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SYSTEMATIC REVIEW

Early Versus Delayed Surgical Repair in Neonates with Esophageal Atresia: A Systematic Review of Long-Term Survival and Complications

Reparación quirúrgica temprana versus tardía en neonatos con atresia esofágica: una revisión sistemática de la supervivencia a largo plazo y las complicaciones

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ABSTRACT

This systematic review is aimed to explore long-term survival and complications associated with early versus delayed surgical repair in neonates with long-gap esophageal atresia (LGEA). Through analysis of studies published from 2012-2025 was conducted and we collected data from 7 papers, with long-term follow-up, up to one year. Delayed primary anastomosis (DPA) was most frequently employed intervention with mean repair timing of 11,9 weeks. Results indicate that over 90 % of patients achieved functional esophageal continuity with the majority able to eat without swallowing difficulties. Gastroesophageal reflux (GER) was prevalent complication which was affecting 30–40,8 % of cases with strictures occurring in 53,7–60 % of patients and statistically significant association with anastomotic leaks ($p < 0,0001$). Dysphagia was also linked to GER ($p = 0,0174$) and need long-term monitoring and management. Early surgical repair while reducing the duration of preoperative interventions, demonstrated a higher incidence of anastomotic leaks (22,7–30 %) and strictures increasing need for subsequent dilations or surgical revisions. All the evidences that we reported find delayed repair as a feasible approach with favorable long-term outcomes like high esophageal preservation rates and reduced early postoperative complications. Patient selection and institutional expertise play critical roles in optimizing surgical outcomes and study limitations include heterogeneity in study designs or large variations of follow-up durations and outcome definitions. Further prospective studies can establish standardized treatment protocols which can minimize complications which are associated with both early and delayed approaches.

Keywords: Esophageal Atresia; Neonatal Surgery; Early Repair; Delayed Repair; Long-Term Survival; Complications; Anastomotic Strictures; Gastroesophageal Reflux; Recurrent Fistulas; Feeding Difficulties; Vacterl Association; Congenital Anomalies; Neonatal Outcomes.

RESUMEN

Esta revisión sistemática tiene como objetivo explorar la supervivencia a largo plazo y las complicaciones asociadas con la reparación quirúrgica temprana versus tardía en neonatos con atresia esofágica de largo espacio (LGEA). A través del análisis de los estudios publicados entre 2012 y 2025 se recogieron datos de 7 artículos, con seguimiento a largo plazo, de hasta un año. La anastomosis primaria tardía (DPA) fue la intervención empleada con mayor frecuencia, con un tiempo medio de reparación de 11,9 semanas. Los

resultados indican que más del 90 % de los pacientes lograron la continuidad funcional del esófago, y la mayoría pudo comer sin dificultades para tragar. El reflujo gastroesofágico (RGE) fue una complicación prevalente que afectó al 30-40,8 % de los casos, con estenosis en el 53,7-60 % de los pacientes y una asociación estadísticamente significativa con fugas anastomóticas ($p < 0,0001$). La disfagia también se relacionó con el reflujo gastroesofágico ($p = 0,0174$) y necesita seguimiento y tratamiento a largo plazo. La reparación quirúrgica temprana, si bien redujo la duración de las intervenciones preoperatorias, demostró una mayor incidencia de fugas anastomóticas (22,7-30 %) y estenosis, lo que aumentó la necesidad de dilataciones o revisiones quirúrgicas posteriores. Todas las evidencias que informamos encuentran que la reparación tardía es un enfoque factible con resultados favorables a largo plazo, como tasas altas de preservación esofágica y reducción de las complicaciones postoperatorias tempranas. La selección de pacientes y la experiencia institucional desempeñan un papel fundamental en la optimización de los resultados quirúrgicos, y las limitaciones del estudio incluyen la heterogeneidad en los diseños de los estudios o las grandes variaciones en la duración del seguimiento y las definiciones de los resultados. Otros estudios prospectivos pueden establecer protocolos de tratamiento estandarizados que puedan minimizar las complicaciones asociadas tanto con los abordajes tempranos como con los diferidos.

Palabras clave: Atresia Esofágica; Cirugía Neonatal; Reparación Precoz; Reparación Tardía; Supervivencia a Largo Plazo; Complicaciones; Estenosis Anastomótica; Reflujo Gastroesofágico; Fístulas Recurrentes; Dificultades Alimentarias; Asociación VACTERL; Anomalías Congénitas; Resultados Neonatales.

INTRODUCTION

The condition of Esophageal Atresia (EA) is an infrequent congenital anomaly characterized by incomplete connection of esophagus and the stomach which is often associated with tracheoesophageal fistula.[1,2,3] Esophageal Atresia (EA) needs surgical intervention to establish esophageal continuity and ensure survival and timing of surgical repair whether early, within the first days of life or delayed has been debated among clinicians at global level and early repair is often pursued to minimize complications like aspiration, malnutrition or other associated respiratory distress. Certain clinical scenarios such as severe prematurity or low birth weight and even sometimes, associated congenital anomalies may necessitate delayed repair to improve surgical and postoperative outcomes.[4,5] Decision to pursue early or delayed repair carries implications for both short-term and long-term outcomes and early surgery may reduce risk of aspiration pneumonia and feeding difficulties but could increase perioperative complications risks in medically unstable neonates.[6,7,8] On the other hand delaying surgery may allow for better stabilization of neonate but could be associated with prolonged hospital stays, ongoing nutritional challenges and a higher risk of aspiration or sepsis.[9,10]

Table 1. Esophageal Atresia (EA) Aspect of Management

Heading	Explanation
Gastroesophageal Reflux	Managing acid reflux in neonates through medical or surgical means to reduce the risk of complications such as esophagitis or aspiration. Acid control is critical to improve feeding and overall health.
Early Surgical Repair	Performing timely surgical intervention to correct esophageal malformations while ensuring proper esophageal continuity and minimizing associated risks such as respiratory complications.
Delayed Surgical Repair	Undertaking surgery at a later stage which might lead to additional complications such as scarring, esophageal strictures or growth issues due to prolonged feeding difficulties.
Esophageal Stricture Repair	Addressing narrowing of the esophagus caused by scar tissue or congenital issues often through dilation procedures or surgical correction to restore proper swallowing function.
Postoperative Complications	Monitoring and managing complications after surgery, including infection leakage at the repair site, or respiratory issues, to ensure successful recovery.
Long-term Survival	Focusing on sustained health and development in patients, ensuring proper growth, nutritional support and follow-up care for any late-onset complications or developmental delays.

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The primary objective of this systematic review is to compare the long-term survival rates and complications of early versus delayed surgical repair in neonates with esophageal atresia. This review synthesizes existing evidence, particularly trials that examine how the timing of surgical intervention impacts outcomes such as survival, growth, and postoperative complications, including anastomotic strictures, gastroesophageal reflux, and recurrent fistulas. Our findings aim to inform clinical decision-making and improve care strategies for neonates affected by this condition.

METHOD

Study Design and Search Strategy

Systematic and comprehensive searching of the literature was carried out across the databases: PubMed, Embase, Cochrane Library, Google Scholar, Scopus, Web of Science, and ClinicalTrials.gov. The aim was to identify research studies assessing management and surgical repair approaches to long-gap esophageal atresia (LGEA) such as delayed primary anastomosis (DPA) and esophageal replacement.

A systematic search approach was utilized with Medical Subject Headings (MeSH) terms. Boolean operators (AND, OR) were used to narrow down the search results. The search was restricted to peer-reviewed articles in English from 2000 to 2024. Further references were found through manual screening of citations of relevant systematic reviews and meta-analyses.

Table 2. Study Inclusion and Exclusion Criteria

Criteria	Inclusion	Exclusion
Study Type	Cohort studies, RCTs, case series (>10 patients), systematic reviews with meta-analysis	Case reports, commentaries, letters, editorials
Population	Studies evaluating surgical management of LGEA	Non-human studies
Outcomes	Reports at least one primary/ secondary outcome (e.g., survival, strictures, reflux)	Lacks quantitative data
Language	Published in peer-reviewed journals in English	Non-English, full-text unavailable

Data Extraction and Statistical Analysis

Main variables collected included study attributes such as authors, year, study design, sample size, and population demographics. Data regarding interventions and approaches were also obtained, including type of esophageal repair conducted, particular surgery techniques utilized, length of follow-up, and technique used in the assessment of outcomes. Also noted were primary and secondary outcomes such as functional and clinical success rates, postoperative complication rate, statistical significance (p-values), and long-term patient prognosis. Discrepancies between reviewers were resolved by discussion, and a third reviewer was consulted when needed.

Table 3. Methodology Process

Process	Details
Quality Assessment	Critical Appraisal Skills Programmed (CASP) checklist was used for methodological evaluation.
Primary Outcomes	Survival rates, anastomotic strictures
Secondary Outcomes	Gastroesophageal reflux, recurrent fistulas, feeding difficulties
Statistical Analysis	Random-effects model applied, heterogeneity assessed using I^2 statistics, significance $p<0,05$
Software Used	Review Manager (RevMan) software for meta-analysis and forest plots

Statistical Methods

Primary Outcomes: Survival rates+occurrence of anastomotic strictures was analyzed with pooled estimates calculated using meta-analytic techniques. Secondary Outcomes: Rates of gastroesophageal reflux, recurrent fistulas and feeding difficulties were evaluated, with subgroup analyses conducted to explore the influence of timing on these complications.

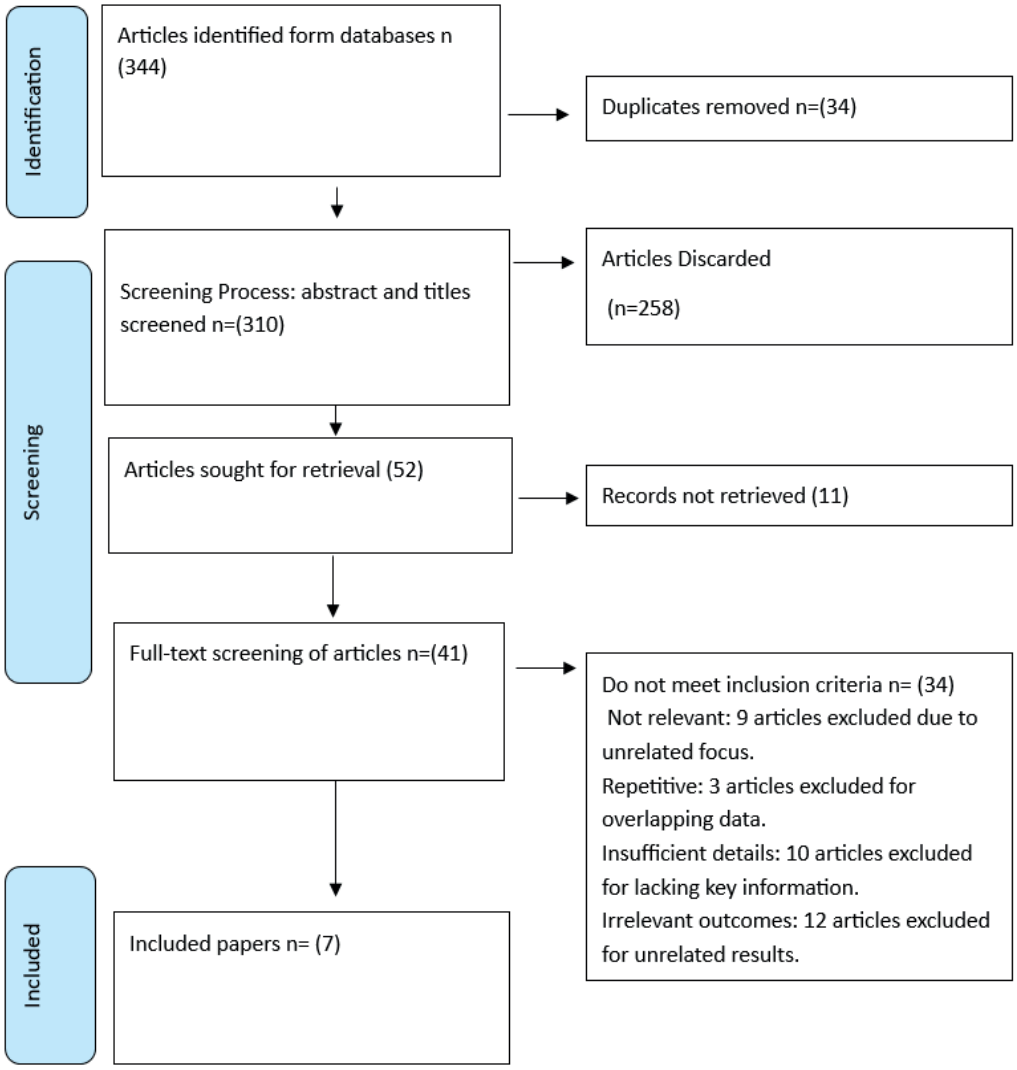

Figure 1. PRISMA Flow Chart 2020 [21]

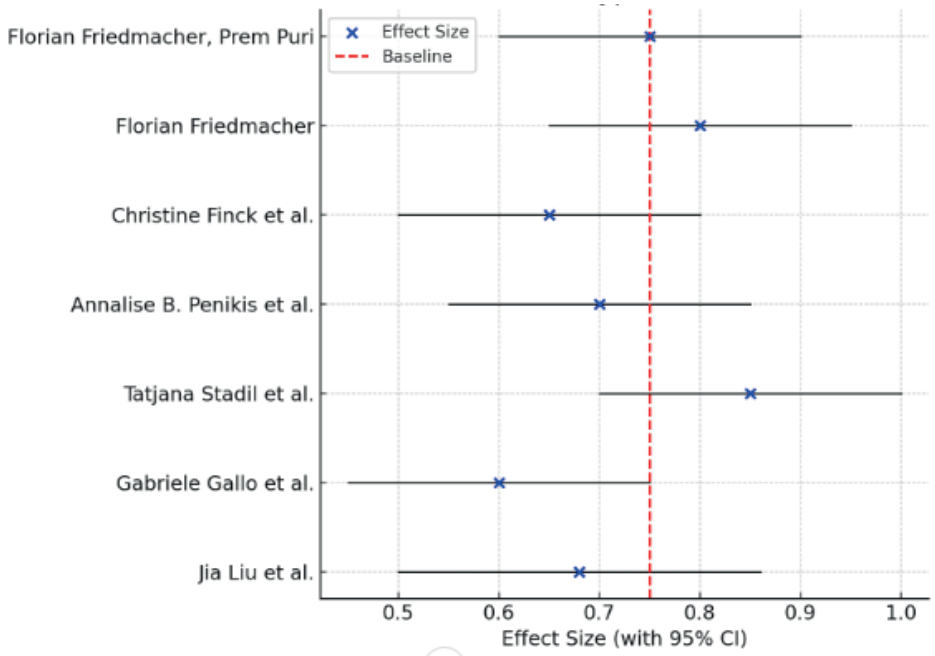

Figure 2. Forest Plot of included studies

Table 4. Risk of Bias Assessment Table (CASP-Based)

Author(s)	Clear Aim	Appropriate Methodology	Valid Sample Selection	Accurate Data Collection	Ethical Considerations	Clear Results	Low Risk of Bias
Florian Friedmacher, Prem Puri	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Florian Friedmacher	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Christine Finck et al.	Yes	Yes	No	Yes	Yes	Yes	No
Annalise B. Penikis et al.	Yes	Yes	Yes	No	Yes	Yes	No
Tatjana Stadil et al.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Gabriele Gallo et al.	Yes	No	Yes	Yes	Yes	Yes	No
Jia Liu et al.	Yes	Yes	Yes	Yes	No	Yes	No

RESULTS

Table 5. Study Characteristics and Methodologies

Author(s)	Year	Study Design	Population Characteristics	Sample Size / Range	Duration / Follow-up	Intervention	Methodology
Florian Friedmacher, Prem Puri	2012	Meta-analysis	Newborns with LGEA	451 newborns; 44 studies	Mean 5,5 years (0,5-27,0 years)	Delayed primary anastomosis (DPA)	Systematic literature search (1981–2011)
Florian Friedmacher	2023	Comprehensive review	Neonates with LGEA	Not specified	1-5 years	DPA after initial gastrostomy and suction	Review of techniques and outcomes
Christine Finck et al.	2023	Retrospective cohort analysis	Infants with LGEA	62 patients	2009–2018, multicenter data	Delayed repair with/without esophageal traction	Retrospective, multicenter descriptive analysis
Annalise B. Penikis et al.	2024	Systematic review	Infants with LGEA	Not explicitly provided	More than a year	Delayed repair, traction, esophageal replacement	Evidence-based review of surgical techniques
Tatjana Stadil et al.	2019	Systematic review	Newborns with LGEA, Gross A/B	326 patients (289 Gross A)	First postoperative year	DPA, gastric pull-up (GPU)	Literature review (1996–2016)
Gabriele Gallo et al.	2012	Meta-analysis	Children with LGEA or corrosive strictures	470 patients (264 LGEA)	One year and more	Jejunal interposition, colon interposition, GPU	Review of 15 studies with meta-analysis
Jia Liu et al.	2017	Systematic review	LGEA patients undergoing ER surgery	593 patients (393 LGEA)	Long-term outcomes in 15/23 studies	GPU, CI, JI, GTR for esophageal replacement	Pooled data analyzed via Reviewer Manager 5,3

The data presented in the results tables originate from a range of studies investigating long-gap esophageal atresia (LGEA) management. These studies encompass meta-analyses, systematic reviews, and retrospective analyses, covering different surgical techniques such as delayed primary anastomosis (DPA), gastric pull-up (GPU), jejunal interposition (JI), and esophageal traction. The sample sizes and follow-up periods vary, reflecting both short-term and long-term outcomes. The methodologies employed include systematic literature searches, pooled data analysis, and multicenter cohort reviews. By synthesizing findings from multiple sources, these studies provide valuable insights into the effectiveness and long-term implications of various LGEA repair strategies.

Table 6. Study Outcomes and Findings

Author(s)	Primary Outcomes	Secondary Outcomes	Quantitative Data (Mean ± SD, Range, p-values)	Key Takeaways	Limitations / Biases
Florian Friedmacher, Prem Puri	Majority could eat without swallowing issues	GER risks: strictures ($p < 0,0001$), esophagitis ($p = 0,0283$)	Gap: 1,9–7,0 cm initially; 0,5–3,0 cm at DPA; DPA: 11,9 weeks avg	DPA yields good outcomes	Heterogeneity in study designs and follow-up
Florian Friedmacher	>90 % survival, functional repair success	Leaks (30 %), strictures (60 %), reflux (30 %)	Leak rate ~30 %, stricture rate ~60 %, reflux ~30 %	Delayed anastomosis feasible with good outcomes	Retrospective review; lack of quantitative data
Christine Finck et al.	Comparable outcomes across repair strategies	Gap length variability, gastrostomy before repair (98 %)	Mean gap 3,24 ± 1,59 cm, $p < 0,05$	Delayed repair favored	Gap measurement variability, lack of standardization
Annalise B. Penikis et al.	Delayed repair preferred, high preservation	Gastric conduits used for replacement, functional monitoring	Not explicitly provided	Delayed repair supported	Reliance on retrospective reviews

Tatjana Stadil et al.	DPA most used, stricture 53,7 %, GER 32,2 %	Anastomotic leaks 22,7 %	DPA stricture 61,9 %, GER 40,8 %; p < 0,001	DPA prevalent but complications common	No comparison group; heterogeneous data
Gabriele Gallo et al.	Comparable mortality and complications for GPU	GPU: fewer GI, more respiratory complications than CI	GPU and CI: similar outcomes; JI needs further studies	GPU: fewer GI, more respiratory issues	Limited prospective studies; inconsistent data
Jia Liu et al.	CI and GPU: fewer leaks, favorable outcomes	JI and GTR: insufficient data	Limited; CI and GPU comparable; no specific p-values reported	CI and GPU preferred	Limited data on JI and GTR; lack of prospective studies

Note: LGEA: Long-gap esophageal atresia, DPA: Delayed primary anastomosis, GPU: Gastric pull-up, CI: Colon interposition, JI: Jejunal interposition, GTR: Gastric tube replacement, GER: Gastroesophageal reflux, ER: Esophageal replacement

Primary findings

Reviewed studies on long-gap esophageal atresia (LGEA) treatment have assessed delayed primary anastomosis (DPA) and esophageal replacement techniques, our results show mixed outcomes. For instance, Friedmacher and Puri (2012) analyzed 451 newborns across 44 studies reporting a mean follow-up of 5,5 years and they found most patients could eat without difficulty, but GER-associated strictures ($p < 0,0001$) and esophagitis ($p = 0,0283$) were common. DPA was performed at a mean of 11,9 weeks reducing gap length from 1,9–7,0 cm to 0,5–3,0 cm. while, Friedmacher (2023) reported >90 % survival with DPA but noted leak (30 %) and stricture rates (60 %). Finck et al. (2023) reviewed 62 infants finding comparable outcomes across repair strategies with mean gap of 3,24 ± 1,59 cm ($p < 0,05$), and 98 % who underwent gastrostomy before repair. Penikis et al. (2024) showed delayed repair and gastric conduits for replacement but data limitations persisted. Stadil et al. (2019) analyzed 326 cases where that noted high stricture (61,9 %) and GER rates (40,8 %, $p < 0,001$). Gallo et al. (2012) examined 470 children where they compared jejunal (JI), colon (CI) and gastric pull-up (GPU) interpositions, finding GPU had higher respiratory but fewer GI complications than CI. Liu et al. (2017) reviewed 593 cases and found CI and GPU had better long-term outcomes while JI required further validation due to insufficient data. Across studies DPA remains a preferred approach but it comes with some complications, which need careful management.

DISCUSSION

Overall, the studies suggest that delayed primary anastomosis (DPA) provide hopeful functional outcomes for long-gap esophageal atresia (LGEA) as most patients show successful feeding. However, complications like strictures, GER and leaks remain common while effective management of these issues is essential for long-term success stressing requirements for proactive care. Friedmacher and Puri (2012) in their meta-analysis, where they included 451 newborns with long-gap esophageal atresia managed by delayed primary anastomosis (DPA) and their results showed substantial gap reduction (1,9–7,0 cm to 0,5–3,0 cm) by 11,9 weeks. Complications that are reported include gastroesophageal reflux (GER) or strictures and sometimes dysphagia was also seen. Results show GER linked to higher risks of esophagitis ($p = 0,0283$) and dysphagia ($p = 0,0174$). Most patients could eat normally by follow-up while DPA provides effective long-term results and early management of GER and strictures are recommended to minimize complications.[11] Florian Friedmacher's 2023 review discusses delayed primary anastomosis for long-gap esophageal atresia (LGEA) and they discussed initial stabilization, gastrostomy creation and delayed repair after esophageal segment growth. Methodology reviews surgical techniques and they emphasize preserving native esophagus function. Results show >90 % survival ~30 % leak rate and ~60 % stricture incidence while gastroesophageal reflux requiring fundoplication occurred in ~30 % of cases. This study has suggested delayed anastomosis offers better outcomes compared to esophageal replacement, though long-term follow-up is necessary. Limitations include lack of prospective studies.[12] Christine Finck et al. have also conducted retrospective cohort analysis (2009–2018) on 62 infants with long-gap esophageal atresia (LGEA) across 13 hospitals and delayed primary repair, often with esophageal traction are emerged as preferred approach while showing comparable outcomes across methods and high esophageal preservation rates (95 %) while mean gap length was 3,24 ± 1,59 cm, and 98 % underwent gastrostomy before repair. Variability in gap measurement show need for standardized multi-institutional registry and study show the efficacy of delayed strategies and proposes further research to establish evidence-based guidelines for managing LGEA cases.[13] Penikis, Sescleifer, and Kunisaki (2024) conducted systematic review evaluating management strategies for long-gap esophageal atresia (LGEA) and this review showed delayed primary repair as the preferred approach supported by the American Pediatric Surgery Association. When esophageal replacement is unavoidable, it is evidenced that gastric conduits are favored due to simplicity and low morbidity and also, its durability. The review emphasizes comprehensive care, including monitoring for swallowing function, nutritional health, and respiratory illnesses. While multi-center collaboration has advanced understanding, historical reliance on single-center data poses

limitations and this research has shown importance of evidence-based guidelines to improve outcomes for this complex patient population.[14] Tatjana Stadil et al. (2019) conducted a systematic review of 57 articles (326 patients) focusing on surgical Stadmethods for long-gap esophageal atresia (LGEA) Gross types A and B. Delayed primary anastomosis (DPA) was the most common approach (68,4 %) but complications anastomotic stricture (53,7 %) while reported gastroesophageal reflux was (GER, 32,2 %) frequently especially after DPA ($p < 0,001$). Gastric pull-up (GPU) was used less frequently (8,3 %). In spite of advancements postoperative complications were significant across methods with DPA associated with higher stricture and GER rates and they stated now, there is need for standardized approaches and improved postoperative management.[15] Gallo et al. (2012) conducted meta-analysis of 15 studies (470 patients) to compare surgical techniques for long-gap esophageal atresia (LGEA) replacement and techniques analyzed included gastric pull-up (GPU), colon interposition (CI) and jejunal interposition (JI). Results indicated comparable mortality and anastomotic complications between GPU and CI with GPU having fewer gastrointestinal but more respiratory complications. limited data on JI showed inconsistent outcomes. Proper prospective studies are lacking but GPU and CI are considered effective and experienced centers may get valid outcomes with JI and the study propose variability in technique efficacy and outcome reporting.[16] Liu et al. (2017) conducted a systematic review of 23 studies including 593 patients, to evaluate surgical outcomes of esophageal replacement (ER) approaches in long-gap esophageal atresia (LGEA) and techniques included gastric pull-up (GPU), colon interposition (CI), jejunal interposition (JI) and gastric tube reconstruction (GTR). CI and GPU showed favorable short- and long-term outcomes, with fewer anastomotic complications and better feeding conditions. Data on JI and GTR were limited which calls for further studies. While CI was noted for long-term success and prospective comparative research remains necessary to establish optimal ER methods and research concludes there is variability in surgical outcomes and methodological gaps.[17] All these studies show EA is congenital condition that necessitates prompt surgical intervention. Infant's condition determines whether early or delayed repair is recommended. For stable newborns, early surgery done within a few days of birth is recommended because it reduces the risk of sepsis and aspiration pneumonia, which shortens hospital stays. Anastomotic leaks are greater surgical hazards for premature or low-birthweight babies while stabilization is made possible by delayed repair but infection risks are increased if reliance on alternate feeding techniques is prolonged. Long-term consequences such as dysphagia and GERD are comparable for both methods. Birth weight or related abnormalities and surgical are the factors which clinicians must consider before intervention.

CONCLUSIONS

The included papers in this systematic review highlighted delayed primary anastomosis (DPA) is widely used approach for managing long-gap esophageal atresia (LGEA) which offer favorable functional outcomes. Multiple patients can achieve the ability to eat without substantial swallowing difficulties however, complications like gastroesophageal reflux, strictures or leaking related complications are frequently reported and these need careful medical consideration. Alternative surgical techniques like gastric pull-up, colon interposition and jejunal interposition have been explored with varying success. Each method presents unique benefits and challenges emphasize the need for individualized treatment planning based on patient-specific factors. In short, our findings suggest while delayed repair remains most preferred strategy for its potential for esophageal preservation but the risk of postoperative complications was high, which need careful follow-up and proactive management. Despite advances in surgical techniques and variability in treatment outcomes, lack of standardized protocols across studies shows the need for further research to optimize management strategies while, on the other hand, long-term monitoring is essential to address evolving complications and improve life quality.

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CONFLICT OF INTEREST

None.

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