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Survival of infants born with esophageal atresia among 24 international birth defects surveillance programs

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Abstract

Background: Esophageal atresia (EA) affects around 2.3–2.6 per 10,000 births world-wide. Infants born with this condition require surgical correction soon after birth. Most survival studies of infants with EA are locally or regionally based. We aimed to describe survival across multiple world regions.

Methods: We included infants diagnosed with EA between 1980 and 2015 from 24 birth defects surveillance programs that are members of the International Clearinghouse for Birth Defects Surveillance and Research. We calculated survival as the proportion of liveborn infants alive at 1 month, 1- and 5-years, among all infants with EA, those with isolated EA, those with EA and additional anomalies or EA and a chromosomal anomaly or genetic syndrome. We also investigated trends in survival over the decades, 1980s–2010s.

Results: We included 6,466 liveborn infants with EA. Survival was 89.4% (95% CI 88.1–90.5) at 1-month, 84.5% (95% CI 83.0–85.9) at 1-year and 82.7% (95% CI 81.2–84.2) at 5-years. One-month survival for infants with isolated EA (97.1%) was higher than for infants with additional anomalies (89.7%) or infants with chromosomal or genetic syndrome diagnoses (57.3%) with little change at 1- and 5-years. Survival at 1 month improved from the 1980s to the 2010s, by 6.5% for infants with isolated EA and by 21.5% for infants with EA and additional anomalies.

Conclusions: Almost all infants with isolated EA survived to 5 years. Mortality was higher for infants with EA and an additional anomaly, including chromosomal or genetic syndromes. Survival improved from the 1980s, particularly for those with additional anomalies.

KEYWORDS
congenital anomalies, esophageal atresia, infant, mortality, survival

1 | INTRODUCTION

Esophageal atresia (EA) is a congenital anomaly of the upper gastrointestinal tract characterized by an absence of the normal continuity of the esophagus. Some cases of EA occur with an abnormal connection between the esophagus and the trachea (tracheoesophageal fistula). EA may occur as an isolated anomaly, or, in about half of all cases, in conjunction with additional structural anomalies or chromosomal disorders (Burge et al., 2013; Cassina et al., 2016; Pedersen, Calzolari, Husby, Garne,, & Eurocat Working group, 2012; Robert et al., 1993; Sfeir et al., 2013; Shaw-Smith, 2006). As EA interrupts the normal connection between mouth and stomach, infants with EA require surgical correction soon after birth to ensure survival (Pedersen et al., 2012; Wang et al., 2014).

Worldwide prevalence is estimated to be around 2.3–2.6 per 10,000 births, (Canfield et al., 2014; EUROCAT

Prevalence Charts and Tables, 2020b; Lupo et al., 2017; Nassar et al., 2012; Robert et al., 1993). However, variation in rates between 1.8 and 3.7 per 10,000 births has been reported in international studies (Nassar et al., 2012).

There are limited international data on survival in infants with EA, with most published studies originating from individual registries or multiple registries within regions in Europe and the United States of America (USA) (Cassina et al., 2016; Nembhard, Waller, Sever, & Canfield, 2001; Tennant, Pearce, Bythell, & Rankin, 2010). To provide an international perspective on the survival of infants born with EA, we aimed to provide an estimate of short- and longer-term survival for children with EA from birth defects registries around the world.

2 | METHODS

2.1 | Data sources

Twenty-four birth defects surveillance programs from Europe, North, Central and South America and Asia, all members of the International Clearinghouse for Birth Defects Surveillance and Research (ICBDSR) provided data for this study. Programs were described as the population- or hospital-based and covered regional, state or national areas. Characteristics of surveillance methods utilized by participating programs are reported in Table 1, with additional details available from the ICBDSR (International Clearinghouse Birth Defects Surveillance and Research, n.d.), the European network of population-based registries for the epidemiological surveillance of congenital anomalies (EUROCAT Member Registries, 2020a), the National Birth Defects Prevention Network (National Birth Defects Prevention Network, n.d.), and from other sources (University of Arkansas for Medical Sciences, 2020).

Each individual program classified cases of EA using either the British Pediatric Association International Classification of Diseases (ICD) coding system ninth revision (ICD9-BPA) or 10th revision (ICD10). We included cases diagnosed with EA with or without tracheoesophageal fistula (ICD9-BPA: 750.30–750.31; ICD10: Q39.0–Q39.1). Occasionally a tracheoesophageal fistula can occur without EA, but this anomaly can go undiagnosed, sometimes for years; this, and other types of esophageal anomalies were not included in this study.

Where possible, registries provided annual data separately for three mutually exclusive groups: infants with isolated EA; with EA occurring with an additional one or more unrelated major anomaly; and with EA and a chromosomal anomaly or genetic syndrome. Programs provided the number of cases diagnosed with EA among live births, stillbirths, and if permitted, among elective termination of pregnancy for fetal anomaly (ETOPFA), as well as annual numbers of total births. The data available by type of EA and years of ascertainment (between 1974 and 2015) varied by the program (Tables 1 and 2 and Tables S1–S3). As few programs reported data before 1980, we restricted analyses to data from 1980 onwards through 2015.

Liveborn infants with EA were followed-up to determine survival, with the number of deaths reported at hospital discharge or 1 week of age, between seven-27 days, 28 days- < 1 year of age, one-4 years of age, and 5 years or longer. Programs varied in the period of follow-up undertaken and the timing of mortality ascertainment (Table 1).

2.2 | Analyses

We calculated prevalence per 10,000 births as the total number of infants with EA among live births, stillbirths, and ETOPFA divided by the total number of all births (live births and stillbirths) in each program. Data were then aggregated for all programs over the study period.

We determined the proportion of infants with EA surviving to 1 month (including programs reporting survival to hospital discharge, 1 week or to 28 days), 1 and 5 years after birth, based on the number of live-born infants with EA. We calculated overall survival at 1 month, 1, and 5 years, for all contributing programs, for programs reporting survival for all EA, isolated EA, and EA occurring with an additional major anomaly or with chromosomal or genetic diagnoses. To compare overall 1-month to 1-year survival, we restricted the analysis to programs with survival data to 1 year. Similarly, when comparing 1 month to 1- and 5-year survival, we limited analyses to programs and birth cohorts with survival data up to 5 years. For this comparison, a restricted cohort for each program was defined by years of birth to ensure a complete 5-year follow-up.

We conducted similar analyses by the decade of birth (1980–1989, 1990–1999, 2000–2009) and for 5 years from 2010 to 2014. Programs included in these analyses provided at least 5 years of data for each period examined (or ≥ 4 years for 2010s) and data for both 1-month and 1-year survival, or 1- and 5-year survival. To investigate longer-term trends in survival, we restricted analyses to programs with birth cohorts spanning 1980s–2000s. From these programs, we also determined the proportion of infants with EA ascertained among ETOPFA and stillbirths by decade to investigate their influence on survival.

TABLE 1 Summary of program characteristics, ascertainment of cases, and follow-up for mortality, International Clearinghouse for Birth Defects Surveillance and Research

Program	Registry type[a]	Ascertainment of cases	Sources of cases[b]	Duration of follow-up to determine mortality	Method for determining mortality, proportion followed
Europe					
Czech Republic	P, N	Up to 15 years	LB + SB	To end of 2015	Linkage to death records, 100%
France, Paris	H, R (~95% births in greater Paris)	Birth hospital	LB + SB + ETOPFA	Hospital discharge	Follow-up by clinician or program staff at hospital discharge, 100%
Germany, Saxony-Anhalt	P, S	Up to 1 year	LB + SB + ETOPFA	1 year of age	Follow-up by clinician or program staff, 100%
Italy, Lombardy	P, R (100% births in northern Lombardy)	Up to 6 years	LB + SB + ETOPFA	To end of 2015	Follow-up by clinician or program staff at hospital discharge, and by linkage to death certificates, 100%
Italy, Tuscany	P, R (~95% births in Tuscany)	Up to 1 year	LB + SB + ETOPFA	To end of 2015	Linkage to death records
Malta	P, N	Up to 1 year	LB + SB	To 1 year of age	Linkage to death records, 100%
Northern Netherlands	P, R	Up to 11 years	LB + SB + ETOPFA	To 1 year of age or more	Follow-up by clinician or program staff, 98%
Slovak Republic	P, N	Birth hospital	LB + SB + ETOPFA	Hospital discharge	Follow-up by clinician or program staff, 99%
Spain, ECEMC	H, R	Birth hospital	LB + SB + some ETOPFA	Hospital discharge	Follow-up by clinician or program staff
Sweden	P, N	1974–1986 up to 1 month, 1987–2014 up to 1 year	LB + SB + ETOPFA	To April 1, 2016	Linkage to death records
Ukraine, OMNI-Net	P, R (~5% births in Ukraine)	Up to 1 year	LB + SB + ETOPFA	1 year of age	Follow-up by clinician or program staff
Wales, CARIS	P, N	Up to 18 years	LB + SB + ETOPFA	18 years of age	Linkage to GP Registry
Asia					
Iran: TRoCA	H, R	Up to 1 year	LB + SB + ETOPFA	Hospital discharge	Follow-up by clinician or program staff at hospital discharge, 100%
Israel	H, R (>15% births in Israel)	Birth hospital	LB	To end of 2014	Follow-up by clinician or program staff at hospital discharge, and by linkage to death certificates, >90%

TABLE 1 (Continued)

Program	Registry type[a]	Ascertainment of cases	Sources of cases[b]	Duration of follow-up to determine mortality	Method for determining mortality, proportion followed
North America					
Mexico, Nuevo Leon	H, R	Birth hospital	LB + SB	Hospital discharge	Follow-up by clinician or program staff at hospital discharge
Mexico, RYVEMCE	H, R (~3.5% of births in Mexico)	Birth hospital	LB + SB	Hospital discharge	Follow-up by clinician or program staff at hospital discharge
USA, Arkansas	P, S	Up to 2 years	LB + SB + ETOPFA	To end 2015	Linkage to death records, 100%
USA, Atlanta MACDP	P, R	Up to 6 years	LB + SB + ETOPFA	To end 2008	Linkage to death records, 90%
USA, Texas BDES	P, S	Up to 1 year	LB + SB + ETOPFA	To end 2013	Follow-up by clinician or program staff at hospital discharge, and by linkage to death certificates, 94%
USA-Utah BDN	P, S	Up to 2 years	LB + SB + ETOPFA	To end 2015	Linkage to death records, 100%
South America[c]					
Argentina: RENAC	H, N (>70% births)	Birth hospital	LB + SB	Hospital discharge	Follow-up by clinician or program staff, 100%
Colombia, Bogotá	H, R (~90% births in Bogota)	Birth hospital	LB + SB + some ETOPFA	To 1 year of age, end of 2014	Follow-up by clinician or program staff at discharge from hospital and by linkage to death certificates
Colombia, Cali	H, R (~98% births in Cali)	Birth hospital	LB + SB + some ETOPFA	To 1 year of age, end of 2014	Follow-up by clinician or program staff at hospital discharge, and by linkage to death certificates
South America, ECLAMC	H, R	Birth hospital	LB + SB	Hospital discharge	Follow-up by clinician or program staff

[a]P = population-based, H = hospital-based, N = national, R = regional, S = state-wide.

[b]LB, live births; SB, stillbirths; ETOPFA, elective terminations of pregnancy for fetal anomaly.

[c]Some data overlap between Argentina, RENAC; Colombia, Bogotá and Cali, with South America, ECLAMC. Colombia, Bogotá: 2001–2010, all data included in South America ECLAMC, 2011–2014 data from only one hospital included in South America ECLAMC. Colombia, Cali: 2011–2014 only data from one hospital included in South America ECLAMC. Some data from Argentina RENAC for 2009–2014 may overlap with South America, ECLAMC data.

TABLE 2 Survival for liveborn infants with esophageal atresia born 1980–2015, International Clearinghouse for Birth Defects Surveillance and Research

	Survival to 1 month				Survival to 1 year				Survival to 5 years			
Program	**Cohort**	***N* infants**	**% Survival**	**95% CI**	**Cohort**	***N* infants**	**% Survival**	**95% CI**	**Cohort**	***N* infants**	**% Survival**	**95% CI**
Europe												
Czech Republic	1994–2014	473	93.7	91.1–95.7	1994–2014	473	87.3	84.0–90.2	1994–2010	351	84.3	80.1–88.0
France, Paris[a]	1981–2014	222	90.1	85.4–93.7								
Germany, Saxony-Anhalt	1980–2014	96	84.4	75.5–91.0	1980–2014	96	79.2	69.7–86.8				
Italy, Lombardy	2003–2012	48	93.8	82.8–98.7	2003–2012	48	91.7	80.0–97.7	2003–2010	42	95.2	83.8–99.4
Italy, Tuscany	1992–2014	125	90.4	83.8–94.9	1992–2014	125	88.8	81.9–93.7	1992–2010	99	86.9	78.6–92.8
Malta	1995–2013	15	93.3	68.1–99.8	1995–2013	15	86.7	59.5–98.3				
Northern Netherlands	1981–2014	136	76.5	68.4–83.3	1981–2014	136	74.3	66.1–81.4				
Slovak Republic[a]	2001–2014	134	85.8	78.7–91.2								
Spain, ECEMC[a]	1980–2013	517	89.4	86.4–91.9								
Sweden	1980–2014	918	89.8	87.6–91.6	1980–2014	918	86.3	83.9–88.4	1980–2010	786	84.9	81.9–87.1
Ukraine, OMNI-Net	2000–2013	82	69.5	58.4–72.9	2000–2013	82	52.4	41.1–63.6				
Wales, CARIS	1998–2014	118	93.2	87.1–97.0	1998–2014	118	89.8	82.9–94.6	1998–2009	80	87.5	78.2–93.8
Asia												
Iran, TRoCA[a]	2005–2012	163	98.8	95.6–99.9								
Israel	2000–2014	52	96.2	86.8–99.5	2000–2013	50	94.0	83.5–98.7	2000–2009	37	91.9	78.1–98.3
North America												
Mexico, Nuevo Leon	2011–2015	27	33.3	16.5–54.0								
Mexico, RYVEMCE[a]	1980–2013	221	83.7	78.2–88.3								
USA, Arkansas	1993–2012	154	89.6	83.7–93.9	1993–2012	154	80.5	73.4–86.5	1993–2010	143	79.0	71.4–85.4
USA, Atlanta MACDP	1980–2007	204	86.8	81.3–91.1	1980–2007	204	83.8	78.0–88.6	1980–2003	167	80.8	74.0–86.5
USA, Texas BDES	1996–2012	1,082	87.2	85.1–89.2	1996–2012	1,082	81.6	79.2–83.9	1996–2008	780	78.7	75.7–81.5
USA, Utah BDN	1999–2012	172	92.4	87.4–95.9	1999–2012	172	86.6	80.6–91.3	1999–2010	155	84.5	77.8–89.8
South America[b]												
Argentina, RENAC[a]	2009–2014	336	69.0	63.8–74.0								
Colombia, Bogotá	2001–2014	117	97.4	92.7–99.5	2001–2013	111	98.2	93.6–99.8				
Colombia, Cali	2011–2014	8	100.0	63.1–100.0	2011–2013	5	100.0	47.8–100.0				
South America, ECLAMC[a]	1995–2014	1,046	65.8	62.8–68.6								
All		6,466	84.1	83.2–84.9		3,789	84.1	82.9–85.3		2,640	82.7	81.2–84.2

TABLE 2 (Continued)

Program	Survival to 1 month				Survival to 1 year				Survival to 5 years			
	Cohort	*N* infants	% Survival	95% CI	Cohort	*N* infants	% Survival	95% CI	Cohort	*N* infants	% Survival	95% CI
Programs with survival data to 1 year ($n = 16$)		3,798	88.7	87.6–89.6		3,789[c]	84.1	82.9-85.3		[d]		
Programs and cohorts with survival data to 5 years ($n = 9$)		2,640	89.4	88.1–90.5		2 ,640	84.5	83.0–85.9		2,640	82.7	81.2–84.2

Abbreviations: BDES, birth defects epidemiology and surveillance branch; BDN, birth defect network; CARIS, congenital anomaly register and information services;CI, confidence interval; ECEMC, Spanish collaborative study of congenital malformations; ECLAMC, South America Latin American collaborative study of congenital malformations; MACDP, metropolitan Atlanta congenital defects program; OMNI-Net, Ukraine birth defects program; RENAC, national network of congenital anomalies of Argentina; RYVEMCE, Mexican registry and epidemiological surveillance of external congenital malformations; TRoCA, Tabriz registry of congenital anomalies.

[a]Survival to hospital discharge.

[b]Some data overlap between Argentina, RENAC; Colombia, Bogotá and Cali, with South America, ECLAMC. Colombia, Bogotá: 2001–2010, all data included in South America ECLAMC, 2011–2014 data from only one hospital included in South America ECLAMC. Colombia, Cali: 2011–2014 only data from one hospital included in South America ECLAMC. Some data from Argentina RENAC for 2009–2014 may overlap with South America, ECLAMC data.

[c]Slight difference in total case numbers due to cohort restriction for follow-up duration in three programs.

[d]Analysis not possible.

We calculated exact binomial 95% confidence intervals (95% CIs) for prevalence and survival estimates. To evaluate trends in survival by decades, we calculated differences in the proportions (with 95% CIs) surviving between the 1980s and 2010s and between consecutive decades (e.g., 1980s to 1990s, 1990s to 2000s). *p*-values <.05 were considered statistically significant. We conducted analyses using Microsoft Excel and StatsDirect (StatsDirect statistical software http://www.statsdirect.com England: StatsDirect Ltd, 2013).

3 | RESULTS

Twenty-four programs participated, with seven programs providing birth cohort data from the 1980s, eight from the 1990s, and nine with more recent data only (Tables 1 and S1). A total of 6,801 cases with EA were identified with an overall prevalence rate of 2.4 (95% CI 2.3–2.5) per 10,000 births (Table S1). The median prevalence of all programs was 2.5 per 10,000 births with an interquartile range from 2.0 to 3.0 per 10,000 births. Among 18 programs reporting ETOPFA and stillbirths, only 3.4% (156/4600) of cases were reported ETOPFA, and 2.2% (102/4600) stillborn infants.

One-month survival for 6,466 liveborn infants with EA was 84.1% (95% CI 83.2–84.9%) (Figure 1, Table 2). Survival to 1 year was 84.1% (95% CI 82.9–85.3%), based on 3,789 infants from 16 programs, and 82.7% (95% CI 81.2–84.2%) of infants survived to 5 years of age ($n = 2{,}640$ infants, from 10 programs) (Figure 1, Table 2).

When only programs with survival data to 1 year were included, 1-month and 1-year survival for infants with any EA was 88.7% (95% CI 87.6–89.6%) and 84.1% (95% CI 82.9–85.3%), respectively (Table 2). Survival to 1 and 5 years was 84.5% (95% CI 83.0–85.9%) and 82.7% (95% CI 81.2–84.2%), respectively, for programs and cohorts contributing data to both analyses (Table 2).

Of liveborn infants with EA, isolated cases comprised 50.3%, additional anomalies were reported for 39.7% and EA with chromosomal or genetic syndromes were found in 10.0% of infants (data from 15 programs reporting all three categories). Overall, 1-month, 1- and 5-year survival rates for infants with isolated EA and those with EA and additional anomalies are shown in Tables S2 and S3. For infants with isolated EA, 1-month survival was 96.0% (95% CI 94.5–97.2%) and 1-year survival 95.3% (95% CI 93.7–96.6%) from programs with survival data to 1 year (Table S2). Five-year survival was 95.3% (95% CI 93.1–96.9%). Of infants with EA and other major congenital anomalies, 87.6% (95% CI 84.9–90.0%) survived 1 month and 82.7% (95% CI

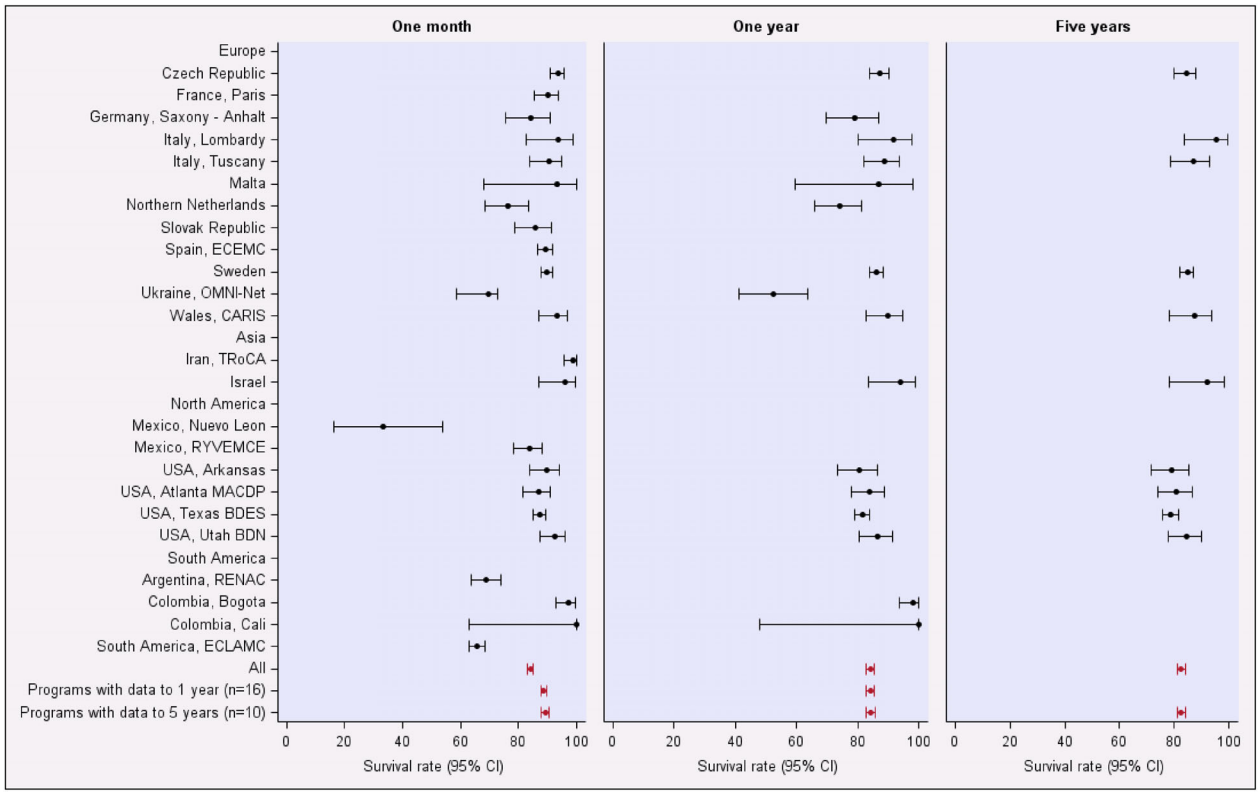

FIGURE 1 Survival for liveborn infants with esophageal atresia born 1980–2015, International Clearinghouse for Birth Defects Surveillance and Research

79.6–85.4%) survived to 1 year (from programs with data to 1 year). For programs with data to 5 years, 1-month survival and 1-year survival were similar and 5-year survival was 80.7% (95% CI 76.8–84.2%) (Table S3). Survival was lowest for infants with EA as well as a chromosomal or genetic syndrome diagnosis, with 62.7% (95% CI 57.2–67.9%) surviving to 1 month ($n = 327$, 15 programs), 54.0% (95% CI 46.8–61.1%) surviving to 1 year ($n = 200$, 10 programs), and 49.5% (95% CI 39.5–59.5%) ($n = 103$, five programs) surviving to 5 years. Programs providing data with 5-year follow-up reported 1-month survival of 57.3% (95% CI 47.2–67.0%), 1-year survival of 50.5% (95% CI 40.5–60.5%) and 5-year survival of 49.5% (95% CI 39.5–59.5%) for the same cohort.

Survival over the decades at 1 month, 1, and 5 years is shown in Table 3. When data were restricted to programs contributing data since the 1980s, 1-month and 1-year survival was higher in the 2010s compared with the 1980s (1-month, $p < .0001$; 1-year $p = .002$) and 5-year survival was higher in the 2000s compared with the 1980s ($p = .03$) (Table 3). Over consecutive decades, for 1-month survival, the proportion of surviving increased from the 1980s to 1990s, and from the 1990s to 2000s, while for 1- and 5-year survival, there were no differences between consecutive decades ($p \geq .05$ for all comparisons) (Table 3).

From the 1980s to the 2010s, we found increasing survival at 1 month and 1 year, for infants born with isolated EA and those with EA and an additional major anomaly (Table S4). For infants born with EA and a chromosomal or genetic syndrome diagnosis, we found no improvements in survival from the 1980s to 2010s at 1 month or 1 year, but numbers of infants born with EA and a chromosomal or genetic syndrome diagnosis in each decade were small, and CIs around the proportion of infants surviving were wide (Table S4). As only one program provided survival data to 5 years by type of EA, we did not assess trends in 5-year survival.

Over the decades from 1980s to 2010s, the proportion of cases ascertained among ETOPFA and stillbirths declined (ETOPFA: 6.5% in the 1980s, 2.7% in the 2010s; stillbirths: 11.2% in 1980s, 2.0% in the 2010s) (Table S5). The proportion of cases among ETOPFA or stillbirths overall decades was higher for those with additional major anomalies or chromosomal or genetic syndrome diagnoses ($n = 3$ programs) (Table 4). Almost all (99.2%) of cases with isolated EA were ascertained among live births. For each type of EA,

improvements in survival from the 1980s were accompanied by a fall in the proportion of stillbirths while the proportion of cases reported from ETOPFA varied (Table 4).

TABLE 3 Trends in survival to 1 month, 1, and 5 years, for liveborn infants with esophageal atresia, born 1980–2015, by decade of birth, International Clearinghouse for Birth Defects Surveillance and Research

Decade of birth	Survival to 1 month				Survival to 1 year				Survival to 5 years			
	Number Programs contributing data	*N* infants	% Survival	95% CI	Number Programs contributing data	*N* infants	% Survival	95% CI	Number Programs contributing data	*N* infants	% Survival	95% CI
All Programs with data for that decade												
1980s[a]	7	476	80.3	76.4–83.7	4	269	77.7	72.2–82.5	2	232	78.9	73.1–83.9
1990s[a]	12	1,209	83.3	81.1–85.4	8	631	83.8	80.7–86.6	5	558	84.2	80.9–87.2
2000s[a]	20	2,946	85.5	84.2–86.8	14	1794	85.2	83.4–86.8	9	1,506	82.8	80.8–84.7
2010s[b]	13	1,117	83.0	80.7–85.1	6	416	89.7	86.3–92.4	[c]			
Programs with data spanning 1980s – 2000s to assess trends												
1980s[a]	7	476	80.3	76.4–83.7 [d,e]	4	269	77.7	72.2–82.5[d]	2	232	78.9	73.1–83.9[d]
1990s[a]	7	788	87.8	85.3–90.0[e,f]	4	451	82.0	78.2–85.5	2	381	85.0	81.1–88.5
2000s[a]	7	760	91.1	88.8–93.0[f]	4	437	86.7	83.2–89.8	2	314	85.7	81.3–89.4[d]
2010s[b]	6	297	92.6	89.0–95.3[d]	3	197	88.3	83.0–92.5[d]	[c]			

Note: Superscript d,e,f show significant difference in survival between these decades ($p < .05$).

Abbreviation: CI, confidence interval.

[a]At least 5 years of data for each decade.

[b]Data to 2013 (4 years data) or 2014.

[c]5-year follow-up for birth cohorts in 2010s not possible.

TABLE 4 Proportion of cases with esophageal ascertained in ETOPFA and stillbirths, and 1 month survival, by decade of birth and type of esophageal atresia, among three programs reporting ETOPFA and stillbirth from 1980s to 2010s

Decade of birth	Number of cases	% ETOPFA	% stillborn	% live born	% of live born infants surviving to 1 month
Isolated EA					
1980s	52	0.0	1.9	98.1	92.2
1990s	63	0.0	0.0	100.0	98.4
2000s	80	0.0	0.0	100.0	97.5
2010s	49	2.0	0.0	98.0	100.0
1980s–2010s	244	0.4	0.4	99.2	97.1
EA with additional major anomaly					
1980s	36	11.1	13.9	75.0	74.1
1990s	48	18.8	6.3	75.0	72.2
2000s	56	12.5	0.0	87.5	87.8
2010s	25	8.0	4.0	88.0	95.5
1980s–2010s	165	13.3	5.5	81.2	82.1
EA with chromosomal or genetic syndrome diagnosis					
1980s	17	17.6	23.5	58.8	20.0
1990s	45	24.4	11.1	64.4	69.0
2000s	39	33.3	2.6	64.1	64.0
2010s	19	21.1	5.3	73.7	71.4
1980s–2010s	120	25.8	9.2	65.0	61.5

Note: Data from three programs (France, Paris; Germany, Saxony-Anhalt; Northern Netherlands).
Abbreviations: EA, esophageal atresia; ETOPFA, elective termination of pregnancy for fetal anomaly.

4 | DISCUSSION

In this international study from 24 surveillance programs spanning four continents, we evaluated the survival of 6,466 liveborn infants with EA to provide survival estimates at various time points in their lifespan (up to 5 years of age). We also evaluated how such survival varied over time (from the 1980s to 2010s) and for specific clinical subsets of EA (isolated, with multiple congenital anomalies, and with genetic syndromes). Current estimates of survival for infants born with EA were 89.4% at 1 month, 84.5% at 1 year, and 82.7% at 5 years of age. Survival was particularly high for infants with isolated EA compared with those with associated anomalies or with chromosomal or genetic conditions (at 1 month, 97.1 vs. 89.7 vs. 57.3%, respectively). Survival also improved through the decades from the 1980s (overall survival of 80.3% at 1 month and 77.7% at 1 year) to the 2010s (92.6% at 1 month and 88.3% at 1 year). Such improvement was particularly notable for infants with EA and additional anomalies (from 70.7 to 92.2% survival at 1 month). When compared with high-income countries, some programs from middle-income countries (RENAC-Argentina, México-Nuevo León, South America ECLAMC, and Ukraine OMNI-Net) had the lowest survival.

Over a similar time span, our study survival rates for all EA combined are similar to those from Europe (87% at 1 week) (Pedersen et al., 2012) and the USA (87.5–90.0% at 1 month, 81.5–84.6% at 1 year) (Wang et al., 2015; Wang, Hu, Druschel, & Kirby, 2011). However, our rates are lower than those from north-eastern Italy (88% at 1 year) (Cassina et al., 2016), but this Italian study excluded infants with chromosomal diagnoses (Cassina et al., 2016). For infants with isolated EA, our 1-year survival rate (96%) was comparable to that reported from the northern parts of the United Kingdom (95%) (Tennant et al., 2010). Our survival rates were highest in the first months of life (1-month and 1-year survival of 89.4 and 84.5%) and then stabilized (82.7% survival at 5 years), a pattern also reported from north-eastern Italy (Cassina et al., 2016). Importantly, longer-term follow-up of children with isolated EA shows that once they reach 5 years, they are almost certain to survive to age 20 years or longer (Tennant et al., 2010; Wang et al., 2011).

In our study, survival in the 2010s for infants with EA and co-existing additional anomalies (92.2% at 1 month,

85.7% at 1 year) or infants with EA and a chromosomal or genetic syndrome diagnoses (69.4% at 1 month, 60.9% at 1 year) was lower than for infants with isolated EA (99.3% at 1 month, 98.9% at 1 year). Lower survival associated with co-occurrence of additional anomalies has been reported by other studies (Cassina et al., 2016; Nembhard et al., 2001; Pedersen et al., 2012; Robert et al., 1993; Sfeir et al., 2013; Wang et al., 2014). Approximately 50% of infants with EA have existing additional anomalies, mostly cardiac anomalies (Cassina et al., 2016; Pedersen et al., 2012), and 6–10% have chromosomal anomalies, most commonly trisomy 21 and trisomy 18 (Pedersen et al., 2012; Shaw-Smith, 2006). These additional cardiac anomalies and trisomies are associated with increased mortality (Dastgiri, Gilmour, & Stone, 2003; Rasmussen, Wong, Yang, May, & Friedman, 2003; Tennant et al., 2010), and most likely contribute to the increased mortality rates for EA.

Survival of infants with EA has been found to be associated with a range of perinatal, socio-demographic, and clinical factors. While we were unable to investigate co-factors associated with mortality, such as low birth weight and preterm birth, these are common among infants with EA. Specifically, 40% or more of infants with EA weigh <2,500 g at birth, (Cassina et al., 2016; Sulkowski et al., 2014), and > 30% are born preterm (Cassina et al., 2016; Sulkowski et al., 2014; Wang et al., 2014). Survival of infants with EA has been associated with birth weight, (Cassina et al., 2016; Sfeir et al., 2013; Sulkowski et al., 2014; Wang et al., 2014) gestational age, (Cassina et al., 2016; Sfeir et al., 2013; Sulkowski et al., 2014; Wang et al., 2014) race, (Sulkowski et al., 2014; Wang et al., 2014), household income, (Wang et al., 2014) timing of repair, (Wang et al., 2014) and hospital characteristics (Wang et al., 2014).

Our findings demonstrating improvement in survival from the 1980s to recent times also have been reported from country-specific studies, including Sweden (Oddsberg, Lu, & Lagergren, 2012) and north-eastern Italy (Cassina et al., 2016). Improvement in survival was found for infants with EA and multiple anomalies, but not for those with isolated EA (Cassina et al., 2016). Increased survival rates over time have been attributed to advances in neonatal intensive care, including centralization of perinatal care, improved neonatal transport systems, nutritional support, and the management of respiratory distress syndrome (Cassina et al., 2016;Lopez et al., 2006; Oddsberg et al., 2012). Management of infants with cardiac anomalies also has improved and may be contributing to improved survival of infants with EA and cardiac anomalies (Lopez et al., 2006; Oddsberg et al., 2012). This improvement in survival over the decades also may be influenced by a fall in the proportion of infants with EA diagnosed in stillbirths. However, the contributions of changes in ETOPFA and stillbirth rates on survival are difficult to determine but relatively small.

We present an international study from 24 surveillance programs over four continents, with almost half (10/24) outside Europe and the USA. We note that findings may be limited by differences in case ascertainment, ETOPFA rates, differentiation of isolated and non-isolated cases (Cassina et al., 2016), and health services available across programs. In addition, for some programs, the number of infants diagnosed with EA was small and confidence intervals were wide. We could not account for many of these factors in our analyses or in interpreting results. In addition, as survival has improved over time, survival rates may be lower among programs including cohorts from the 1980s compared with those programs with infants born in more recent decades. There also may be overestimation of 1-month survival from programs with follow-up to hospital discharge if infants with EA were discharged home but then died before 1 month. However, this is unlikely to have a great effect on results as infants born with EA are very ill and likely to remain in hospital until death or successful treatment.

In summary, our large international collaborative study including over 6,800 infants from 24 surveillance programs, many of which were population-based, exemplifies the value of birth defect registries and surveillance programs in assessing not only the birth prevalence of congenital anomalies, but also in tracking some critical health outcomes, such as survival. Almost all infants with isolated EA survive to 5 years, but the risk of mortality is higher for infants born with additional major anomalies or with chromosomal or genetic syndrome diagnoses. Importantly, survival has improved since the 1980s, particularly for infants with EA and additional diagnoses, and it is highly recommended to follow these infants to promote positive long-term outcomes.

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CONFLICT OF INTEREST

All authors have confirmed that they have no conflict of interest.

DISCLAIMER

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the US Centers for Disease Control and Prevention

DATA AVAILABILITY STATEMENT

Research data are not shared.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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