Accepted Manuscript online: 2022-05-06 Article published online: 2022-06-12

National Trends in Survival and Short-Term Outcomes of Periviable Births ≤24 Weeks Gestation in the United States, 2009 to 2018

Harshit Doshi, MBBS[1] Samarth Shukla, MD[2] Shalinkumar Patel, MBBS, MPH[2] Grace Annan Cudjoe, MB ChB[3] Wendy Boakye, MB, ChB[4] Narendrasinh Parmar, MD[5] Parth Bhatt, MBBS, MPH[6] Fredrick Dapaah-Siakwan, MD[7] Keyur Donda, MBBS[8]

[1] Neonatal Intensive Care Unit, Golisano Children's Hospital of Southwest Florida, Florida
[2] University of Florida College of Medicine, Jacksonville, Florida
[3] University of Ghana School of Medicine and Dentistry, Accra, Ghana
[4] National Institute of Health, Bethesda, Maryland
[5] Department of Pediatrics Brookdale University Hospital and Medical Center, Brooklyn, New York
[6] Department of Pediatrics, United Hospital Center, Bridgeport, West Virginia
[7] Neonatal Intensive Care Unit, Valley Children's Hospital, Madera, California
[8] Department of Pediatrics/Division of Neonatology University of South Florida, Tampa, Florida

Address for correspondence Keyur Donda, MBBS, Department of Pediatrics, University of South Florida, 5 Tampa General Cir, HMT 4th Floor, Suite #450, Tampa, FL 33606 (e-mail: kdonda@usf.edu).

Am J Perinatol

Abstract

Objective Data from the academic medical centers in the United States showing improvements in survival of periviable infants born at 22 to 24 weeks GA may not be nationally representative since a substantial proportion of preterm infants are cared for in community hospital-based neonatal intensive care units. Our objective was to examine the national trends in survival and other short-term outcomes among preterm infants born at ≤24 weeks gestational age (GA) in the United States from 2009 to 2018.

Study Design This was a retrospective, repeated cross-sectional analysis of the National Inpatient Sample for preterm infants ≤24 weeks GA. The primary outcome was the trends in survival to discharge. Secondary outcomes were the trends in the composite outcome of death or one or more major morbidity (bronchopulmonary dysplasia, necrotizing enterocolitis stage ≥2, periventricular leukomalacia, severe intraventricular hemorrhage, and severe retinopathy of prematurity). The Cochran–Armitage trend test was used for trend analysis. *p*-Value <0.05 was considered significant.

Results Among 71,854 infants born at ≤24 weeks GA, 34,251 (47.6%) survived less than 1 day and were excluded. Almost 93% of those who survived <1 day were of ≤23 weeks GA. Among the 37,603 infants included in the study cohort, 48.1% were born at 24 weeks GA. Survival to discharge at GA ≤ 23 weeks increased from 29.6% in 2009 to 41.7% in 2018 ($p < 0.001$), while survival to discharge at GA 24 weeks increased from

Keywords
- periviable preterm infants
- survival
- national inpatient sample
- trends

received
January 9, 2022
accepted
April 29, 2022

Thieme Medical Publishers, Inc.,
333 Seventh Avenue, 18th Floor,
New York, NY 10001, USA

DOI https://doi.org/10.1055/a-1845-2526.
ISSN 0735-1631.

58.3 to 65.9% ($p < 0.001$). There was a significant decline in the secondary outcomes among all the periviable infants who survived ≥1 day of life.

Conclusion Survival to discharge among preterm infants ≤24 weeks GA significantly increased, while death or major morbidities significantly decreased from 2009 to 2018. The postdischarge survival, health care resource use, and long neurodevelopmental outcomes of these infants need further investigation.

Key Points

- Survival increased significantly in infants ≤24 weeks GA in the United States from 2009 to 2018.
- Death or major morbidity in infants ≤24 weeks GA decreased significantly from 2009 to 2018.
- Death or surgical procedures including tracheostomy, VP shunt placement, and PDA surgical closure in infants <=24 weeks GA decreased significantly from 2009 to 2018.

Periviable births have been defined as deliveries occurring from $20^{0/7}$ to $25^{6/7}$.[1] These infants are born at the cusp of viability and are at high risk for death or serious morbidities and also incur substantial health care costs during the initial birth hospitalization.[2,3] Despite the extremely high rate of mortality in this group of infants, several studies have reported a gradual improvement in the survival rate over the last few decades. Younge et al. published a study in 2017 which included 4,000 preterm infants with GA between 22 and 24 weeks from 11 academic centers in the United States and demonstrated that survival and survival without neurodevelopmental impairment significantly increased during the study period.[4] Another study that included preterm infants from 26 U.S. centers participating in Neonatal Research Network showed that survival increased markedly for infants born at 23 and 24 weeks GA between 1993 and 2012.[5] Similar results have been reported from other developed countries.[6,7]

However, these outcomes vary among hospitals and geographic regions due to differences in the practice of offering potentially lifesaving treatments before and after birth.[8,9] These variations in the initiation of active treatment are not surprising given that clinicians and parents may elect to only provide comfort care rather than the resuscitation of premature infants not expected to survive. The interventions considered active treatment include any of the following: surfactant therapy, tracheal intubation, ventilatory support (including continuous positive airway pressure, bag–valve–mask ventilation, or mechanical ventilation), parenteral nutrition, epinephrine, or chest compressions.[8]

In the 1970s, most states in the United States developed coordinated regional systems for perinatal care that were predominantly focused on neonatal outcomes. Three levels of perinatal services were designated as levels I, II, and III in an increasing order of intensity and complexity for both maternal and neonatal care.[10,11] The designated regional or tertiary care centers provided the highest levels of obstetric and neonatal care and served smaller facilities' needs through education and transport services. These regional perinatal centers were mostly academic centers.[12–14]

Since the 1980s, there has been a breakdown of the regionalization of perinatal and neonatal care services due to the explosion in the growth and number of neonatal intensive care units (NICUs) in nonacademic community hospitals.[15–18] Thus, a growing number of extremely preterm infants, including periviable infants, are born and cared for in some of these community hospital-based NICUs. As a result, data from the academic medical centers in the United States showing improvements in the survival of periviable infants born at 22 to 24 weeks GA may not be nationally representative. Additionally, there are limited data on the trends in major morbidities in this population of extremely preterm infants. Constantly changing data on outcomes of extremely premature infants may affect decisions to intervene in the event of preterm delivery. A population-based nationally representative outcome data obtained from community hospitals can better aid in guiding clinicians, families, hospitals, and policymakers. We aimed to examine the national trends in survival to discharge and in-hospital outcomes of major morbidities among extremely preterm infants born at ≤24 weeks gestation in the United States from 2009 to 2018.

Materials and Methods

Study Design and Data Source

We conducted a retrospective, repeated cross-sectional analysis of the Healthcare Cost and Utilization Project's (HCUP) National Inpatient Sample (NIS) database from 2009 through 2018 (the latest available data year at the time of analysis).[19] The NIS is the largest publicly available all-payer database of hospital discharges from community, nonrehabilitation hospitals in the United States. The NIS is released every year by HCUP, and it includes a 20% stratified sample of all discharges (approximately 7 million) from U.S. community hospitals. The number of states and hospitals contributing data to NIS increased from 1,045 hospitals in 38 states in 2006 to 4,584 hospitals in 48 states in 2017. In 2012, the NIS design changed from including all discharges within a 20% stratified random sample of hospitals to a 20% self-weighted, stratified, systematic random sample of discharges from all hospitals.

These discharges captured in the NIS contain 35 million hospitalizations annually and represent approximately 97% of all U.S. hospitalizations when weighted. We used the "TRENDWT" variable provided by HCUP for the years prior to 2012 to make estimates comparable to the new NIS design which began in 2012.[20] Each hospitalization in this database is deidentified and maintained as a unique entry that has 1 primary diagnosis and <30 secondary diagnoses along with up to 25 procedure codes using *International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9 CM) and *10th Revision* (ICD-10 CM). The NIS database has been extensively used by researchers and policymakers to make national estimates of health care utilization and outcomes in numerous conditions.[21–25] The study involved publicly available deidentified data and was, thus, exempt from the institutional review board review.

Study Population

We identified neonates (age ≤28 days) using the "Neomat" variable which identifies discharges with neonatal and/or maternal diagnoses and procedures. The inclusion criteria were neonatal hospitalizations with gestational age (GA) ≤24, birthweight ≤750 g, and survival for at least 1 day. All preterm hospitalizations with birthweight >750 g were excluded to avoid the inclusion of errors related to improbable birthweights. Early death (<12 hours of age) among extremely low-birth-weight infants may reflect an assessment of nonviability by obstetricians and neonatologists.[26] Due to variations in clinical practice guiding active resuscitation and withdrawal of care to periviable preterm infants, all infants who survived for <1 day were excluded to avoid the inclusion of infants who received only comfort care. To avoid duplication of data, we identified and excluded neonates who were transferred out to short-term hospitals, skilled nursing facilities, or intermediate care facilities, or another type of facility, using the "DISPUNIFORM" variable in keeping with previous studies that utilized HCUP databases.[23,25,27] Details of the population derivation are shown in ►Fig. 1.

Definition of Variables

Patient-level characteristics such as sex, race, median household income as per ZIP code, primary payer (Medicare/Medicaid, private insurance, self-pay, and other), and hospital-level characteristics such as hospital location (rural or urban) and teaching status (rural, urban nonteaching, and urban teaching), hospital bed size (small, medium, and large), and hospital region (Northeast, Midwest, South, and West;) were abstracted. The distribution of the various states in each census region is available at https://www.hcup-s.ahrq.gov/db/nation/nis/NIS_Introduction_2017.jsp#table2app1. Race was categorized as White, non-Hispanic Black, Hispanic, and others. Comorbidities/complications were identified with ICD-9 and ICD-10 diagnostic and procedure codes as shown in ►Supplemental Table S1, (available online only).

Outcome Measures

Our primary outcome was the trend in survival to discharge of periviable preterm infants ≤24 weeks GA from 2009 through 2018. The secondary outcomes were to quantify and trend the short-term in-hospital outcomes of death or any of the major morbidities defined as bronchopulmonary dysplasia (BPD), necrotizing enterocolitis (NEC) stage ≥2, periventricular leukomalacia (PVL), severe intraventricular hemorrhage (IVH; grade 3 or 4), severe neurological injury (including grade 3 or 4 IVH or PVL), and severe retinopathy of prematurity (ROP; stage 3–5) in keeping with previous studies.[28–31] Other outcomes included in-hospital death or any of these procedures: surgical closure of patent ductus arteriosus (PDA), tracheostomy, ventriculoperitoneal shunt placement, and gastrostomy tube placement. These co-morbidities and procedures were identified with ICD-9 and ICD-10 procedure codes.

Statistical Analysis

We reported proportions with standard error of the mean for categorical variables. The periviable infants included in the study were stratified into two groups based on GA (≤23 weeks and 24 weeks). We used the chi-square test for proportions to compare these two groups. The Cochran–Armitage trend test for categorical variables was used to assess trends in both the primary and secondary outcomes during the study period. Statistical analyses were performed using SPSS V26.0 (IBM Corp, Armonk, NY). A p-value of < 0.05 was considered significant for all analyses.

Results

We identified 37 million live births, and 71,854 infants were born at or before 24 weeks gestation during the study period from the years 2009 to 2018. Among these, 34,251 (47.7%) survived less than 1 day and were excluded from the study. Almost 93% of those who survived less than 1 day were ≤23 weeks GA. ►Fig. 1 shows the derivation of the eligible population. Of the hospitalizations that met the inclusion criteria, 19,520 infants were born at ≤23 weeks GA and 18,083 infants were born at 24 weeks GA.

The demographic and baseline characteristics of infants included in the study are shown in ►Table 1. Briefly, 40.2% of the infants were delivered by a cesarean section, 35.6% were White, 34.2% were Black, 35.3% had private insurance, and a majority of them were discharged from large bed size (69.5%) or teaching hospitals (86.4%). Compared with infants born at ≤23 weeks GA, those born at 24 weeks GA were more likely to have maternal hypertension (2.5 vs. 1.1%), placental abruption (2.9 vs. 2.0%), and more likely to have a cesarean delivery (53.4 vs. 28.0%) (►Table 2). There were no significant differences in racial origin and median household income.

Our primary outcome was survival to discharge among the periviable infants. Over the study period, a significant proportion of these infants died during the initial hospitalization. The mortality rate was exceptionally high among infants born at ≤23 weeks GA as compared with those born at 24 weeks GA (64.7 vs. 35.7%, $p < 0.001$) (►Supplemental Table S2 and ►Supplemental Fig. S1). However, the trends in survival to discharge during the study period showed a significant improvement (►Fig. 2). Survival to discharge

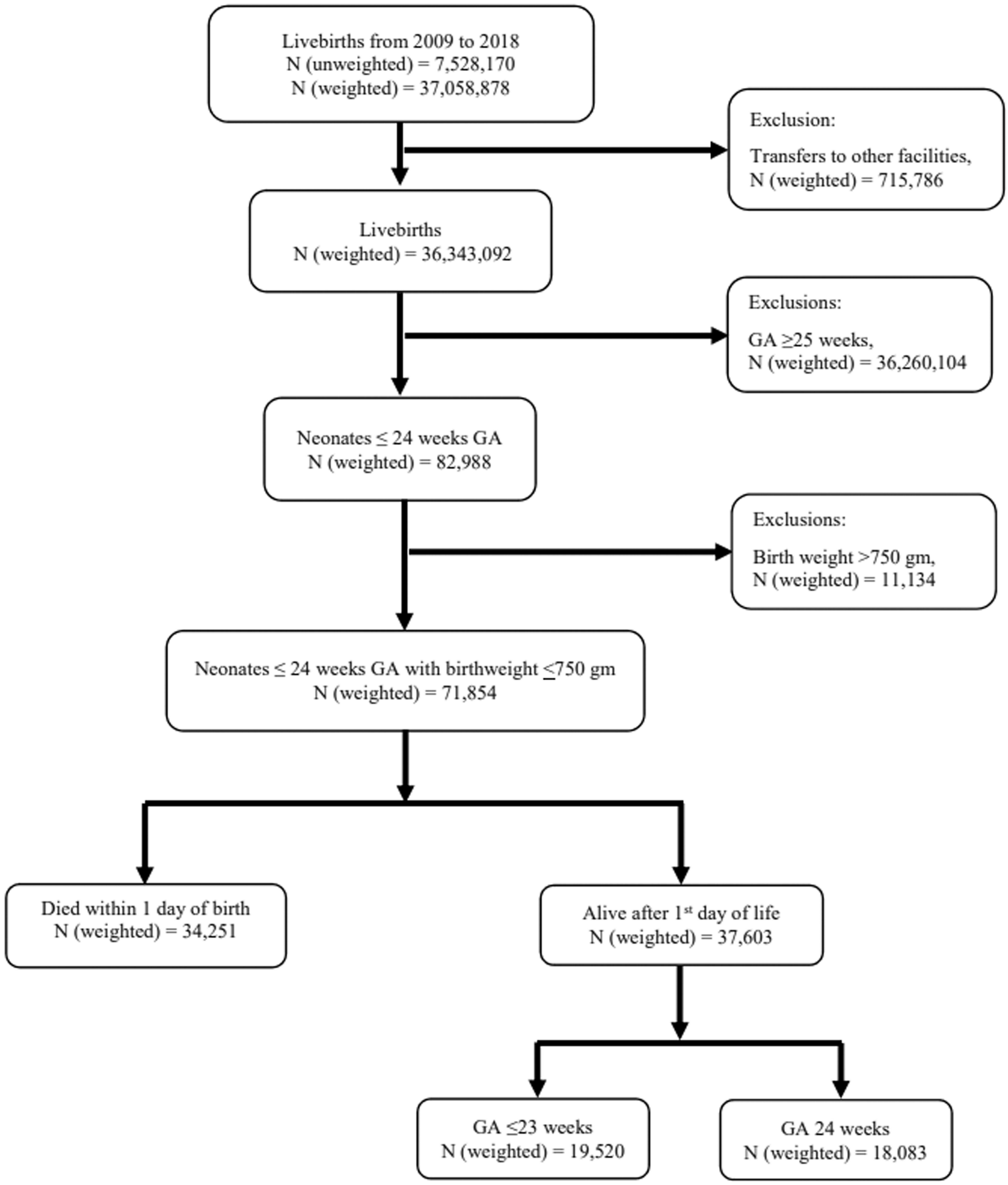

Fig. 1 Patient flow and eligibility diagram.

among infants born at ≤23 weeks GA increased from 29.6% in 2009 to 41.7% in 2018 ($p < 0.001$). Similarly, survival to discharge for infants born at 24 weeks GA increased from 58.3% in 2009 to 65.9% in 2018 ($p < 0.001$).

Our secondary outcomes included a composite of death or any of the major morbidities, including BPD, severe NEC, severe neurological injury, and severe ROP. We also compared the composite outcome of death or procedures such as ventriculoperitoneal (VP) shunt, tracheostomy, or gastrostomy tube (GT) placement, and surgical closure of PDA. All the composite outcomes were significantly higher among infants born at ≤23 weeks GA (►**Supplemental Table S2**). About 90% of infants born at ≤ 23 weeks GA either died or had one of the major morbidities compared with 80% among infants born at 24 weeks GA. The prevalence of procedures such as VP shunt, tracheostomy, or GT placement, and surgical closure of PDA were also significantly higher in the lower GA group.

Table 1 Baseline characteristics of infants born at ≤24 weeks GA and survived ≥1 day in the United States from 2009 through 2018

	N = 37,603 % (SEM)
GA group	
GA ≤23 wk	51.9 (0.5)
GA 24 wk	48.1 (0.5)
Multiple gestation	1.5 (0.2)
Malpresentation	2.7 (0.2)
Maternal hypertension	1.8 (0.1)
Maternal diabetes	1.8 (0.1)
Chorioamnionitis	2.5 (0.2)
Prolonged rupture of membranes	4.0 (0.2)
Placental abruption	2.4 (0.2)
Gender	
Male	49.9 (0.5)
Female	
Cesarean birth	40.2 (0.7)
SGA	1.8 (0.1)
Race	
Caucasian	35.6 (0.7)
Black	34.2 (0.7)
Hispanic	18.3 (0.6)
Other	12.0 (0.4)
Median household income national quartile for patient ZIP code	
0–25th percentile	36.2 (0.7)
25–50th percentile	25.2 (0.6)
50–75th percentile	22.7 (0.5)
75–100th percentile	15.9 (0.8)
Type of insurance	
Private	35.3 (0.7)
Medicaid/self-pay/other	64.7 (0.7)
Hospital teaching status	
Nonteaching	13.6 (0.7)
Teaching	86.4 (0.7)
Hospital bed size	
Small/medium	30.5 (0.9)
Large	69.5 (0.9)
Hospital region	
Northeast	14.4 (0.6)
Midwest	22.4 (0.9)
South	42.7 (1)
West	20.5 (0.8)

Abbreviations: GA, gestational age; SEM, standard error of the mean; SGA, small for gestational age.

Table 2 Comparison of baseline characteristics of infants born at ≤24 weeks GA, stratified by GA

	GA ≤23 wk N = 19,520 % (SEM)	GA 24 wk N = 18,083 % (SEM)	p-Value
Multiple Gestation	1.6 (0.2)	1.4 (0.2)	0.59
Malpresentation	2.6 (0.2)	2.8 (0.3)	0.64
Maternal hypertension	1.1 (0.2)	2.5 (0.2)	<0.001
Maternal diabetes	1.6 (0.2)	2.0 (0.2)	0.17
Chorioamnionitis	2.5 (0.3)	2.5 (0.2)	0.95
Prolonged rupture of membranes	3.7 (0.3)	4.3 (0.3)	0.12
Placental abruption	2.0 (0.2)	2.9 (0.3)	0.02
Gender			
Male	51.0 (0.7)	48.8 (0.8)	
Female			
Cesarean birth	28.0 (0.7)	53.4 (1.0)	<0.001
SGA	1.2 (0.2)	2.5 (0.2)	<0.001
Race			
Caucasian	34.9 (0.9)	36.4 (0.9)	0.57
Black	34.4 (0.8)	34.0 (0.9)	
Hispanic	18.4 (0.7)	18.1 (0.7)	
Other	12.3 (0.5)	11.6 (0.6)	
Median household income national quartile for patient ZIP code			
0–25th percentile	36.3 (0.8)	36.1 (0.9)	0.79
25–50th percentile	25.3 (0.7)	25.1 (0.7)	
50–75th percentile	22.3 (0.6)	23.2 (0.7)	
75–100th percentile	16.2 (0.9)	15.6 (0.8)	
Type of insurance			
Private	55.0 (0.8)	57.7 (0.9)	0.02
Medicaid/self-pay/other	45.0 (0.8)	42.3 (0.9)	
Hospital teaching status			
Nonteaching	15.5 (0.6)	11.5 (0.8)	<0.001
Teaching	84.5 (0.6)	88.5 (0.8)	
Hospital bed size			
Small/medium	31.2 (0.9)	29.8 (1.0)	0.18
Large	68.8 (0.9)	70.2 (1.0)	
Hospital region			
Northeast	14.3 (0.6)	14.5 (0.7)	0.03
Midwest	23.5 (0.9)	21.1 (1.0)	
South	41.4 (1.0)	44.1 (1.1)	
West	20.8 (0.7)	20.2 (0.9)	

Abbreviations: GA, gestational age; SEM, standard error of the mean; SGA, small for gestational age.

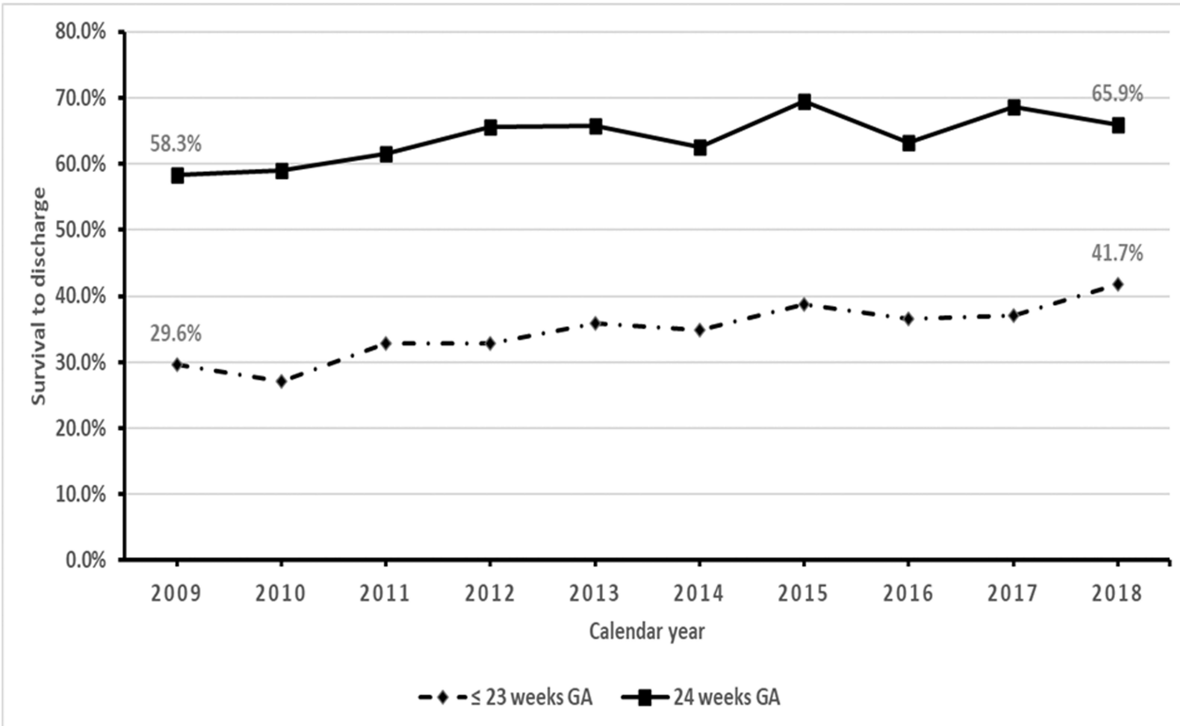

Fig. 2 Trends in survival to discharge of periviable preterm infants born at ≤24 weeks GA, 2009 to 2018. GA, gestational age.

However, this high incidence of adverse outcomes among periviable infants showed an encouraging trend over the years 2009 to 2018 (►**Fig. 3**). There was a significant decline in the composite outcome of death or any major morbidity (BPD, severe NEC, severe ROP, and severe neurological injury) during the study period. The proportion of these periviable infants who died prior to discharge or underwent procedures including tracheostomy, VP shunt placement, and surgical PDA closure also showed a consistently declining trend. The incidence of in-hospital death or GT placement showed a statistically insignificant decline ($p = 0.18$) (►**Figs. 2A–H**).

Discussion

In this analysis of a nationally representative sample, we showed that periviable infants continue to have a significantly high rate of mortality during the initial hospitalization. However, over the last decade, the rate of survival to discharge has considerably improved, and this improvement in survival is more pronounced for infants born at 22 and 23 weeks GA. Similarly, the incidence of death or major short-term in-hospital morbidities continues to be high but shows significantly improving trends over the study period.

Our findings are consistent with several other studies conducted at large national and international academic centers.[4,5,32,33] On the contrary, some studies have reported improved survival for extremely premature infants but no significant change in the short-term morbidities.[34,35] Perinatal care practices have been shown to be different across hospitals, and this can at least partially account for variation in outcomes of periviable infants.[8,36] Geographic and regional variations in policies affecting perinatal interventions and outcomes of extremely preterm infants have also been documented.[9,37] Perinatal interventions such as antenatal corticosteroids, neonatal resuscitation, and mechanical ventilation may not be offered to infants born at the cusp of viability. Instead, centers may provide comfort care when faced with these situations. We excluded infants who survived less than 1 day to account for practices where neonatal resuscitation is actively withheld. The difference in approaches to providing resuscitative and intensive care to periviable infants is likely because most of the outcome data are reported from large academic centers with frequent use of intensive care.[38] These academic centers are selected by peer review and represent academic institutions with large obstetric and neonatal services, expertise in caring for high-risk mothers and extremely preterm infants, and experience in multicenter clinical research. All delivery hospitals at NRN sites are included in the registry and represent almost 5% of all extremely preterm births in the United States.[5] Research from California has demonstrated that teaching hospitals and hospitals with integrated delivery systems are more likely to have 24-hour on-call physician staffing patterns (childbirth physicians and anesthesiologists) and more likely to be able to perform an emergency cesarean section in 30 minutes when compared with community hospitals.[39] Thus, the trends in outcomes at these academic centers may not reflect practices in other smaller or nonacademic hospitals and, thus, are not representative of the entirety of the United States. Our study attempts to address this limitation in the generalizability of previously available data. The NIS approximates a 20% stratified sample of discharges

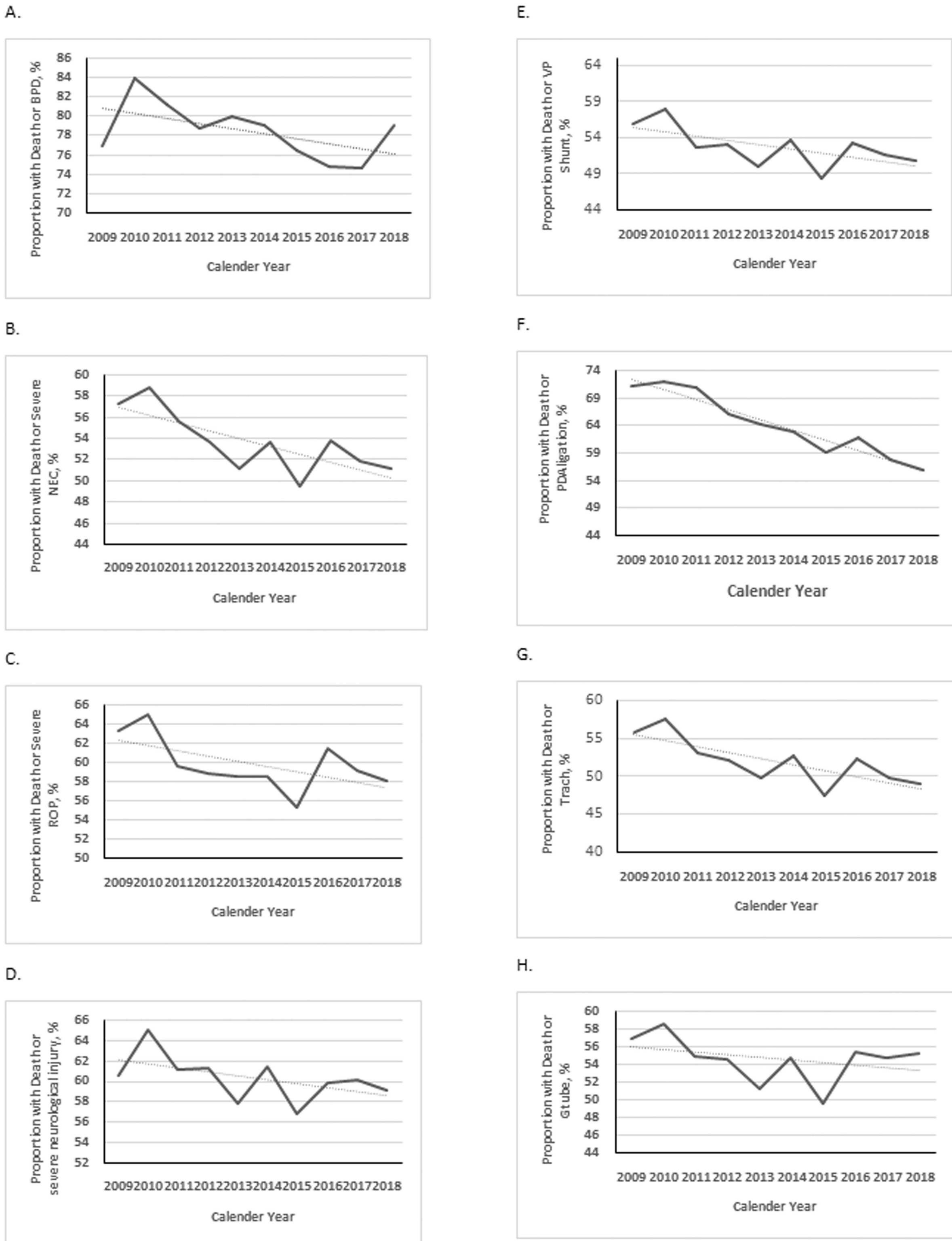

Fig. 3 Trends in the composite outcomes of death or morbidity among infants born at ≤24 weeks GA, 2009 to 2018. The broken lines represent the linear trend line. Severe neurological injury includes grade 3 or 4 IVH or PVL. (**A**) *p*-Value for trend in death or BPD = 0.001. (**B**) *p*-Value for trend in death or severe NEC <0.001. (**C**) *p*-Value for trend in death or severe ROP = 0.012. (**D**) *p*-Value for trend in death or severe neurological injury = 0.042. (**E**) *p*-Value for trend in death or VP shunt placement = 0.004. (**F**) *p*-Value for trend in death or PDA ligation < 0.001. (**G**) *p*-Value for trend in death or tracheostomy <0.001. (**H**) *p*-Value for trend in death or GT placement = 0.18. BPD, bronchopulmonary dysplasia; GA, gestational age; NEC, necrotizing enterocolitis.

from U.S. community hospitals (both academic and nonacademic) from 48 U.S. states and, when weighted, represents 97% of all U.S. hospitalizations. As a result, the data regarding in-hospital outcomes and trends in the outcomes reported in the present study can be generalized to the entire country.

While we found a significant decrease in the composite outcome of in-hospital death or any of these procedures: surgical closure of PDA, tracheostomy, and ventriculoperitoneal shunt placement, the decreased death or gastrostomy tube placement was not statistically significant. These trends are due in part to the significant decline in mortality and improvement in survival to discharge. While recent studies have demonstrated increased placement of gastrostomy tubes in very low birth weight preterm infants and those with BPD,[40,41] we did not find the decreased trend of the composite outcome of death or gastrostomy tube placement significant. This could be due to the divergent and opposite trajectories of the two, decreasing mortality leading to increased survival of these periviable preterm infants who later receive the gastrostomy tubes.

We acknowledge certain limitations related to this study. The accuracy of the NIS database depends on the appropriate coding of diagnoses and procedures. This leads to a potential for inaccuracies related to documentation and coding. However, major primary diagnoses involving periviable GAs and major morbidities such as BPD, severe IVH, etc., and mortality are more likely to be coded reliably. NIS being an administrative database, it is possible that some of the data may be missing. However, this is likely to have an insignificant effect on the results due to the large sample size. Additionally, any study evaluating the trends in morbidities and mortality of preterm infants cannot be reliably interpreted without the information on antenatal corticosteroid administration. Multiple reports have shown that antenatal corticosteroid administration improves the outcomes of preterm infants, even those born at the margins of viability.[42,43] Since the NIS database does not provide any medication information, we were unable to evaluate the impact of antenatal corticosteroids on the outcomes of our study. Also, since ICD coding does not segregate infants born at 22 and 23 weeks GA, we could not compare the outcomes between these groups. Lastly, the NIS database only provides all-cause mortality. Consequently, we cannot comment on factors or causes affecting the trends in mortality.

Improving the survival of periviable and extremely preterm infants may lead to a longer length of stay. It may also lead to a higher number of infants with significant in-hospital morbidities and the need for additional beds, personnel, and equipment. Our study provides more refined and latest data on outcomes of periviable infants. It can help health care providers develop or modify current perinatal practices to be more evidence-based. This data can enable health systems to devise policies that address the changing health care needs of periviable infants.

Conclusion

In this retrospective cross-sectional study using a nationwide database, we found that survival to discharge of periviable infants born between 22 and 24 weeks of GA increased significantly from 2009 to 2018. Simultaneously, the incidence of major morbidities associated with extreme prematurity continues to be high but shows an improving trend.

Prior Presentation of Abstract or Poster

An abstract of this study was accepted for oral presentation at the 2021 American Academy of Pediatrics National Conference and Exhibition Meeting.

Data Sharing Statement

Deidentified individual participant data will not be made available. The raw data were obtained from the Agency for Healthcare Research and Quality (https://www.hcup-us.ahrq.gov)

Contributors' Statement

G.A.C., W.B., and N.P. designed the data collection instruments, collected data, performed the initial analyses, and reviewed and revised the manuscript. S.S. and P.B. conceptualized and designed the study, performed the initial analyses, drafted the initial manuscript, and reviewed and revised the manuscript. K.D., H.D., and F.D.-S. conceptualized and designed the study, coordinated, and supervised data collection, and critically reviewed the manuscript for important intellectual content. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

Funding

None.

Conflict of Interest

None declared.

Acknowledgments

The authors would like to thank the Healthcare Cost and Utilization Project of the Agency for Research and Healthcare Quality for the use of the data from the National Inpatient Sample.

References

1 Raju TNK, Mercer BM, Burchfield DJ, Joseph GF Jr. Periviable birth. Obstet Gynecol 2014;123(05):1083–1096
2 Hayman WR, Leuthner SR, Laventhal NT, Brousseau DC, Lagatta JM. Cost comparison of mechanically ventilated patients across the age span. J Perinatol 2015;35(12):1020–1026
3 Allen KM, Smith B, Iliev I, Evans J, Werthammer J. Short term cost of care for the surviving periviable neonate. J Neonatal Perinatal Med 2017;10(02):191–194
4 Younge N, Goldstein RF, Bann CM, et al; Eunice Kennedy Shriver National Institute of Child Health and Human Development Neonatal Research Network. Survival and neurodevelopmental outcomes among periviable infants. N Engl J Med 2017;376(07):617–628
5 Stoll BJ, Hansen NI, Bell EF, et al; Eunice Kennedy Shriver National Institute of Child Health and Human Development Neonatal Research Network. Trends in care practices, morbidity, and mortality of extremely preterm neonates, 1993-2012. JAMA 2015;314 (10):1039–1051

6 Kono Y, Yonemoto N, Nakanishi H, Kusuda S, Fujimura M. Changes in survival and neurodevelopmental outcomes of infants born at <25 weeks' gestation: a retrospective observational study in tertiary centres in Japan. BMJ Paediatr Open 2018;2(01):e000211
7 Norman M, Hallberg B, Abrahamsson T, et al. Association between year of birth and 1-year survival among extremely preterm infants in Sweden during 2004-2007 and 2014-2016. JAMA 2019;321(12):1188–1199
8 Rysavy MA, Li L, Bell EF, et al; Eunice Kennedy Shriver National Institute of Child Health and Human Development Neonatal Research Network. Between-hospital variation in treatment and outcomes in extremely preterm infants. N Engl J Med 2015;372(19):1801–1811
9 Boghossian NS, Geraci M, Edwards EM, Ehret DEY, Saade GR, Horbar JD. Regional and racial-ethnic differences in perinatal interventions among periviable births. Obstet Gynecol 2020;135(04):885–895
10 Barfield WD, Papile LA, Baley JE, et al; American Academy of Pediatrics Committee on Fetus And Newborn. Levels of neonatal care. Pediatrics 2012;130(03):587–597
11 Levels of Maternal Care | ACOG. Accessed March 26, 2022 at: https://www.acog.org/clinical/clinical-guidance/obstetric-care-consensus/articles/2019/08/levels-of-maternal-care
12 Meuli RL, Cohen LJ. Regionalization of perinatal care. West J Med 1984;141(05):695–697
13 Hein HA. Regionalized perinatal care in North America. Semin Neonatol 2004;9(02):111–116
14 Hein HA. Regionalization of perinatal health care: a lesson learned but lost. J Perinatol 1999;19(8 Pt 1):584–588
15 The Regionalized Perinatal Care Program - RWJF Accessed October 14, 2021 at: https://www.rwjf.org/en/library/research/2001/01/to-improve-health-and-health-care-2001/the-regionalized-perinatal-care-program.html
16 The Dartmouth Atlas of Neonatal Intensive Care Accessed December 10, 2021 at: https://www.dartmouthatlas.org/Neonatal_Atlas_090419.pdf
17 Gould JB, Marks AR, Chavez G. Expansion of community-based perinatal care in California. J Perinatol 2002;22(08):630–640
18 Haberland CA, Phibbs CS, Baker LC. Effect of opening midlevel neonatal intensive care units on the location of low birth weight births in California. Pediatrics 2006;118(06):e1667–e1679
19 HCUP-US NIS Overview Accessed January 12, 2020 at: https://www.hcup-us.ahrq.gov/nisoverview.jsp
20 HCUP NIS Trend Weights. Healthcare Cost and Utilization Project (HCUP). Published 2015. Accessed January 12, 2019 at: https://www.hcup-us.ahrq.gov/db/nation/nis/trendwghts.jsp
21 Kourtis AP, Bansil P, Posner SF, Johnson C, Jamieson DJ. Trends in hospitalizations of HIV-infected children and adolescents in the United States: analysis of data from the 1994-2003 Nationwide Inpatient Sample. Pediatrics 2007;120(02):e236–e243
22 Zickafoose JS, Benneyworth BD, Riebschleger MP, Espinosa CM, Davis MM. Hospitalizations for intussusception before and after the reintroduction of rotavirus vaccine in the United States. Arch Pediatr Adolesc Med 2012;166(04):350–355
23 Hirai AH, Ko JY, Owens PL, Stocks C, Patrick SW. Neonatal Abstinence Syndrome and Maternal Opioid-Related Diagnoses in the US, 2010-2017. JAMA 2021;325(02):146–155
24 Donda K, Vijayakanthi N, Dapaah-Siakwan F, Bhatt P, Rastogi D, Rastogi S. Trends in epidemiology and outcomes of respiratory distress syndrome in the United States. Pediatr Pulmonol 2019;54(04):405–414
25 Donda K, Sharma M, Amponsah JK, et al. Trends in the incidence, mortality, and cost of neonatal herpes simplex virus hospitalizations in the United States from 2003 to 2014. J Perinatol 2019;39(05):697–707
26 Shankaran S, Fanaroff AA, Wright LL, et al. Risk factors for early death among extremely low-birth-weight infants. Am J Obstet Gynecol 2002;186(04):796–802
27 Bhatt P, Lekshminarayanan A, Donda K, et al. National trends in neonatal extracorporeal membrane oxygenation in the United States. J Perinatol 2018;38(08):1106–1113
28 Jiang S, Huang X, Zhang L, et al; Reduction of Infection in Neonatal Intensive Care Units Using the Evidence-Based Practice for Improving Quality (REIN-EPIQ) Study Group. Estimated survival and major comorbidities of very preterm infants discharged against medical advice vs treated with intensive care in China. JAMA Netw Open 2021;4(06):e2113197–e2113197
29 Anderson JG, Baer RJ, Partridge JC, et al. Survival and major morbidity of extremely preterm infants: a population-based study. Pediatrics 2016;138(01):e20154434
30 Zhu Z, Yuan L, Wang J, et al. Mortality and morbidity of infants born extremely preterm at tertiary medical centers in China from 2010 to 2019. JAMA Netw Open 2021;4(05):e219382–e219382
31 Edstedt Bonamy AK, Zeitlin J, Piedvache A, et al; Epice Research Group. Wide variation in severe neonatal morbidity among very preterm infants in European regions. Arch Dis Child Fetal Neonatal Ed 2019;104(01):F36–F45
32 Shafey A, Bashir RA, Shah P, Synnes A, Yang J, Kelly ENCanadian Neonatal Network and Canadian Neonatal Follow-Up Network Investigators. Outcomes and resource usage of infants born at ≤ 25 weeks gestation in Canada. Paediatr Child Health 2020;25(04):207–215
33 Lui K, Lee SK, Kusuda S, et al; International Network for Evaluation of Outcomes (iNeo) of neonates Investigators. Trends in outcomes for neonates born very preterm and very low birth weight in 11 high-income countries. J Pediatr 2019;215:32–40.e14
34 Ancel PY, Goffinet F, Kuhn P, et al; EPIPAGE-2 Writing Group. Survival and morbidity of preterm children born at 22 through 34 weeks' gestation in France in 2011: results of the EPIPAGE-2 cohort study. JAMA Pediatr 2015;169(03):230–238
35 Costeloe KL, Hennessy EM, Haider S, Stacey F, Marlow N, Draper ES. Short term outcomes after extreme preterm birth in England: comparison of two birth cohorts in 1995 and 2006 (the EPICure studies). BMJ 2012;345(7886):e7976
36 Bonet M, Cuttini M, Piedvache A, et al; MOSAIC and EPICE research groups. Changes in management policies for extremely preterm births and neonatal outcomes from 2003 to 2012: two population-based studies in ten European regions. BJOG 2017;124(10):1595–1604
37 Maier RF, Blondel B, Piedvache A, et al; MOSAIC and EPICE Research Groups. Duration and time trends in hospital stay for very preterm infants differ across European regions. Pediatr Crit Care Med 2018;19(12):1153–1161
38 Rysavy MA, Tyson JE, Stoll BJ. Changing outcomes, changing policies for periviable births. BJOG 2017;124(10):1605–1605
39 Korst LM, Feldman DS, Bollman DL, et al. Variation in childbirth services in California: a cross-sectional survey of childbirth hospitals. Am J Obstet Gynecol 2015;213(04):523.e1–523.e8
40 Hatch LD, Scott TA, Walsh WF, Goldin AB, Blakely ML, Patrick SW. National and regional trends in gastrostomy in very low birth weight infants in the USA: 2000-2012. J Perinatol 2018;38(09):1270–1276
41 Boakye W, Biney B, Preko E, Poku FA, Anim-Koranteng C, Donda K, Nkrumah-Ababio N, Dapaah-Siakwan F. Inpatient burden and resource use in preterm infants with bronchopulmonary dysplasia undergoing gastrostomy tube placement. The American Journal of Gastroenterology 2021;116:S590–S591
42 Mori R, Kusuda S, Fujimura MNeonatal Research Network Japan. Antenatal corticosteroids promote survival of extremely preterm infants born at 22 to 23 weeks of gestation. J Pediatr 2011;159(01):110–114.e1
43 Rossi RM, DeFranco EA, Hall ES. Association of antenatal corticosteroid exposure and infant survival at 22 and 23 Weeks. Am J Perinatol 2021(November):. Doi: 10.1055/S-0041-1740062

