

Anaesthetic Management of Tracheoesophageal Fistula: A Narrative Review of Principles, Challenges and Evolving Strategies

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ABSTRACT

Tracheoesophageal Fistula (TEF), which is usually associated with Oesophageal Atresia (EA), is known to be a common congenital anomaly requiring urgent surgical intervention in the neonatal period. Anaesthetic management of TEF repair is very challenging because of the pathological communication between the airway and gastrointestinal tract, immature neonatal physiology, as well as frequent association with congenital anomalies, especially cardiac defects. Key aspects include the embryological basis, anatomical classification and pathophysiological implications influencing protection ventilation and airway, along with risk stratification using established prognostic systems such as the Spitz classification. Preoperative evaluation which is focused upon stabilisation strategies for minimising aspiration as well as respiratory compromise, detailed assessment for associated anomalies and optimisation of metabolic and respiratory status. Intraoperative management emphasises strategies into airway control inclusive of distal endotracheal tube placement, fibreoptic bronchoscopy-guided localisation of the fistula, lung-protective ventilation for reduction of gastric insufflation and barotrauma. Postoperative anaesthetic and critical care management including decisions regarding elective ventilation, analgesia, monitoring and the prevention of complications such as anastomotic leak and recurrent fistula are also reviewed. Advancements such as opioid-sparing multimodal analgesia, minimally invasive surgery techniques as well as protocol-based multidisciplinary care pathways have contributed further in improved perioperative outcomes. Despite such developments there are significant gaps also remains into high-quality evidence further guiding optimal ventilation strategies, extubation criteria, long-term outcomes. This narrative review article highlights current practices, recent advances, future directions into research for evidence-based anaesthetic management of TEF repair.

Keywords: Airway management, Bronchoscopy, Neonatal anaesthesia, Oesophageal atresia, Ventilation strategies

INTRODUCTION

The TEF is known to be a congenital anomaly which is characterised by an abnormal connection between trachea and the oesophagus, frequently occurring in association with EA [1,2]. The failure of the embryonic foregut to separate properly into distinct tracheal-oesophageal tubes during early gestation highlight its development, resulting in significant clinical challenges including aspiration, respiratory distress, as well as feeding intolerance in the neonatal period [3]. Approximately one in 2,500 to 4,500 live births are affected, thereby making TEF along with EA one of the most common congenital defects that require emergency type of surgical care in infancy [4].

The earliest documented description of EA which is usually accompanied by TEF, dates back to 1670 when William Durston first reported a “monstrous birth” in Plymouth along with Thomas Gibson later providing clearer clinical and necropsy insights into proximal EA with distal fistula in the late 17th century [5]. TEF was explained throughout 19th century as clinicians in Europe, North America reported cases, which further helped setting stage for attempts at surgical correction toward the end of that century [6]. However, it was not until early-mid of 20th century that significant surgical progress was made [6]. By the period of 1930s-1940s, pioneering surgeons like Ladd, Leven and Cameron Haight, Michigan, further introduced surgical approaches for primary surgical repair as well as end-to-end anastomosis [7].

Clinically, infants having TEF usually present shortly after birth with excessive salivation, coughing, choking, or cyanosis with feedings due to the fistulous communication which further permits aspiration of oral contents into the airway [8]. Early diagnosis and appropriate surgical correction remain very essential for minimising morbidity, preventing life-threatening complications including

recurrent pneumonia, malnutrition [8]. Although majority of TEFs are discovered in neonatal age, isolated variants such as H-type fistula without associated EA includes only few cases and it can be more challenging to diagnose without targeted imaging approach, endoscopic evaluation [9]. Over subsequent decades development into thoracoscopic approaches further reflects evolution into treatment of TEF from being fatal condition to one having high rates of survival, ongoing improvements in outcomes [7]. The present narrative review article aims to synthesise current evidence regarding anaesthetic management of TEF, highlighting key principles, clinical features, recent advances along with future research directions to optimise outcomes in patients.

Embryological Basis and Anatomical Classification of Tracheoesophageal Fistula (TEF)

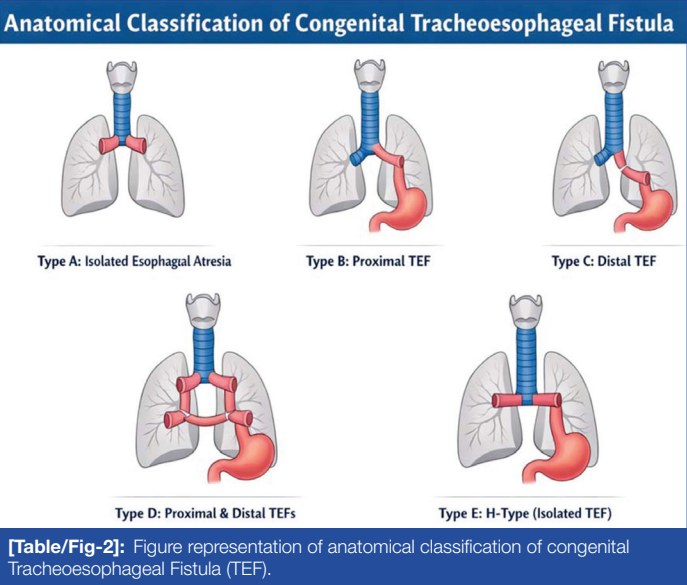
During early stages of embryonic development, trachea and oesophagus originate from a common foregut tube [10]. Around fourth to sixth week of gestation, longitudinal Tracheoesophageal folds form and fuse for creating a Tracheoesophageal septum, which separates the foregut into a ventral respiratory (laryngotracheal) tube and a dorsal oesophageal tube [10,11]. Disruption of this separation process because of genetic, molecular, or environmental factors further influence dorsal-ventral patterning and morphogenesis resulting in Tracheoesophageal defects, including TEF and EA [10,11]. Research studies of animal models have also highlighted roles for key signalling pathways (such as WNT, BMP and SHH) in normal morphogenesis of foregut [11,12]. Additionally, other molecular pathways including Fibroblast Growth Factor (FGF) signalling, Retinoic Acid (RA) signalling and Notch signalling, as well as transcription factors such as SRY-box transcription factor 2 (SOX2) and NK2 homeobox 1 (NKX2-1).1, have been implicated in regulating dorsal-ventral patterning and epithelial differentiation

during tracheoesophageal development [11,12]. Perturbations in all of these mechanisms can cause persistent communication between trachea and oesophagus or incomplete oesophageal development [11,12].

Clinically, congenital TEFs are categorised which was based upon anatomic relationship between oesophagus and trachea [13]. The classification inclusive of five main types such as, Type A (isolated EA without TEF), Type B (EA with proximal TEF), Type C (EA with distal TEF which is known to be the most common form, that accounts usually for ~85% of cases), Type D (EA with both proximal and distal TEFs) and Type E (H-type) (a fistula without associated EA) [13]. This classification helps in diagnosis-surgical planning, along with its Type C is known as the prototypical presentation of proximal blind oesophageal pouch as well as distal tracheoesophageal communication [13]. Congenital TEFs further contrast with acquired TEFs, which also arise postnatally because of trauma, malignancy, chronic inflammation [13]. Anatomical Classification of Congenital TEF is described in [Table/Fig-1]. Anatomical Classification of congenital TEF is depicted through [Table/Fig-2].

Type	Anatomical description	Key features/clinical notes
Type A	Oesophageal Atresia (EA) without Tracheoesophageal Fistula (TEF)	Both oesophageal ends end blindly; no communication with trachea
Type B	EA with proximal Tracheoesophageal Fistula (TEF)	Rare; proximal oesophagus communicates with trachea
Type C	EA with distal Tracheoesophageal Fistula (TEF)	Most common type (~85%); proximal blind oesophageal pouch with distal tracheoesophageal communication
Type D	EA with both proximal and distal Tracheoesophageal Fistula (TEF)	Very rare; fistulous connections at both oesophageal ends
Type E (H-type)	Tracheoesophageal Fistula (TEF) without Oesophageal Atresia (EA)	Esophagus is continuous; isolated fistula resembling the letter "H"

[Table/Fig-1]: Anatomical classification of congenital Tracheoesophageal Fistula (TEF) [13].



[Table/Fig-2]: Figure representation of anatomical classification of congenital Tracheoesophageal Fistula (TEF).

Pathophysiological Considerations of Tracheoesophageal Fistula (TEF) Relevant to Anaesthesia

The TEF is defined as an abnormal communication between trachea and oesophagus resulting in disruption of normal anatomical separation between airway as well as gastrointestinal tract [3,14]. TEF can occur in both congenital, acquired forms [14]. Congenital TEF usually occurs along with EA due to abnormal embryologic separation of foregut during early development whereas acquired type TEF can arise secondary to malignancy, trauma, prolonged endotracheal intubation, radiotherapy [13,14]. The presence of this

pathological communication predisposes patients to aspiration of gastric or oral contents into airway thereby leading to complications such as aspiration pneumonia, recurrent respiratory infections and feeding difficulties [13].

From an anaesthetic perspective, presence of a TEF creates a pathological communication between airway as well as gastrointestinal tract, which further affects ventilation, airway protection [15]. During spontaneous or assisted ventilation, usually along with positive pressure, gas preferentially escapes through fistula into the stomach, resulting in gastric insufflation [15]. Progressive gastric distension causes elevation of diaphragm, reduces compliance of lung, worsens ventilation-perfusion mismatch and can also precipitate severe hypoventilation and hypoxaemia [15]. Gastric overdistension further increases intragastric pressure, thereby elevating risk of regurgitation as well as pulmonary aspiration, is a major cause of perioperative morbidity in neonates with TEF [15]. All of these mechanisms highlight anaesthetic principle of avoiding mask ventilation using positive pressure, as well as maintaining spontaneous respiration until definitive airway control is achieved [16,17].

Positive pressure ventilation in TEF is complicated by having difficulty in achieving effective lung ventilation, usually in distal fistulas, where a significant portion of delivered tidal volume is lost to the gastrointestinal tract [16]. High airway pressures not only worsen gastric insufflation but it can also cause preferential ventilation of one lung, pneumonitis, or barotrauma [16]. Many neonates also have varying degrees of pulmonary hypoplasia, especially in long-gap EA or those having associated antenatal polyhydramnios and prematurity [16]. Hypoplastic lungs exhibit reduced compliance, impaired exchange of gas, making them highly sensitive to even brief periods of hypoxia, hypercapnia during induction as well as intubation [16,17].

These challenges are further increased due to neonatal physiological limitations, including reduced Functional Residual Capacity (FRC), high oxygen consumption, minimal oxygen reserve, which all together result into rapid desaturation during apnoea [18]. Furthermore, up to half of infants having TEF also have related congenital anomalies, which is most commonly in spectrum Vertebral, Anorectal, Cardiac, Tracheoesophageal, Renal and Limb anomalies (VACTERL) [18]. Of these, congenital heart disease is particularly relevant to anaesthesia, as it can significantly cause alteration of haemodynamic responses to hypoxia, anaesthetic agents, as well as positive pressure ventilation [18,19]. Consequently, pathophysiology of TEF further requires meticulous preoperative assessment, gentle airway management strategies, controlled ventilation techniques, close coordination between anaesthesia-surgical teams for reducing complications which are related to respiration and aspiration [18].

Preoperative Evaluation and Optimisation in Tracheoesophageal Fistula (TEF)

Preoperative anaesthetic assessment, optimisation for neonates having TEF is a very critical multidisciplinary process aimed at minimising aspiration, respiratory compromise and perioperative morbidity and mortality [20]. Initial stabilisation strategies including maintaining neonate in a semi-upright (head-up) position to use gravity for reducing reflux, pooling of secretions, continuous suctioning of upper oesophageal pouch and oropharynx for prevention of regurgitation and strict avoidance of positive-pressure mask ventilation before securing the airway, as mask ventilation can insufflate the gastrointestinal tract through fistula as well as worsen ventilation by diaphragmatic elevation [20,21]. In addition, neonates are usually nursed in prone or lateral positions with a suction catheter placed in the blind proximal oesophageal pouch for allowing continuous drainage of secretions and further reduce risk of pulmonary aspiration [20,22].

Intravenous fluids must be instituted promptly for correcting dehydration along with maintaining normoglycaemia and prophylactic antibiotics are considered if aspiration or pneumonia is suspected [23]. Routine investigations in preoperative period that include plain chest radiographs, which usually demonstrate a coiled feeding tube in blind upper pouch which confirms diagnosis, as well as arterial blood gas analysis, serum electrolytes for assessment of respiratory function, metabolic status [24]. Failure to advance an orogastric tube beyond approximately 8-13 cm from mouth can raise early suspicion of EA with TEF which is often used as an initial bedside diagnostic indicator in neonates [22,24]. Importantly, echocardiography is recommended for identification of congenital cardiac anomalies which present in substantial proportion of cases which significantly influence perioperative management and can also reveal vascular anomalies such as a right-sided aortic arch that alter the surgical approach [25]. As cardiac anomalies highly influence anaesthetic risk as well as surgical planning so detailed echocardiographic assessment is considered an essential component of preoperative evaluation [24,25]. Antenatal diagnosis which is done through ultrasound can raise suspicion through findings such as polyhydramnios, a small or absent fetal stomach, thus prompting early neonatal planning as well as team coordination [25].

Risk stratification forms an essential part of preoperative assessment, which further helps to guide clinical decision-making and perioperative counselling [26]. Spitz classification is used most widely which stratifies infants depending upon birth weight (>1500 g vs <1500 g) as well as presence of major congenital cardiac anomalies [26]. Neonates without having any major cardiac disease, along with a birth weight ≥1500 g shows highest survival, whereas those with both low birth weight as well as significant cardiac disease have markedly poorer outcomes [26]. External validation studies which have consistently shown about predictive value of Spitz classification for mortality and morbidity in EA/TEF populations [26,27]. Moreover, prematurity and low birth weight independently worsen anaesthetic risk because of immature respiratory physiology along with higher susceptibility to perioperative stress thus it makes the meticulous optimisation of respiratory status and thermal regulation imperative [26,27]. Preoperative management is also inclusive of optimisation of respiratory function, administration of humidified oxygen when required, maintenance of normothermia, correction of electrolyte imbalances and preparation of blood products if significant surgical blood loss is anticipated [22,27]. Early identification and management of sepsis, pneumonia prior to definitive repair are also important as pulmonary infections significantly increase perioperative risk in various patients [27]. Risk stratification in neonates with TEF is depicted in [Table/Fig-3].

Intraoperative Anaesthetic Management and Airway Strategies

Intraoperative anaesthetic management for neonates who are undergoing repair of TEF usually centers upon secure airway control

Risk factor/ Classification	Criteria	Prognostic implication
Spitz classification - Group-I	Birth weight ≥1500 g and no major congenital cardiac anomaly	Highest survival rates; favourable perioperative and anaesthetic outcomes
Spitz classification - Group-II	Birth weight <1500 g or presence of major congenital cardiac anomaly	Intermediate survival; increased perioperative risk
Spitz classification - Group III	Birth weight <1500 g and major congenital cardiac anomaly	Lowest survival; markedly increased anaesthetic and surgical morbidity
Prematurity	Gestational age <37 weeks	Immature respiratory control, reduced Functional Residual Capacity (FRC), higher risk of perioperative respiratory failure

Low birth weight	<1500 g (very low birth weight)	Increased susceptibility to hypothermia, metabolic instability and ventilatory complications
Congenital cardiac anomalies	Structural heart disease (e.g., VSD, TOF, complex cyanotic lesions)	Major determinant of mortality; necessitates tailored anaesthetic and haemodynamic management
Pulmonary infection	Aspiration pneumonia, sepsis	Increased perioperative respiratory compromise and postoperative ventilation requirement
Sepsis/Metabolic derangement	Positive cultures, abnormal ABG/ electrolytes	Higher perioperative morbidity; mandates optimisation before definitive repair

[Table/Fig-3]: Risk stratification in neonates with Tracheoesophageal Fistula (TEF).

and effective ventilation while minimising ventilation through fistula for reduction of gastric distension and aspiration risks [28]. General anaesthesia is usually administered for definitive repair procedure with careful planning of airway management strategies which are tailored to location, size of the fistula [28]. After induction, careful positioning of tracheal tube distal to fistula is paramount; placing the endotracheal tube below fistula site further helps to ensure effective ventilation of lung as well as reduces air passage into gastrointestinal tract thus limiting gastric insufflation and diaphragmatic compromise [28,29]. A commonly described technique which involves advancing endotracheal tube deliberately into right main bronchus followed by gradual withdrawal until bilateral breath sounds are detected thereby positioning tube tip just above the carina but distal to the fistula [22,29]. Intraoperative bronchoscopy has been utilised further for properly localising fistula as well as guiding tracheal tube placement, given that most type C TEFs are located near carina and may not lend themselves to blind deep intubation without precise localisation [28]. Both rigid and flexible bronchoscopy can also help evaluate associated airway anomalies such as laryngomalacia, tracheomalacia, laryngeal cleft, subglottic stenosis, vocal cord paresis which can further influence airway management along with ventilation strategies [22].

Fogarty, balloon-tipped catheters can also be used in few selected cases for temporarily occluding larger fistulas when available and when guided by fibreoptic equipment, facilitating more stable type of ventilation [28,30]. In staged repair procedures, a Fogarty catheter can also be introduced retrogradely through a gastrostomy and advanced under bronchoscopic guidance for occlusion of distal fistula thereby preventing air leak into the gastrointestinal tract during ventilation [22,28,30]. Controlled ventilation with carefully titrated low tidal volumes, minimal positive pressure is recommended to avoid forcing air through fistula into the stomach which can aggravate gastric distension, impair diaphragmatic movement, as well as precipitate aspiration [29]. Peak inspiratory pressures must be kept as low as possible particularly during positive-pressure ventilation as excessive pressures preferentially direct airflow through fistula resulting in gastric distension as well as compromised lung ventilation [22,29].

Maintaining adequate oxygenation, haemodynamic stability throughout surgical repair is another type of core perioperative objective [14]. Neonates having TEF usually have compromised pulmonary mechanics because of recurrent aspiration, pre-existing pneumonia, respiratory distress thereby it makes vigilant intraoperative monitoring essential [31]. Pulse oximetry, capnography, invasive blood pressure monitoring, as well as frequent arterial blood gases further assist into guiding ventilation, oxygen delivery while anaesthetic depth must be sufficient to blunt surgical stimulation without inducing excessive respiratory depression [31]. Standard intraoperative monitoring must be inclusive of electrocardiography, non-invasive blood pressure measurement, pulse oximetry along with consideration of preductal and postductal oxygen saturation monitoring also where feasible, arterial line placement for continuous blood pressure monitoring and arterial blood gas analysis [31,32]. Strategies inclusive of assisted-controlled ventilation following

spontaneous breathing until ligation of the fistula are described which allow smoother transition, avoid high positive pressures early in the procedure [31]. Where facilities permit, maintaining spontaneous ventilation during induction as well as initial airway management can help further to reduce the risk of gastric distension before performing definitive airway control [32]. Short periods of gentle bag-mask ventilation can occasionally be required during airway instrumentation however it should be performed cautiously due to the risk of gastric insufflation [32].

Finally, collaborative communication along with surgical team throughout intraoperative period enhances safety of patient, usually during critical moments such as fistula ligation and mobilisation [33]. Surgeons, anaesthesiologists must coordinate timing for adjustments into strategy of ventilation, suctioning to clear secretions, as well as response to changes in thoracic dynamics during surgical manipulation [33]. Ventilatory parameters can need frequent adjustment during lung retraction or mediastinal manipulation as well as brief coordinated pauses in ventilation may sometimes be required to facilitate surgical exposure [22,33]. The anaesthetic plan must resolve potential complications like inadvertent endotracheal tube displacement, sudden changes into airway pressures, desaturation events along with contingency measures that are ready to ensure rapid correction [32,33].

Postoperative Anaesthetic and Critical Care Management

Postoperative anaesthetic, critical care management plays an important role into determination of outcomes following surgical repair TEF, as this period is associated having a high risk of respiratory, cardiovascular, surgical complications. The decision between early extubation versus elective postoperative ventilation must be individualised [34]. As many neonates usually remain intubated for a period after surgery, planning for postoperative care in a Neonatal Intensive Care Unit (NICU) must ideally be done prior to operation for ensuring availability of appropriate monitoring and ventilatory support [34,35]. Many neonates further need elective postoperative mechanical ventilation, usually those with prematurity, low birth weight, significant preoperative pulmonary disease, associated major cardiac anomalies, intraoperative instability, or prolonged and technically difficult repairs [34,35]. Controlled ventilation thereby allows proper oxygenation which also reduces work of breathing and minimises tension on anastomosis through avoiding excessive spontaneous respiratory effort, crying, which can predispose to anastomotic disruption [35]. However, prolonged endotracheal intubation can further expose anastomotic site to sustained pressure from the endotracheal tube; therefore, the duration of postoperative ventilation should be minimised whenever clinically feasible [22,35]. Lung-protective ventilation strategies having low tidal volumes, careful titration of positive end-expiratory pressure as well as avoidance of hyperinflation are recommended due to underlying pulmonary vulnerability from aspiration or pneumonia [36,37]. Adequate sedation, analgesia are very essential to ensure comfort, synchrony with the ventilator and haemodynamic stability, while avoiding excessive respiratory depression [36,38].

Close monitoring in neonatal intensive care unit is mandatory for detecting early postoperative complications as well as for identifying risk factors for extubation failure and reintubation, which include prematurity, low birth weight, persistent pulmonary infection, tracheomalacia, cardiac disease and inadequate pain control [39]. Reintubation can be required because of excessive airway secretions or tracheobronchomalacia; however, repeated airway instrumentation must be avoided whenever possible as hyperextension of neck during reintubation can place tension on the oesophageal anastomosis [22]. Continuous pulse oximetry,

capnography in ventilated patients, invasive blood pressure monitoring when it is indicated along with serial arterial blood gas analyses further helps guiding ventilatory-metabolic management [40]. Additional postoperative laboratory monitoring inclusive of complete blood count with particular attention to haematocrit levels may assist in evaluating haemodynamic stability and oxygen-carrying capacity [22,40].

Postoperative pain management which is commonly achieved through continuous opioid infusions, supplemented with paracetamol as part of a multimodal analgesic strategy for reducing opioid requirements [38]. Regional techniques like thoracic epidural analgesia have been described in selected centres; however their usage remains controversial in neonates because of the technical challenges, concerns regarding haemodynamic as well as neurological safety, should be reserved for experienced hands [41,42]. Furthermore, epidural analgesia can be avoided in neonates having significant cardiac anomalies due to the potential reduction in systemic vascular resistance and alternative techniques such as wound infiltration with local anaesthetic may be considered [41,42]. Fluid, electrolyte balance must be meticulously managed for avoiding fluid overload which can further worsen pulmonary function while also maintaining adequate perfusion [43]. Postoperative fluid management must be guided by haemodynamic parameters as well as laboratory tests including serum sodium, creatinine and urea levels [43]. Thermal regulation is usually important in premature and low-birth-weight neonates, as hypothermia increases consumption of oxygen and metabolic stress [43].

Respiratory complications such as atelectasis, pneumonia, air leaks, ventilator-associated complications, as well as tracheomalacia-related airway collapse are known to be common and it necessitate prolonged respiratory support [44]. Other potential postoperative complications inclusive of pneumothorax, tracheal leak and recurrent laryngeal nerve injury which may contribute into respiratory compromise thereby requires prompt recognition [22,44]. Early signs of anastomotic leak like unexplained desaturation, increased ventilatory requirements, sepsis can be identified promptly, while recurrent fistula formation must be suspected in cases of persistent-recurrent respiratory symptoms after initial recovery of patient [44]. Feeding is usually not done until anastomotic integrity is confirmed, as well as total parenteral nutrition can be needed in the interim [45]. Multidisciplinary coordination between anaesthesiologists, neonatologists, surgeons, nursing staff remains very important for optimising recovery, reducing morbidity and improving survival in this vulnerable population inclusive of neonatal and paediatric cases [36]. Postoperative anaesthetic and critical care considerations in TEF are described in [Table/Fig-4] [34-45].

Domains	Key components	Clinical significance	References
Ventilation strategy	Early extubation vs elective postoperative ventilation	Individualised decision based on neonatal condition and surgical factors	[34]
	Indications for elective ventilation: prematurity, low birth weight, pulmonary disease, cardiac anomalies, intraoperative instability, prolonged repair	Reduces work of breathing and anastomotic stress	[34,35]
	Lung-protective ventilation (low tidal volume, optimal PEEP, avoid hyperinflation)	Prevents gastric distension, barotrauma and ventilator-induced lung injury	[36,37]
Sedation and analgesia	Adequate sedation to ensure ventilator synchrony and haemodynamic stability	Prevents agitation, crying and anastomotic disruption	[36,38]

	Opioid infusion with paracetamol (multimodal analgesia)	Effective pain control with opioid-sparing effect	[38]
	Thoracic epidural analgesia (controversial)	Limited to specialised centres due to safety concerns	[41,42]
Monitoring and ICU Care	NICU admission with continuous monitoring	Early detection of complications and extubation failure	[34,35]
	Pulse oximetry, capnography, ABG analysis, invasive BP monitoring (when indicated)	Optimises ventilatory and metabolic management	[40]
Risk factors for reintubation	Prematurity, low birth weight, pulmonary infection, tracheomalacia, cardiac disease, poor analgesia	Predicts prolonged ventilation and adverse outcomes	[39]
Fluid and thermal management	Strict fluid and electrolyte balance	Avoids pulmonary oedema while maintaining perfusion	[43]
	Thermal regulation	Prevents increased oxygen consumption and metabolic stress	[43]
Postoperative complications	Atelectasis, pneumonia, air leaks, ventilator-associated complications	Common causes of prolonged respiratory support	[44]
	Tracheomalacia-related airway collapse	May require prolonged ventilation or airway support	[44]
	Anastomotic leak	Suggested by desaturation, sepsis, increased ventilatory needs	[44]
	Recurrent Tracheoesophageal Fistula (TEF)	Suspected with persistent or recurrent respiratory symptoms	[44]
Nutrition	Delayed enteral feeding until anastomotic integrity confirmed	Prevents leak and aspiration	[45]
	Total parenteral nutrition	Supports growth and recovery during nil-per-oral period	[45]
Multidisciplinary care	Coordination between anaesthesiology, neonatology, surgery, nursing	Improves outcomes and survival	[36]

[Table/Fig-4]: Postoperative anaesthetic and critical care considerations in Tracheoesophageal Fistula (TEF) [34-45].
PEEP:Positive end-expiratory pressure; BP:Blood pressure; ABG:Arterial blood gas

Contemporary Advances in Anaesthesia for Tracheoesophageal Fistula (TEF)

Recent advances into anaesthesia for TEF repair have further emphasised individualised, physiology-guided perioperative management which aimed at improving safety as well as helps accelerating recovery. Contemporary evidence supports that increasing usage of multimodal, opioid-sparing techniques in anaesthesia, combining non-opioid analgesics along with selective regional blocks, to minimise opioid-induced respiratory depression while also maintaining effective analgesia thereby facilitating earlier extubation [38]. Airway management has evolved having routine incorporation of fiberoptic bronchoscopy for accurately localising fistula also optimising endotracheal tube positioning distal to the fistula, thereby reducing gastric insufflation and improving ventilation [28,46].

Advances in the minimally invasive, endoscopic surgical approaches have influenced practice related to anaesthesia thereby necessitating refined ventilation strategies, enhanced monitoring,

close intraoperative coordination with surgical team [47]. Additionally, the adoption of multidisciplinary, protocol-based perioperative care pathways, supported by advanced neonatal intensive care as well as vigilant postoperative monitoring has contributed into improvement of respiratory stability, reduced perioperative morbidity in this high-risk neonatal population [47].

Future Directions, Research Gaps in Anaesthetic Management of Tracheoesophageal Fistula (TEF)

Future directions in anaesthesia for TEF repair highlight several important research gaps despite having recent advances in perioperative care [47]. Current evidence underscores need for large, multicentre prospective studies for validating emerging strategies including opioid-sparing or opioid-free anaesthesia, optimal ventilation protocols and fibreoptic-guided airway algorithms; presently supported mainly by small or single-centre studies [38,48]. There is very limited high-quality informative data properly defining ideal criteria for extubation, ventilation strategies, as well as analgesic regimens across varying anatomical types and risk profiles related to TEF [29,49]. Furthermore, impact of different anaesthetic techniques on long-term respiratory, neurodevelopmental outcomes remains studied poorly regarding TEF patient care [50]. Standardised outcome reporting, collaborative research frameworks are therefore very essential for developing evidence-based, precision-guided anaesthetic protocols which can help to improve short and long-term outcomes in neonates undergoing TEF repair [47,50].

CONCLUSION(S)

Anaesthetic management of TEF repair is very complex that further demands a thorough understanding of neonatal physiology, fistula-related pathophysiology and associated congenital anomalies. Optimal outcomes which are based upon meticulous preoperative stabilisation, precise airway and ventilation strategies, vigilant intraoperative monitoring as well as structured postoperative critical care. Contemporary advances inclusive of fibreoptic-guided airway management, lung-protective ventilation, opioid-sparing analgesia have helped to improve perioperative safety. However, significant evidence gaps also persist thus underscoring the need for multicentre, standardised research for refining anaesthetic protocols as well as improve both short and long-term neonatal outcomes.

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