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Conflict of Interest:

Reinhard Busse is a member of the German government commission for modern and needs-based hospital care (Regierungskommission für eine moderne und bedarfsgerechte Krankenhausversorgung). The other authors have no conflict of interest.

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Abstract

Background:

Esophageal atresia (EA) is a complex malformation. Multidisciplinary management is necessary, with the operative repair being the most challenging step in the treatment algorithm. The complete care structure for children with EA in Germany has not been analyzed yet.

Methods:

In the observed period 2016-2022, inpatient EA cases were analyzed 1) during the hospital stay of birth, and 2) during the hospital stay of corrective surgery in patients aged up to 365 days, both based on national hospital discharge data. Patients' comorbidities, hospital caseload, treatment characteristics (e.g. surgical approach) and outcome parameters were analyzed.

Results:

1) 1,190 newborn EA cases were treated in 260 hospitals during the perinatal period. 54% had at least one additional malformation, and 16% had a birthweight below 1,500 grams. In-hospital mortality was 8.4%.

2) 1,475 corrective operations for EA were performed in 111 hospitals with a consistent median annual caseload of 2 (P25-P95 1-8) per hospital. At least one indicator for a complicated perioperative course was documented in 63.7% of cases. The use of bronchoscopy was coded in 50% of cases. Median ventilation time during the entire hospital stay was 176 hours (P25-P95: 95-1759 hours).

Conclusions:

Newborns with EA are complex and early postoperative complications are common. The care structure is decentralized, and there was no trend towards centralization in the observed period. The low documented use of bronchoscopy is noteworthy. Centralization of the highly complex and schedulable corrective surgery for EA is necessary to evaluate outcomes and might improve the quality of care and resource utilization.

Category of the manuscript and type of study: original article, observational cross-sectional study, secondary data analysis

Keywords: esophageal atresia, volume-outcome relationship, quality of care, centralization, caseload

Background:

Esophageal atresia (EA) is a complex malformation characterized by a discontinuity of the esophagus *with* or *without* a persistent connection to the trachea (tracheoesophageal fistula, TEF). It is commonly associated with additional malformations [1–3]. The incidence throughout Europe from 2016 to 2022 has been reported to be 2.59 per 10,000 live and still births from 20 weeks of gestational age [4]. Coming from a condition with a 100% lethality in the presurgical era, survival has greatly improved over the past century and the focus has shifted towards reducing short-term complications and handling long-term morbidity [5]. 5-year-survival is currently estimated at 85% [6]. There is consensus that the management of EA requires highly specialized surgical care and an experienced multidisciplinary team [7–9]. Therefore, centralization of the corrective surgery for esophageal atresia is unequivocally recommended [7–9]. A volume-outcome correlation has been shown for the treatment of other complex malformations such as biliary atresia [10] and congenital diaphragmatic hernia [11] as well as for surgery of the complex organ system esophagus in adults [12].

However, previous studies did not identify such a correlation for the treatment of EA in children, with all of the studies struggling with a low overall caseload per hospital [3,13,14].

To date, surgical care for complex malformations, including EA, is decentral in Germany [15,16]. A complete national registration of cases with EA in Germany is still missing, which makes evaluation of the complete care situation for EA during the perinatal period and corrective surgery difficult. This study aims to provide a nationwide analysis of the treatment of all children under 365 days with EA regarding patient characteristics, hospital caseload and outcome parameters in Germany.

Methods:

The methodological approach of this observational, descriptive administrative-data based analysis relies on a previously published study [17].

Data:

Microdata of the diagnosis-related groups (DRG)-statistics of the years from 2016 to 2022 were accessed by controlled remote data processing through the Research Data Center of the German Federal Statistical Office. The DRG statistics encompass data records of all hospital cases billed according to the DRG system as they include all patients treated in German hospitals, regardless of their insurance status or origin. Data include, among others, age, gender, diagnoses (International Statistical Classification of Diseases and Related Health Problems - 10. Revision - German Modification, ICD-10-GM), procedures (German operations and procedure code, OPS), perioperative ventilation time, length of stay (LOS), and discharge mode. Cases can be attributed to a particular institution by using a pseudonymized institutional code [18].

Cases:

Two analysis groups were defined:

1. EA cases during the hospital stay of birth; all newborn inpatient cases aged up to 7 days with an EA diagnosis, excluding admissions transferred-in from another hospital.
2. EA cases during the hospital stay of corrective surgery; all inpatient cases from birth up to the age of 365 days with an EA diagnosis and a procedure code for corrective surgery.

Case selection is depicted in figure 1 and the definitions of the units of analysis are shown in supplementary table A.

Variables:

Cases of both analysis groups were divided into 3 EA forms as reflected by ICD-10, which only distinguishes between EA *with* TEF, EA *without* TEF and congenital TEF without atresia (H-type fistula). A certain classification system, e.g. according to *Gross* or *Vogt [19]*, is not reflected. Additional malformations were identified based on the coded diagnoses (ICD).

To describe the structure of the health care provision, the annual number of treating hospitals as well as the annual hospital caseload of EA cases in the hospital of birth (analysis 1), and in the hospital of corrective surgery (analysis 2) were considered, respectively. The surgical approach to corrective surgery (e.g. primary anastomosis) and additional procedures (e.g. bronchoscopy) were identified by using procedure codes (OPS).

For analysis 1, the birth weight (below 1,500 grams) was described. The type of treatment was divided into corrective surgery *and/or* supportive surgery (tracheostomy,

esophagostomy, gastrostomy, elongation of the esophagus or ligation of a tracheoesophageal fistula) *or* no surgical measures. The age limit was set to seven days to focus on newborns. For analysis 2, the total mechanical ventilation time was registered according to coding standards. It is counted as a sum of invasive (via intubation) and non-invasive (via continuous positive airway pressure (CPAP) and high flow nasal cannula (HFNC)) hours of ventilation as long as the patient is subject to intensive care including all episodes during the same hospital stay [20]. The age limit was set to 365 days to explore treatment characteristics during the initial repair, not on redo surgeries after failed anastomosis at a higher age.

Indicators of early postoperative complications or a complicated course were defined through diagnosis codes (e.g., anastomotic leakage), or through procedure codes (e.g., postoperative chest tube insertion). Because a single case could be affected by multiple complications, the occurrence of at least one indicator for a complication or a complicated course was defined as an index parameter.

Analysis:

Descriptive evaluation of patients' characteristics, treatment characteristics and health care providers were carried out for both analysis groups. Nominal characteristics were displayed as percentages. Continuous characteristics, such as length of stay or hospital caseload, were displayed as median with interquartile range. The number of treatment cases and the number of hospitals per year were expressed as mean values.

For analysis 2 an additional division according to the hospital's caseload was undertaken. In each year of observation, cases with corrective surgery for EA were sorted into three groups of approximately equal size according to the annual caseload of their treating hospital

(caseload terciles low, medium, and high). All variables were stratified according to the caseload tercile. Treating hospitals were only considered in a year if they had at least one case of corrective surgery in the respective year.

The risk of experiencing complications or a complicated course (index parameter) was analyzed by using a generalized logistic regression model in analysis 2, which considered the distribution of cases in hospitals (cluster-structured data). The form of EA, gender, the presence of additional malformations, and a gastric transposition during the corrective surgery (as indicator for the extent of EA) were considered as risk factors in the regression model. Associations between the risk factors and the index parameter were expressed as odds ratios (OR) with 95% confidence intervals.

Calculations were carried out by using SAS version 9.3. Reporting adheres to the RECORD (Reporting of studies Conducted using Observational Routinely-collected health Data) Statement [21].

Results

Analysis 1: EA cases during the hospital stay of birth

1,190 EA cases were documented in newborns aged up to seven days between 2016 and 2022 in Germany in 260 different hospitals. The average annual incidence of children born with EA was 170 cases (range 157-184). 520 (43.7%) newborns were female. 189 (15.9%) of all newborns with EA had a birth weight below 1,500g. EA *with* TEF (ICD-10 Q39.1) was coded in 830 (69.7%) cases, EA without TEF (ICD-10 Q39.0) in 308 (25.9%) cases, and H-type fistula (ICD-10 Q39.2) in 52 (4.4%) cases. 642 (54%) cases presented with at least one additional malformation, predominantly affecting the cardiovascular system (n=443; 37%),

followed by the respiratory system (n=158; 13%) including tracheomalacia. Chromosomal anomalies were documented in 67 (5.6%) cases (table 1).

Of the 260 hospitals, 43.5% had a pediatric surgical department according to the department code.

639 (53.7%) EA cases received corrective surgery at the hospital of birth and 172 (14.5%) had additional supportive surgery. 69 (5.8%) cases received supportive surgery alone without corrective surgery during the hospital stay of birth. 475 (39.9%) cases were transferred to another hospital and 615 (51.7%) were regularly discharged. 100 children (8.4% of all newborn EA cases) died during the hospital stay of birth, of which 73 did not have corrective surgery and 27 had corrective surgery in the hospital of birth. The median length of stay in the hospital of birth was 19 days (IQR 1-48).

Analysis 2: EA cases during the hospital stay of corrective surgery (aged up to 365 days).

From 2016 to 2022, 1,475 corrective surgeries for EA in children aged up to 365 days were performed in 111 different hospitals in Germany. On average, 211 cases of corrective surgery per year (range 192-228 cases) were treated in 72 hospitals on average (range 69 to 76 hospitals). At least 42 hospitals did not perform corrective surgery for EA each year (supplementary table B). The median annual caseload per hospital was 2 (IQR 1-4), the maximum 95th percentile was 13 cases in a single year. There was no trend towards a change in the number of hospitals performing corrective surgery for EA and no change in the median annual caseload during the observed period (supplementary table B).

Division of cases into terciles according to the annual caseload of their treating hospital revealed that one third was treated in about 44 (62%) hospitals with a median caseload of 1

(IQR 1-2) corrective surgery per year (low caseload tercile), one third of cases was treated in about 18 (25%) hospitals with a median caseload of 4 (IQR 3-5) cases per year (middle caseload tercile), and one tercile of patients was treated in about 10 (13%) hospitals with a median caseload of 7 (IQR 6-8) cases per year (high caseload tercile, table 2).

Hospitals where corrective surgery was performed coded EA with TEF in 1.271 (86.2%), EA without TEF in 143 (9.7%) and H-type fistula in 61 (4.1%) cases. 615 (41.7%) cases were female. 866 (58.7%) cases presented with at least one additional malformation. 1,250 (84.7%) received a primary anastomosis, 122 (8.3%) underwent gastric transposition and 76 (5.2%) had H-type fistula repair. Bronchoscopy was coded in 738 (50%) cases. This rate increased from 46% to 55% in the observed period (supplementary table C). The total ventilation time during the entire hospital stay was at median 176 hours (IQR 95h-463h) with a 95th percentile of 1,759 hours (table 2). The median length of hospital stay (LOS) was 30 days (table 2). 41 (2.8%) patients died within this hospital stay (table 3).

At least one indicator for a complicated course was documented in 939 (63.7%) of EA cases during the hospital stay of corrective surgery. The most frequently coded conditions were blood transfusion (n=606, 41%), bouginage or dilatation of the esophagus during the same inpatient stay (n=294, 20%), septicemia or systemic inflammatory response syndrome (n=216, 15%), and a lesion of the pleura including pneumothorax (n=169, 11.5%). Signs of anastomotic leakage, like insufficiency of anastomosis or perforation of esophagus, were documented in 105 (7%) cases, and mediastinitis or mediastinal abscess in 88 (6%). In 77 (5.2%) cases, a chest tube was placed in a separate procedure that followed corrective surgery. A vocal cord paresis was documented in 44 (3%) cases. In addition to those complications summarized in the index, cyanosis and respiratory failure were coded in 766

(52%) cases, and esophageal stenosis and recurrent fistula were coded in 150 (10%) cases (table 3).

Logistic regression revealed associations between different variables and the risk of the occurrence of at least one index indicator. Gastric transposition was strongly associated with a complicated course (OR 8.8). EA without TEF was associated with a higher risk for a complicated course (OR 3.4) compared to EA with TEF, while H-type fistula was associated with a decreased risk for a complicated course (OR 0.5). The presence of at least one additional malformation increased the risk of a complicated course (OR 1.9). Female sex was not significantly associated (table 4) with additional perioperative risk.

Discussion

This secondary data analysis represents a complete dataset of all children with EA at birth, and at the time of corrective surgery in German hospitals. It reveals a high complexity of children born with EA, a high frequency of a complicated course after corrective surgery and highly fragmented care structure.

Treatment of newborns with EA during the hospital stay of birth (analysis 1)

1,190 newborns with EA from 2016-2022 correspond to an incidence of 2.18:10,000 live births. This is slightly lower than 2.59:10.000 reported by EUROCAT for the same period, but EUROCAT includes still births from 20 weeks gestation [4]. Compared to literature also using ICD-10 [2,13], the rate of EA with TEF (69.7% vs. 85-88.2%) and without TEF (25.9% vs 11.8-15%) seems to be inaccurate in this analysis. This might be due to a faulty coding when hospitals do not undertake further diagnostics and therefore do not detect a fistula. The male-to-female ratio of 1.4:1, the incidence of additional malformations (54%) and

chromosomal anomalies (5.6%) as well as the number of children with a birth weight below 1,500g (15.9%) are in accordance with the literature [1,2,22].

The distribution of EA patients upon birth is scattered across 260 hospitals, where a pediatric surgical department is not always present (43.5% only). This is in accordance with analyses of the perinatal care structure in Germany [23]. Planned delivery in a specialized center can often not be organized, because the EA is not reliably detectable by prenatal diagnostics [24]. Consequently, initial conservative stabilization of the newborn followed by transferal is common practice in Germany. Results from a single-center study suggest transferal to be safe [25] and the concentration of the life-defining corrective surgery in a specialized center with an expert multidisciplinary team is recommended by the European Reference Network for Rare Inherited Congenital Anomalies (ERNICA) [8].

8.4% patients died during the hospital stay of birth. Evidence suggests that most deaths occur within the first days of life [1,2,26]. The mortality rate in our series places average among results of an international analysis that included data from four continents with very different standards in neonatological care. Over the past two decades, 1-month-survival rates of 91.1-92.6% were shown [6]. Studies from France and Poland even report short-term mortality rates around 5% [9,22]. In our series, 6.1% of patients died without undergoing corrective surgery. This fraction needs to be seen as an indicator for the morbidity of children with EA and it seems to have remained stable over the past decade as a previous German study reported 5.9% [2]. The remaining 2.3% (8.4% overall minus 6.1% without surgery) might be considered surgery associated deaths. A few single-center studies that focused on operative cases only have shown a remarkable 0% of surgery associated mortality [5]. However, these studies usually have relatively small cohorts and did not

include all types of EA and comorbidities. Mortality is a strong outcome parameter, comparison must be handled with care and differences when investigating mortality must be taken into account (e.g. follow-up and case selection). The high proportion of patients that died without surgery highlights the importance of population-based data analysis complimentary to surgical registries.

Treatment of children with EA during the hospital stay of corrective surgery (analysis 2)

This analysis reveals a decentralized care structure for the schedulable [8,25] and complex corrective surgery for EA. 1,475 corrective surgeries for EA were performed in 111 different hospitals from 2016 to 2022. The discrepancy between corrective surgeries and the number of children born with EA in the same period (n=1,190) is likely due to either patients who were born abroad but received corrective surgery in Germany or probably to a larger extend patients who received re-do surgeries in separate hospital stays. The rate for re-do corrective surgeries has been reported to be high and reasons vary from recurrent TEF refractory anastomotic stricture and undetected proximal TEF [27]. The distribution of EA forms in this analysis was in accordance with the literature (86.2% EA with TEF, 9.7% EA without TEF, H-type fistula 4.1%) while most studies do not include H-type fistula [2,8,19,22]. Surprisingly, there were more h-type fistula repairs (n=76) than h-type fistulas (n=61), which is probably due to faulty coding.

The median hospital caseload (2 cases per year) as well as the number of hospitals performing corrective surgery (72 hospitals per year) remained stable over the examined period. The European Reference Network for Rare Inherited Congenital Anomalies (ERNICA) has made an unequivocal recommendation for a minimum caseload of 5 corrective surgeries per hospital per year in the consensus paper from 2019 [8]. In the present analysis a trend to

put this call for centralization into practice on a national level in Germany was not observed. It becomes evident that the median annual caseload of 7 in the 'high' caseload tercile reflects little more than one case every two months. An actual clinical routine is unlikely at this level. The establishment of a volume-outcome relationship seems not feasible, as real high-volume providers are missing in Germany.

There was striking number of 63.7% of cases where at least one indicator for a complicated course was coded. Putting this number alone into perspective is challenging because previous studies differ widely in the definition of complications as well as in the quality of data and methodology of data collection. However, it can be seen as another indicator for the complexity of patients with EA. The probability of complications to occur almost doubled in presence of an additional malformation, which affected 58% of cases (OR 1.94). The most frequently coded condition was the necessity of a blood transfusions in 41% of cases. This was considered as an indicator for a complicated course, as it points towards severe comorbidity. The role of blood transfusions in newborn patients with pediatric index operations has been previously evaluated. The presence of a structural heart defect, prematurity, history of preoperative blood transfusion and EA/TEF repair itself were all shown to be associated with a higher incidence of perioperative blood transfusion [28]. Its value to assess bleeding complications in this study is limited, as no stratification has been made towards additional malformations or very low birth weight.

The incidence of anastomotic leakage was 7.1% in our study, mediastinitis and/or abscess of the mediastinum were coded in 6.0% of cases. The placing of a chest tube in a separate procedure after corrective surgery, which might be the consequence of the aforementioned complications, was necessary in 5.2% of cases. Our findings are within the upper range of 2-

8% previously reported in European literature [9,13,26]. Anastomotic leakage is generally considered a short-term complication, so despite the longer follow up of at least one year in other studies, our results are still comparable. Bouginage or dilatation of the esophagus point towards stricture or stenosis, these were coded in 20% of cases during the hospital stay for corrective surgery. The necessity for such an “early” postoperative dilatation might point towards clinically more relevant stenosis, but the reasons cannot be clearly identified using hospital discharge data. Previous studies have found rates ranging from 21-57% [2,9,13,22]. All of the aforementioned had a considerably longer follow-up of at least one year after corrective surgery. Stricture and stenosis are possible long-term complications, thus time of follow-up will affect the rate.

The necessity of preoperative bronchoscopy has been highlighted in multiple publications and guidelines [7,9,29]. Its purpose is to secure the diagnosis of EA, to locate the fistula and establish the type of EA, as well as to assist with the controlled airway management. The utmost importance of preoperative bronchoscopy becomes most evident in light of *Gross type D* [19] EA, where a second fistula is present and might be overlooked during corrective surgery [7]. Despite the recommendation in the ERNICA consensus paper in 2019 [29], we only observed a marginal increase in the rate of bronchoscopies.

We observed a high variability regarding duration of mechanical ventilation with a median of 7.33 days and a range from 4 days in the 25^{th} percentile to 73.3 days in the 95^{th} percentile as a cumulated number of invasive and non-invasive ventilation [20]. Two international studies reported a median of postoperative mechanical ventilation of 3 days (range 0-117 days)[3], and approximately 4 days [30], respectively. Early extubation is desirable but not always feasible [30]. Patients’ characteristics must be considered, as prematurity and comorbidity

can lead to extended postoperative ventilation. We can conclude that ventilation, which is resource intense, is affected by great unpredictability. As it is bound to capacities of intensive care, forecasting resource requirements is impossible with the overall low caseload per hospital and the great variability of length of ventilation.

Policy implications

The high rate of associated comorbidity, prematurity, and the frequency of a complicated postoperative course with long hours of perioperative ventilation emphasizes the complexity of children with EA. This raises the question of how specialized care for EA at the time of corrective surgery should be provided. The ERNICA consensus statement [8] recommends a minimum caseload as a positive volume-outcome relationship was evaluated as highly likely for the complex treatment of EA, and a multidisciplinary team is needed. The number of 5 suggested is not a recommendation of the ideal caseload for high quality of care but can rather be seen as a first step towards centralization.

A comparison to esophageal surgery in adults seems appropriate. For esophageal surgery in adults, a strong hospital volume-outcome relationship was shown for mortality, which was associated with failure to rescue from complications [31,32]. While the statutory minimum volume for adult esophageal surgery in German hospitals was recently raised from 10 to 26 annual cases per hospital site [33], no requirements exist for the treatment of esophageal atresia in children to date. One prerequisite for setting a statutory minimum volume is that the considered treatment is schedulable and complex, which holds true for esophageal surgery in children as well. Another prerequisite is that there is evidence of a volume-outcome relationship.[31] However, this cannot be studied as long as the provision of care is completely fragmented, and real high-volume providers are not existent in the German

health system. For rare diseases, the need to use subsidiary evidence from common diseases has been acknowledged within the European Reference Networks for rare diseases [34]. Given the strong evidence for a volume outcome relation in adult esophageal surgery [35] regardless of the underlying diagnosis [36] and the relevance of achieving the best possible outcomes in these very young children, the introduction of a statutory minimum volume for the treatment of esophageal atresia might be a necessary step to improve the quality of care for EA in German hospitals.

Strength and limitations

The strength of this study is the complete evaluation of EA patients in German hospitals, regardless of their insurance status or origin. Limitations occur from the limited information available in hospital discharge data. As the data allow no person-related linkage across datasets, the present study could only investigate outcomes that occur during the hospital stay. However, the measurement of long-term outcomes, such as functionality or the occurrence of long-term complications would be necessary to comprehensively assess the quality of EA care in Germany. Due to data protection law, the data provided in DRG statistics cannot be linked to a specific hospital.

Conclusion:

The majority of newborns with EA are complex and multimorbid patients that commonly present a challenging postoperative course. Their management requires a multidisciplinary team which emphasizes the need for specialized centers. However, the care structure in Germany for the treatment of EA is highly fragmented and no trend towards centralization of corrective surgery for EA could be observed in the investigated period. The apparent omission of a preoperative bronchoscopy in 50% of patients might be a sign of lacking

infrastructure, which endangers the outcome of corrective surgery for EA and is an avoidable shortcoming. Lastly, the variability of resource consumption especially with regard to the length of ventilation and length of hospital stay is high.

Due to the overall low annual caseload per hospital, the complexity of cases and the rarity of the condition, a volume-outcome relationship within Germany cannot be established. Furthermore, the high number of hospitals with extremely low caseload might hinder successful surgical training programs. In light of the European Reference Networks' recommendations of the use of subsidiary evidence in rare and complex diseases where the establishment of direct evidence is not possible, the detailed understanding of the volume-outcome relationship for esophageal surgery of adults and other complex malformations in children needs to be considered. Centralization of the highly complex and schedulable corrective surgery for EA is necessary to evaluate outcomes and might improve the quality of care, resource utilization and planning on a hospital level.

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Figure legends

Figure 1 Case selection

Legend: Notes: EA = esophageal atresia

Table 1 Esophageal Atresia (EA) cases during the hospital of birth (analysis 1)

Legend: Notes: EA = Esophageal Atresia; TEF = Tracheoesophageal Fistula; P25 = 25. percentile; P75 = 75. Percentile

[1]The presence of a pediatric surgical department was assumed if at least 10 cases (among all inpatient cases) with the specialty department codes (1300 and 1513) were identified in a hospital per year.

Table 2 EA cases during the hospital stay of corrective surgery aged up to 365 days (analysis 2)

Legend: Notes: EA = Esophageal Atresia; TEF = Tracheoesophageal Fistula; P25 = 25. percentile; P75 = 75. percentile; P95 = 95. percentile

[1]cumulative of invasive (via intubation) and non-invasive (CPAP, HFNC) hours of ventilation as long as the patient is subject to intensive care including all episodes during the same hospital stay

Table 3 Indicators of a complicated course at the time of corrective surgery (analysis 2)

Legend: Notes: [1]Coded during the same inpatient stay; [2] Coded at different date after corrective surgery

Table 4 Risk factors association with a complicated course at corrective surgery (analysis 2)

Legend: Notes: EA = Esophageal Atresia; TEF = Tracheoesophageal Fistula

Supplementary Table A Definition of units of analysis and variables

Notes: EA = Esophageal Atresia; TEF = Tracheoesophageal Fistula

Supplementary Table B Caseload development of treating hospitals from 2016 to 2022

Supplementary Table C Development of treatment characteristics from 2016 – 2022

Notes: EA = Esophageal Atresia; TEF = Tracheoesophageal Fistula

Table 1 Esophageal Atresia (EA) cases during the hospital of birth (analysis 1)

Cases with EA diagnosis during the hospital stay of birth from 2016 to 2022		
Cases in the entire period	N	1,190
Cases per year	Mean (Min. - Max.)	170 (157 - 184)
Hospitals characterisitics		
Number of hospitals by institutional code in the entire period	N	260
Hospitals with at least one case at birth per year	Mean (Min. - Max.)	101 (95 -110)
Caseload per hospital per year	Median (P25-P75)	1 (1 - 2)
Hospitals with pediatric surgical department[1]	%	43.5%
Thereof hospitals performing surgical measures		
Number of hospitals by institutional code in the entire period	N	93
Hospitals with at least one case of supportive or corrective surgery per year	Mean (Min. - Max.)	51 (48 - 56)
Caseload per hospital per year	Median (P25-P75)	2 (1 - 3)
Cases characteristics		
Female	N (%)	520 (43.7)
Birth weight below 1,500 grams	N (%)	189 (15.9)
Type of EA (according to ICD-10-GM)		
EA with tracheoesophageal fistula (TEF)	N (%)	830 (69.7)
EA without fistula	N (%)	308 (25.9)
Congenital TEF without atresia (H-type fistula)	N (%)	52 (4.4)
Additional malformation (multiple codings possible)		
Malformation of the cardiovascular system	N (%)	443 (37.2)
Malformation of the respiratory system	N (%)	158 (13.3)
Malformation of the small instestine	N (%)	55 (4.6)
Malformation of the anorectal system	N (%)	116 (9.7)
Malformation of the urinary system	N (%)	131 (11.0)
Malformation of the spine, limbs or bony thorax	N (%)	148 (12.4)
Chromosomal anomalies	N (%)	67 (5.6)
Index: at least one additional malformation	**N (%)**	**642 (54.0)**
Treatment characteristics		
Corrective surgery	N (%)	639 (53.7)
Thereof with bronchoscopy	N (%)	297 (25.0)
Thereof with supportive surgery	N (%)	172 (14.5)
Thereof with gastric transposition	N (%)	28 (2.4)
Supportive surgery without corrective surgery	N (%)	69 (5.8)
Neither supportive nor corrective surgery	N (%)	482 (40.0)
Discharge mode		
Regularly discharged home alive	N (%)	615 (51.7)
Transferred-out to another acute care hospital	N (%)	475 (39.9)
Died	N (%)	100 (8.4)
Died without corrective surgery	N (%)	73 (6.1)
Died after corrective surgery	N (%)	27 (2.3)
Length of initial hospital stay (days)	Median (P25-P75)	19 (1 - 48)

Notes: EA = Esophageal Atresia; TEF = Tracheoesophageal Fistula; P25 = 25. percentile; P75 = 75. Percentile

[1]The presence of a pediatric surgical department was assumed if at least 10 cases (among all inpatient cases) with the specialty department codes (1300 and 1513) were identified in a hospital per year.

Table 2 EA cases during the hospital stay of corrective surgery aged up to 365 days (analysis 2)

Cases with EA diagnosis in the hospital stay of corrective surgery from 2016 to 2022					
Cases aged up to 365 days with corrective surgery in the entire period		N (%)			1,475
Cases per year		Mean (Min.- Max.)			211 (192 - 228)
Hospitals characteristics		**Hospital caseload**			**Total**
		1. tercile	**2. tercile**	**3. tercile**	
Hospitals with at least one case of corrective surgery per year	Mean	44.4	17.6	9.6	**71.6**
Caseload per hospital per year	Median (P25-P75)	1 (1 - 2)	4 (3 - 5)	7 (6 - 8)	**2 (1 - 4)**
	P95	3	5	13	**8**
Cases characteristics					
All cases with corrective surgery	N	484	482	509	**1,475**
Female	N (%)	210 (43.3)	197 (40.9)	208 (40.9)	**615 (41.7)**
At least one additional malformation	N (%)	254 (52.5)	294 (61.0)	318 (62.5)	**866 (58.7)**
Type of EA					
EA with TEF	N (%)	433 (89.5)	424 (88.0)	414 (81.3)	**1,271 (86.2)**
EA without fistula	N (%)	35 (7.2)	42 (8.7)	66 (13.0)	**143 (9.7)**
Congenital TEF without atresia (H-type fistula)	N (%)	16 (3.3)	16 (3.3)	29 (5.7)	**61 (4.1)**
Treatment characteristics					
Surgical approach to corrective surgery					
Primary anastomosis	N (%)	425 (87.8)	426 (88.4)	399 (78.4)	**1,250 (84.7)**
Gastric transposition	N (%)	25 (5.2)	32 (6.6)	65 (12.8)	**122 (8.3)**
H-type fistula repair	N (%)	24 (5.0)	19 (3.9)	33 (6.5)	**76 (5.2)**
Other	N (%)	10 (2.1)	5 (1.0)	12 (2.4)	**27 (1.8)**
Bronchoscopy	N (%)				**738 (50.0)**
Total hours of mechanical ventilation (invasive and non-invasive)[1]	Median (P25-P75)				**176 (95 - 463)**
	P95				**1,759**
Length of hospital stay (days)	Median (P25-P75)				**30 (19 - 61)**

Notes: EA = Esophageal Atresia; TEF = Tracheoesophageal Fistula; P25 = 25. percentile; P75 = 75. percentile; P95 = 95. percentile
[1]cumulative of invasive (via intubation) and non-invasive (CPAP, HFNC) hours of ventilation as long as the patient is subject to intensive care including all episodes during the same hospital stay

Table 3 Indicators of a complicated course at the time of corrective surgery (analysis 2)

Indicators of … (multiple codings possible)		**Total**
Perioperative blood transfusion (>=1 unit)	N (%)	606 (41.1)
Intraoperative lesion of nearby structures		
Pleura incl. pneumothorax	N (%)	169 (11.5)
Thoracic duct	N (%)	84 (5.7)
Vocal cord paresis (recurrent nerve)	N (%)	44 (3.0)
Trachea or bronchi	N (%)	26 (1.8)
Diaphragm paresis (phrenic nerve)	N (%)	18 (1.2)
Lesion to stomach	N (%)	17 (1.2)
Early postoperative complications		
Septicaemia or systemic inflammatory response syndrome	N (%)	216 (14.6)
Postoperative respiratory distress	N (%)	67 (4.5)
Intracerebral hemorrhage	N (%)	64 (4.3)
Leakage of anastomosis (Insufficiency or perforation)	N (%)	105 (7.1)
Mediastinitis or abscess in the mediastinum	N (%)	88 (6.0)
Wound infection	N (%)	52 (3.5)
Peritonitis	N (%)	8 (0.5)
Revision surgery in the same hospital stay		
Bouginage or dilatation of the esophagus	N (%)	294 (19.9)
Chest tube insertion [2]	N (%)	77 (5.2)
Recurrent fistula repair [2]	N (%)	14 (0.9)
Endoscopic vacuum sponge therapy	N (%)	10 (0.7)
Index: at least one indicator coded	**N (%)**	**939 (63.7)**
Died	**N (%)**	**41 (2.8)**
Other conditions with uncertain coding (not considered in index)		
Cyanosis or respiratory failure	N (%)	**766 (51.9)**
Stenosis and recurrent fistula	N (%)	**150 (10.2)**

Notes: [1] Coded during the same inpatient stay; [2] Coded at different date after corrective surgery

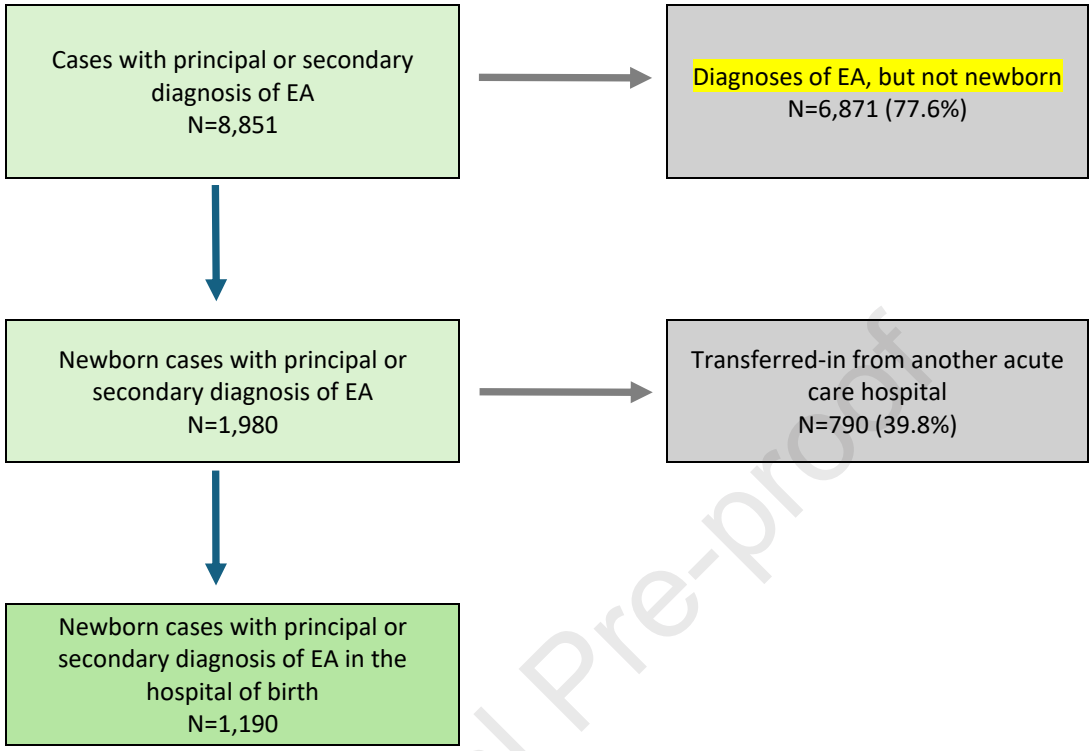
Table 4 Risk factors association with a complicated course at corrective surgery (analysis 2)

Variable	N (%)	Odds Ratio	Confidence Intervall (95%)	
Female	615 (41.7)	**1.08**	0.86	1.37
H-type fistula (vs EA with TEF)	61 (4.1)	**0.52**	0.32	0.86
EA without fistula (vs EA with TEF)	143 (9.7)	**3.42**	2.02	5.77
At least one associated malformation	866 (58.7)	**1.94**	1.55	2.43
Reconstructive surgery via gastric transposition	122 (8.3)	**8.78**	4.11	18.75
N=1,190. Area under the curve (c-statistics): 0.657				

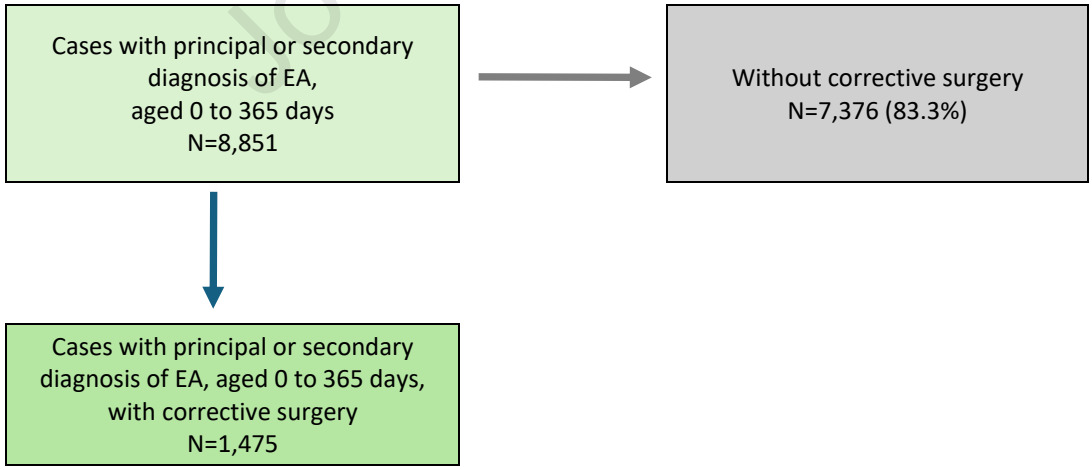
Notes: EA = Esophageal Atresia; TEF = Tracheoesophageal Fistula

Figure 1 Case selection

Analysis 1:
Esophageal atresia (EA) cases during the hospital stay of birth



Analysis 2:
EA cases during the hospital stay of corrective surgery (aged up to 365 days).



Notes: EA = esophageal atresia

Highlights

- Esophageal atresia is a rare and complex malformation that is commonly associated with additional malformations.
- The care structure is decentralized in Germany. Due to the overall low caseload per hospital, the establishment of a volume-outcome relationship seems not feasible.