive airway pressure may improve symptoms of airway obstruction. However, severe cases may require intubation and mechanical ventilation.

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For infants with airway malacia due to TOF/APVS, prone positioning may reduce tracheobronchial compression and symptoms.

What chest imaging findings are commonly seen in TOF/APVS?

Chest radiography may show an enlarged cardiac silhouette related to RV hypertrophy and pulmonary artery dilation. In the presence of airway mechanical obstruction, the lungs may appear hyperinflated and/or demonstrate patchy atelectasis.

Computed tomography (CT) scan or magnetic resonance imaging (MRI) may be considered in cases where delineation of extrinsic bronchial obstruction due to compression from pulmonary arteries is necessary. For longer studies, general anesthesia is often required, which may pose additional risk for airway obstruction and difficulty with ventilation.

What are surgical repair options and considerations?

Goals for surgical repair of TOF/APVS include improvement of pulmonary blood flow (PBF) by reducing regurgitation, closure of the VSD to eliminate ventricular shunting and pulmonary arterioplasty to reduce airway compression if necessary. Timing of repair is dictated by the degree of cyanosis and effective PBF as well as the degree of respiratory obstruction. Even with adequate PBF, tachypnea and respiratory failure can cause failure to thrive prompting consideration of repair.

Repair of the VSD in TOF is typically performed through a right atriotomy or right ventriculotomy. The RVOT may be repaired with a pulmonary homograft at the level of the main pulmonary artery; the ventriculotomy for VSD repair can be used as the anchor point of the conduit. Using a *valved* conduit limits RV and pulmonary artery end-diastolic volume to reduce pulmonary regurgitation and right ventricular volume overload. Repair may also include narrowing or reduction of the pulmonary arteries by pulmonary arterioplasty or aneurysm resection. Consultation with otolaryngology and/or pulmonology with use of pre- and postoperative direct laryngoscopy/bronchoscopy may aid in directing the repair.

Low birth weight, repair in the neonatal period, and the presence of severe respiratory disease are risk factors that significantly increase mortality. Preoperative mechanical ventilation is also an independent risk factor for increased mortality following repair.

Anesthetic Implications

What important considerations exist in evaluating patients with TOF/APVS?

In addition to the routine preoperative considerations, special attention should be paid to both respiratory and cardiac systems prior to general anesthesia for patients with TOF/APVS. A focused cardiac history and physical exam should explore signs and symptoms of RV dysfunction and/or venous congestion. Dyspnea, tachypnea, wheezing, feeding difficulty, failure to gain weight, tachycardia, jugular venous distention, and liver distention may be present. Preoperative evaluation should include a recent echocardiogram to determine the presence of any residual atrial or ventricular shunts, and to evaluate ventricular function and conduit integrity. Conduit regurgitation and or stenosis may present with RV dysfunction accompanied by elevated end-diastolic pressure and volume.

Patients with a history of moderate or severe TOF/APVS may continue to experience persistent obstructive pulmonary disease and tracheomalacia even after complete repair. A small percentage of patients may require tracheostomy. Long-term respiratory pathology may include tracheo/bronchomalacia, persistent wheezing and air trapping, and recurrent pulmonary infections. Current respiratory infection secondary to ineffective clearance may require postponement of elective surgery and institution of appropriate medical therapy prior to anesthesia. Depending on symptoms, chest radiography may help assess lung fields and the degree of air trapping. Respiratory medications including bronchodilators should

be continued and can be escalated in the preoperative period to support respiratory dynamics.

Although not specifically associated with TOF/APVS, patients presenting with congenital cardiac disease should be evaluated for the presence of genetic or dysmorphic syndromes. Current genetic studies estimate between 20% and 30% of congenital cardiac disease can be attributed to genetic or environmental factors. Further genetic diagnosis may have implications on anesthetic management including airway pathology and metabolic requirements.

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What induction techniques could be considered for this procedure?

The proposed anesthetic plan should consider both the degree of residual cardiac disease and/or dysfunction and the degree of existing respiratory pathology. When cardiac function is preserved, induction may be achieved through either inhalation or intravenous routes. Spontaneous ventilation for the patient undergoing direct laryngoscopy in this instance is nearly always desired to allow for in situ assessment of tracheobronchial tree anatomy and airway dynamics, including the degree of tracheobronchomalacia. Intravenous medications such as propofol or dexmedetomidine can be titrated to maintain spontaneous ventilation and limit operating room pollution of inhaled gases during direct laryngoscopy. The use of aerosolized lidocaine by the proceduralist will aid in decreasing airway irritability. Oxygen may be insufflated via an endotracheal tube placed in the side of the mouth during the procedure to assist in maintaining adequate saturations. Monitoring of adequacy of ventilation with chest excursion, tidal volumes, and capnography must be used in combination to continually evaluate the patient's respiratory status. Patients with significant respiratory disease will experience profound airway collapse without the support of positive airway pressure.

In patients with long-standing cardiac disease and poor RV function, changes in intrathoracic pressure related to mechanical ventilation, positive end-expiratory pressure and/or airway obstruction during spontaneous ventilation may precipitate worsening RV performance and impair cardiac output via increased intrathoracic pressure and RV afterload. Particular attention to cardiac output is warranted in these patients, and the anesthetic plan may

include intravenous induction and availability or administration of vasoactive medications to support cardiac function. However, in most patients with TOF/APVS the respiratory pathology after repair is more significant than the degree of residual cardiac pathology.

During inhalational induction the patient develops significant retractions with limited chest excursion: what should be done?

These symptoms are generally indicative of lower airway obstruction related to bronchomalacia. They are frequently accompanied by decreased capnography waveform and tidal volume. Standard upper airway manipulations of jaw thrust, chin lift, and oral airway should be tried but frequently do not relieve the obstruction as it is distal and not related to the upper airway. Without resolution, air trapping may occur and the patient may desaturate and become hypercarbic.

The use of positive pressure usually aids in relieving the distal airway obstruction. Titrating the adjustable pressure-limiting valve with mask ventilation to achieve adequate tidal volumes will determine the amount of positive end-expiratory pressure required to maintain lower airway patency. A balance should be considered between maintaining expiratory airway pressure to prevent lower airway obstruction and minimizing end-expiratory pressure to allow for complete exhalation. If end-expiratory pressure is ineffective, pressure support or mechanical ventilation may be beneficial.

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What ventilation strategies could be utilized during laryngoscopy and bronchoscopy?

During bronchoscopy, use of a supraglottic airway device or endotracheal tube can maintain upper airway patency and allow for titration of inhaled anesthetics. However, positive end-expiratory pressure may be required to support tracheobronchial integrity if significant malacia is present.

The approach to positive pressure ventilation in patients with TOF/APVS should always consider the likelihood of significant tracheobronchomalacia in this patient population. Spontaneous ventilation, if tolerated, or moderate end-expiratory pressure may be good choices to support airway patency. Adequate ventilation and oxygenation with spontaneous ventilation and sufficient depth of anesthesia to tolerate bronchoscopy may be difficult to achieve. Periods of apnea during laryngoscopy may be tolerated in combination with periods of intermittent mask ventilation.

Whatever technique is chosen, meticulous monitoring for signs of airway collapse or obstruction, along with ETCO_2 , chest rise, exhaled tidal volumes, and SpO_2 is necessary. Constant communication between the otolaryngologist and anesthesiologist before and during the procedure is vital to patient safety and procedural efficiency.

What postoperative issues can arise?

Patients who have undergone TOF/APVS repair are at ongoing risk for bronchomalacia and airway clearance challenges; these risks are increased both intraoperatively and postoperatively. Management should include measures to decrease airway resistance and improve airflow throughout the upper and lower airways. Perioperative steroids and postoperative racemic epinephrine may decrease swelling and airway resistance from laryngoscopy and bronchoscopy.

For patients with severe bronchomalacia, postoperative continuous positive airway pressure via mask or high flow

nasal cannula may provide airway support and may be necessary until residual anesthetic effects have dissipated. For acute, short-term reduction in airway resistance and turbulent flow, helium and oxygen may be administered through a nasal cannula or mask. Patients requiring continuous positive pressure or helium should be closely monitored in an intensive care setting following diagnostic or interventional laryngoscopy and bronchoscopy.

Suggested Reading

Cowan J. R. and Ware S. M. Genetics and genetic testing in congenital heart disease. *Clin Perinatol* 2015; **42**: 373–93.

Dorobantu D. M., Stoicescu C., Tulloh R. M., et al. Surgical repair of tetralogy of Fallot with absent pulmonary valve: favorable long-term results. *Semin Thorac Cardiovasc Surg* 2019; **31**: 847–9.

Hew C. C., Daebritz S. H., Zurakowski D., et al. Valved homograft replacement of aneurysmal pulmonary arteries for severely symptomatic absent pulmonary valve syndrome. *Ann Thorac Surg* 2002; **73**: 1778–85.

Rabinovitch M., Rabinovitch S., David I., et al. Compression of intrapulmonary bronchi by abnormally branching pulmonary arteries associated with absent pulmonary valves. *Am J Cardiol* 1982; **50**: 804–13.

Yeager S. B., Van D. V., Waters B. L., et al. Prenatal role of the ductus arteriosus in absent pulmonary valve syndrome. *Echocardiography* 2002; **19**: 489–493.

Zach M., Beitzke A., Singer H., et al. The syndrome of absent pulmonary valve and ventricular septal defect—anatomical features and embryological implications. *Basic Res Cardiol* 74: 54–68.