South Afr J Anaesth Analg. 2022;28(5 Suppl 1):S50-54
https://doi.org/10.36303/SAJAA.2022.28.5.2909

South Afr J Anaesth Analg
ISSN 2220-1181 EISSN 2220-1173

FCA REFRESHER COURSE

Anaesthesia for thoracic surgery in paediatric patients: congenital diaphragmatic hernia and tracheo-oesophageal fistula repairs – what is new?

G Leballo

Department of Anaesthesia, School of Clinical Medicine, Faculty of Health Sciences, Charlotte Maxeke Johannesburg Academic Hospital, University of the Witwatersrand, South Africa
Corresponding author, email: *gontse.leballo@wits.ac.za*

Anaesthesia for thoracic surgery in a neonate poses challenges that relate to both complexities in neonatal physiology (especially in premature infants), as well as surgical challenges that arise with thoracic surgery in this patient population. A thorough understanding of the physiological implications and anaesthetic considerations for congenital diaphragmatic hernia (CDH) and tracheo-oesophageal fistula (TOF) repairs is paramount to clinicians administering anaesthesia in these patients. This narrative review is aimed at re-visiting the anatomical lesions, their pathophysiology, current management guidelines, anaesthetic considerations, and anaesthesia management.

Keywords: thoracic surgery, paediatric patient, congenital diaphragmatic hernia, tracheo-oesophageal fistula repairs

Embryology

In a review article by Mayer and colleagues,[1] the embryological development of the diaphragm following rat models by observing them through scanning electron microscopy (SEM) is divided into three events; the formation of the pleuroperitoneal fold (PPF), formation of the posthepatic mesenchymal plate (PHMP), and the development of the diaphragm and PPF closure. The theory on the involvement of the PHMP was postulated in the 1980s by Iritani, who explained the possible association of its impaired development to that of abnormal formation of lung buds.[2] During the formation of the PPF, at about 12 embryonic days (ED), lung buds in rat models can be seen invading into the peritoneal cavity.[2] This is closely followed by formation of the PHMP, a mesentery identified between the transverse septum cranially, the liver ventrally and the PPF laterally. By the 17th ED, the opened and large pleuroperitoneal canals (PPC) close, with great expansion of the pleural cavities, around the pericardial cavity.[1] Abnormal development of the diaphragm in human fetuses still remains a controversial topic. The aetiology of congenital diaphragmatic hernia (CDH) is unknown and is deemed to be multifactorial. Genetic, environmental, and nutritional factors have been implicated.[3,4] Failure of fusion of the PPF with the transverse septum and the oesophageal mesentery is what is thought to cause this diaphragmatic defect.[4]

The aetiology of tracheo-oesophageal fistula (TOF) is also not clearly understood, as most of the studies involve animal subjects.[5,6] There are three known theories that explain the development and separation of the primitive foregut into a ventral and dorsal portion, which would become the future tracheo-laryngeal tube and the oesophagus, respectively.[6] Fundamentally, the fistula is postulated to occur when there is failure of the ventral and dorsal segments of the foregut to separate.

Pathophysiology

Congenital diaphragmatic hernia

In CDH, the abdominal organs protrude through the diaphragmatic defect into the thoracic cavity. The subtypes of the defect are dependent on the size, as well as their location (Figure 1).[3] Bochdalek hernias are the most common subtype (70–75%) located posterolaterally;[4,7,8] most frequently occurring on the left (85%) than the right (13%) side, with bilateral defects presenting rarely (2%).[7,8] Bochdalek hernias are postulated to occur as a result of failure of the PPF to fuse.[4] Anterior defects (23–28%) are known as the Morgagni subtype,[7] occurring due to herniation of viscera through the foramen of Morgagni, an anatomical defect through the transverse septum.[4] Central defects (2–7%) can also occur.[3] Important physiological complications occur as a result of CDH, which carries a great burden in terms of clinical management and administration of anaesthesia.

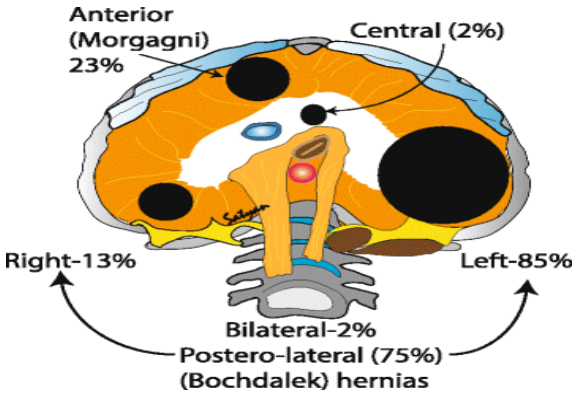
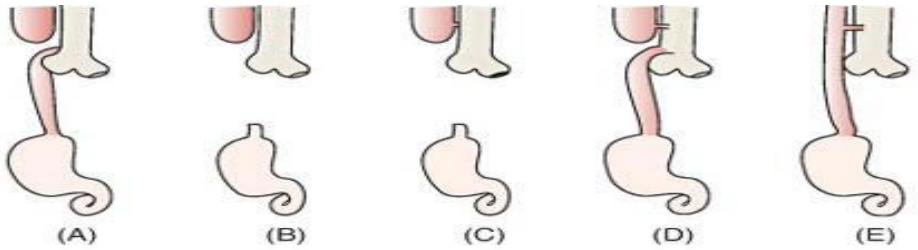


Figure 1: A schematic diagram representing the congenital diaphragmatic hernia subtypes according to their anatomical location
© Satyan Lakshminrusimha



	A	B	C	D	E
Description	Proximal OA distal TOF	True OA without fistula	Proximal TOF	Proximal and distal fistula	Isolated TOF (H or N fistula)
Abnormal x-ray	Distal gas	Gasless abdomen	Gasless abdomen	Distal gas	Distal gas
Incidence	85%	6%	3%	1%	6%
Gross classification	C	A	B	D	E

Figure 2: The anatomical classifications of trachea-oesophageal fistula according to both the Vogt and Gross classifications[18]
TOF – trachea-oesophageal fistula, OA – oesophageal atresia

Pulmonary hypoplasia is one such unavoidable consequence of the disease process. This can affect the lung that is ipsilateral to the defect, as well as the contra-lateral lung. A "dual-hit" hypothesis has been proposed,[9] which explains that the initial insult of aberrant diaphragmatic formation is related to multifactorial factors during organogenesis (environmental and genetic) which can result in bilateral lung hypoplasia; while the second insult results in lung growth abnormalities on the ipsilateral side probably as a result of compression by abdominal viscera.[3,4,9] This lung tissue hypoplasia can lead to the manifestation of pulmonary hypertension (PHT). This is due to the paucity of pulmonary vasculature growth, vascular remodelling, and altered vasoreactivity.[10,11] As a result of the elevated pulmonary pressures, some patients can develop a right-sided strain pattern with right ventricular dysfunction.[3] Left ventricular dysfunction can also result due to smaller left ventricular mass, especially in left-sided lesions.[3] Low ventricular outputs have been reported in both right and left-sided lesions.[12]

CDH is associated with a number of chromosomal abnormalities which include trisomies 13, 18 and 21.[4,13] Associated genetic abnormalities are Fryns syndrome,[4,14] Pentalogy of Cantrell, Beckwith-Wiedemann, CHARGE, Goldenhar sequence and Pierre-Robin sequence.[3,4] The most common cardiac lesions associated with CDH are ventricular septal defects (29%) and atrial septal defects (26%).[4] The diagnosis can be made antenatally, but following delivery, clinically the patient can present with a scaphoid abdomen associated with signs of respiratory distress.[4] Prognosis is dependent on the presence of associated cardiac lesions, the extent of pulmonary hypoplasia, and the presence of hepatic herniation.[3]

Tracheo-oesophageal fistula

The anatomical classification of oesophageal and/or tracheal atresia is usually identified by the Gross classification (1953), although originally described by Vogt in 1929.[6,15] Gross type C (Figure 2), is the most common of these lesions (86%) known to present with a distal TOF and a proximal oesophageal atresia (OA).[5,15] This anatomical defect also presents with associated congenital abnormalities. Anomalies are more common in paediatric patients with isolated OA when compared to the combined TOF defect.[5] The VACTREL association (vertebral, anorectal, cardiac, tracheal, renal and limb abnormalities) is seen in 50% of the TOF cases,[5,15] with cardiac lesions occurring in about 20% of the diagnosed[6] TOF defects.[5,16,17] The affected paediatric patient presents postnatally with excessive drawling, coughing and choking when feeds are being introduced, cyanosis, and signs of respiratory distress.[6,15-17] Postnatal diagnosis is often investigated following clinical suspicion. Failure to pass a nasogastric tube (NGT) beyond 7 cm, and a confirmatory chest-x-ray (CXR) showing a curled NGT (in cases of a blind-ending oesophageal pouch) provides sufficient evidence of the diagnosis.[15] Prognosis is often measured according to the associated cardiac abnormality present, as well as the neonate's birth weight (Table I).[17]

Perioperative considerations

A thorough preoperative assessment of paediatric patients presenting for thoracic surgery is paramount. An extensive history taking, followed by adequate preoperative workup, aids in appropriate planning and management. CDH and TOF repairs are not surgical emergencies; a multidisciplinary team should be involved in the patients' perioperative care. These procedures should ideally be performed in a tertiary institution, where

Table I: Spitz prognostic classification for trachea-oesophageal fistula

Group	Features	Survival
I	Birth weight > 1 500 g, no major cardiac anomaly	98.5%
II	Birth weight < 1 500 g, or major cardiac anomaly	82%
III	Birth weight < 1 500 g, and major cardiac anomaly	50%

medical expertise is readily available. Anticipation of associated comorbid factors necessitates for timeous consultation with experts in that field.

Congenital diaphragmatic hernia

Paediatric patients presenting with respiratory distress due to CDH require medical stabilisation before the planned surgical repair.

- Patients are intubated and mechanically ventilated in preparation for the surgical procedure. The optimal mode of ventilation is still unknown. Protective ventilation strategies are encouraged to avoid further lung injury.[4] The ventilation in infants with CDH (VICI) trial, did not find a superior mode of ventilation in this population between conventional mechanical ventilation (CMV) and high-frequency oscillatory ventilation as the initial mode of intervention (HFOV); however, patients initially ventilated with CMV lead to better clinical outcomes (shorter ventilation time and intensive care unit (ICU) stay/decreased requirement for extracorporeal membrane oxygenation (ECMO)/least use of pharmacotherapy).[19] The CDH EURO Consortium recommends pressure control ventilation (PCV), with settings adapted to achieve: preductal saturations between 80 and 95%, postductal saturation above 70%, targeted PCO_2 levels between 50 and 70 mmHg, PEEP between 3 and 5 cmH_2O, PIP less than 25 cmH_2O and a respiratory rate between 40 and 60 breaths per minute.[20]
- There is limited data on the evidence of ECMO use in paediatric patients with CDH. The VICI trial did not show added benefit in ECMO use for CDH patients.[19] This form of cardiopulmonary support is often used in some centres as a form of rescue therapy.[21] The CDH EURO Consortium Update of 2015 recommends ECMO rescue therapy as shown in Table II.[20]

Table II: ECMO use recommendation in CDH patients (*Grade D level of evidence*)

Inability to maintain preductal sats > 85% Inability to maintain postductal sats > 70% OI of ≥ 40 (present for at least 3 hours) PIP > 28 cmH_2O or MAP° > 17 cmH_2O required to maintain sats > 85%
Inadequate O_2 delivery with metabolic acidosis (despite optimal ventilation) • Lactate > 5 mmol/l • pH < 7.15 High PCO_2 levels with respiratory acidosis (despite optimal ventilation) • pH < 7.15
Systemic hypotension (resistant to fluid and ionotropic therapy) • UO < 0.5 ml/kg/hour (12–24-hour period)

Sats – oxygen saturation, OI – oxygenation index, PIP – peak inspiratory pressure, MAP° – mean airway pressure, UO – urine output

- Pharmacotherapy is important in the management of PHT. Inhaled nitric oxide (INO), a selective pulmonary vasodilator, is responsible for the management of PHT by causing relaxation to smooth muscles.[3] It is initiated according to the severity of the disease process; and response to therapy is monitored by the oxygenation index (OI).[3] There is currently no evidence in support for the use of prostaglandins and prostacyclin in the management of CDH. Despite the lack of literature to support the use of phosphodiesterase inhibitors (PDE-I) in children with CDH; sildenafil (PDE-5-I) and milrinone (PDE-3-I), have shown some improvement in lowering pulmonary vascular pressure, especially in centres without ECMO expertise.[3]
- Haemodynamic support and the choice of a vasopressor or an inotrope depends on the presence or absence of cardiac lesions, as well as the targeted physiological goals. Adequate organ perfusion can be evaluated by "normal heart rate range for gestational age, urine output levels above 1 ml/kg/hr, adequate capillary refill, lactate levels below 3–5 mmol/l, and pH levels more than 7.2."[3]

Tracheo-oesophageal fistula

The choice for an open or thoracoscopic approach in TOF repairs depends on the haemodynamic status of the patient, the presence and severity of a cardiac lesion, and surgical expertise. An NGT is inserted to minimise the risk of aspirations and is part of resuscitation and patient stabilisation. An intravenous line is mandatory to maintain hydration and avoid hypoglycaemia while the patient is kept nil per os.

- Thoracoscopic procedures are becoming a common surgical approach owing to their minimally invasive intervention. Severe haemodynamic instability is the major contraindication,[22] while other contraindications include severe cardiac lesions, weight < 1 500 g, and a distended abdomen.[22,23] A general anaesthetic technique with an endotracheal tube is performed. CO_2 insufflation pressures are usually kept between 4–8 mmHg, at a flow rate of 1–2 L/min.[22] Adequate ventilation has been explained by a case series of 45 patients presenting for paediatric thoracoscopic procedures. It includes utilising PCV mode, maintaining peak airway pressures between 12 and 15 cmH_2O, FiO_2 between 60 and 80%, an inspiratory/expiratory (I:E) ratio of 1–1.5 and a respiratory rate between 35 and 55 breaths per minute.[23]
- The open surgical approach (thoracotomy) is commonly performed by many centres. The standard technique involves a muscle-sparing right postero-lateral thoracotomy.[22] Rigid bronchoscopy provides information about the level of the fistula and its size; and different airway management techniques can be explored. During rigid bronchoscopy, the fistula can be occluded prograde by a Fogarty catheter; or retrograde through an existing gastrotomy.[6] Tracheal intubation by deep insertion of an endotracheal tube (ETT) to the carina, then slowly pulling it up until both lungs are ventilated is an alternative technique.[6] Allowing for spontaneous breathing by the child requires meticulous planning (sedation and sufficient pain management) and can help in mitigating complications such as hypoxaemia.[6,24]

Premedication, monitoring and induction of anaesthesia

Choosing a suitable pharmacological agent for premedication should depend on the age of the child, the severity of the anatomical lesion, the experience of the anaesthesiologist and

Table III: Airway devices for one-lung ventilation in a paediatric patient[25]

Age	ETT (IM mm)	BB size location	EZ-blocker	Univent	DLT
Newborn	3.0	3 Fr (E)	-	-	-
0–2 years	3.5–4.0	3–5 Fr (E)	-	-	-
2–6 years	4.0–5.0	5 Fr (E/I)	-	-	-
6–8 years	5.0–6.0	5 Fr (I)	E	3.5	-
8–10 years	6.0–6.5	7 Fr (E/I)	E	3.5	26 Fr
10–12 years	6.5–7.0	7 Fr (I)	E/I	4.5	26–28 Fr
> 12 years	7.0–7.5	7–9 Fr (E/I)	E/I	4.5–6.0	32–35 Fr

OLV – one-lung ventilation, ETT – endotracheal tube, IM – internal diameter, DLT – double lumen tube, Fr – French, E – extraluminal, I – intraluminal

access to the agent. Anxiolytics such as midazolam have been described.[25] Dexmedetomidine is also gaining momentum due to its favourable effects of sedation without precipitating respiratory depression. Patients with TOF, and OA can present with secretions and the use of glycopyrrolate as a premedication can be beneficial.[25]

Standard monitoring includes non-invasive blood pressure, an electrocardiogram, pre and postductal saturation monitoring, temperature, and end-tidal CO_2 ($ETCO_2$). The insertion of invasive monitors, such as an arterial line and a central venous catheter, is patient-tailored, especially for those presenting with haemodynamic instability and major cardiovascular lesions where the use of ionotropic support might be needed.

Anaesthesia induction in a haemodynamically stable patient is commonly achieved by inhalational induction with sevoflurane, or an intravenous induction.[25] The aim in most of these cases is maintaining spontaneous ventilation. Where mechanical ventilation is possible, after securing the airway with an ETT, a muscle relaxant can be administered, or following ligation of the lesion.

One-lung ventilation (OLV) is not an absolute necessity with most of these intra-thoracic lesions. Airway planning and management should involve both the anaesthesiologist and the paediatric surgeon; in order to accommodate the patient's physiology and the clinicians' expectations. The challenge lies not only in the availability of the required equipment, but also in the comfort of their use. Table III from Murray and colleagues,[25] the available options in terms of OLV in the paediatric patient.

Conclusion

Paediatric patients presenting for thoracic surgery can present a challenge for the anaesthesiologist. Their comorbid burden, especially cardiac congenital lesions, presents added challenges. Perioperative considerations are unique in this patient population; these include shared airway challenges, positive pressure ventilation, ECMO rescue use, OLV strategies, and haemodynamic challenges. A good perioperative plan involving a multidisciplinary approach should ideally result in good clinical outcomes.

ORCID

G Leballo https://orcid.org/0000-0003-2217-6288

References

1. Mayer S, Metzger R, Kluth D. The embryology of the diaphragm. Semin Pediatr Surg. 2011;20(3):161-9. https://doi.org/10.1053/j.sempedsurg.2011.03.006.
2. Iritani I. Experimental study on embryogenesis of congenital diaphragmatic hernia. Anat Embryol (Berl). 1984;169(2):133-9. https://doi.org/10.1007/BF00303142.
3. Chandrasekharan PK, Rawat M, Madappa R, Rothstein DH, Lakshminrusimha S. Congenital diaphragmatic hernia - a review. Matern Health Neonatol Perinatol. 2017;3:6. https://doi.org/10.1186/s40748-017-0045-1.
4. Quinney M, Wellesley H. Anaesthetic management of patients with a congenital diaphragmatic hernia. BJA Educ. 2018;18(4):95-101. https://doi.org/10.1016/j.bjae.2018.01.001.
5. Al-Rawi O, Booker P. Oesophageal atresia and tracheo-oesophageal fistula. Continuing Education in Anaesthesia Critical Care and Pain. 2007;7(1):15-19. https://doi.org/10.1093/bjaceaccp/mkl062.
6. Motshabi P. Anaesthesia for oesophageal atresia with or without tracheo-oesophageal atresia. S Afr J Anaesth Analg. 2014;20(5):19-25. https://doi.org/10.1080/22201181.2014.979632.
7. Greer JJ. Current concepts on the pathogenesis and etiology of congenital diaphragmatic hernia. Respir Physiol Neurobiol. 2013;189(2):232-40. https://doi.org/10.1016/j.resp.2013.04.015.
8. Veenma DC, De Klein A, Tibboel D. Developmental and genetic aspects of congenital diaphragmatic hernia. Pediatr Pulmonol. 2012;47(6):534-45. https://doi.org/10.1002/ppul.22553.
9. Keijzer R, Liu J, Deimling J, Tibboel D, Post M. Dual-hit hypothesis explains pulmonary hypoplasia in the nitrofen model of congenital diaphragmatic hernia. Am J Pathol. 2000;156(4):1299-306. https://doi.org/10.1016/S0002-9440(10)65000-6.
10. Lath NR, Galambos C, Rocha AB, et al. Defective pulmonary innervation and autonomic imbalance in congenital diaphragmatic hernia. Am J Physiol Lung Cell Mol Physiol. 2012;302(4):L390-8. https://doi.org/10.1152/ajplung.00275.2011.
11. Shehata SM, Mooi WJ, Okazaki T, et al. Enhanced expression of vascular endothelial growth factor in lungs of newborn infants with congenital diaphragmatic hernia and pulmonary hypertension. Thorax. 1999;54(5):427-31. https://doi.org/10.1136/thx.54.5.427.
12. Byrne FA, Keller RL, Meadows J, et al. Severe left diaphragmatic hernia limits size of fetal left heart more than does right diaphragmatic hernia. Ultrasound Obstet Gynecol. 2015;46(6):688-94. https://doi.org/10.1002/uog.14790.
13. Pober BR, Lin A, Russell M, et al. Infants with Bochdalek diaphragmatic hernia: sibling precurrence and monozygotic twin discordance in a hospital-based malformation surveillance program. Am J Med Genet A. 2005;138a(2):81-88. https://doi.org/10.1002/ajmg.a.30904.
14. Slavotinek AM. Fryns syndrome: a review of the phenotype and diagnostic guidelines. Am J Med Genet A. 2004;124a(4):427-33. https://doi.org/10.1002/ajmg.a.20381.
15. Lal DR. Chapter 392. Anatomic disorders of the esophagus. In: Rudolph CD, Rudolph AM, Lister GE, First LR, Gershon AA, editors. Rudolph's Pediatrics, 22e. New York, NY: The McGraw-Hill Companies; 2011.
16. Gayle JA, Gómez SL, Baluch A, et al. Anesthetic considerations for the neonate with tracheoesophageal fistula. Middle East J Anaesthesiol. 2008;19(6):1241-54.
17. Spitz L. Oesophageal atresia. Orphanet J Rare Dis. 2007;2:24. https://doi.org/10.1186/1750-1172-2-24.
18. Beasley SW. Esophageal atresia and tracheoesophageal fistula. In: Oldham KT, Colombani PM, Foglia RP, et al., editors. Principles and Practice of Pediatric Surgery. Philadelphia: Lippincott Williams & Wilkins; 2005. p. 1040
19. Snoek KG, Capolupo I, Van Rosmalen J, et al. Conventional mechanical ventilation versus high-frequency oscillatory ventilation for congenital diaphragmatic hernia: a randomized clinical trial (The VICI-trial). Ann Surg. 2016;263(5):867-74. https://doi.org/10.1097/SLA.0000000000001533.
20. Snoek KG, Reiss IK, Greenough A, et al. Standardized postnatal management of infants with congenital diaphragmatic hernia in Europe: The CDH EURO

Consortium Consensus - 2015 Update. Neonatology. 2016;110(1):66-74. https://doi.org/10.1159/000444210.

21. Snyder AN, Cheng T, Burjonrappa S. A nationwide database analysis of demographics and outcomes related to extracorporeal membrane oxygenation (ECMO) in congenital diaphragmatic hernia. Pediatr Surg Int. 2021;37(11):1505-13. https://doi.org/10.1007/s00383-021-04979-y.
22. Slater BJ, Rothenberg SS. Tracheoesophageal fistula. Semin Pediatr Surg. 2016;25(3):176-78. https://doi.org/10.1053/j.sempedsurg.2016.02.010.
23. Liu H, Le C, Chen J, et al. Anesthetic management of thoracoscopic procedures in neonates: a retrospective analysis of 45 cases. Transl Pediatr. 2021;10(8):2035-43. https://doi.org/10.21037/tp-21-265.
24. Hosking C, Motshabi-Chakane P. Thoracotomy in a spontaneously breathing neonate undergoing tracheo-oesophageal fistula repair: case study. S Afr J Anaesth Analg. 2013;19(6):321-2. https://doi.org/10.1080/22201173.2013.10872948.
25. Murray-Torres TM, Winch PD, Naguib AN, Tobias JD. Anesthesia for thoracic surgery in infants and children. Saudi J Anaesth. 2021;15(3):283-99. https://doi.org/10.4103/sja.SJA_350_20.