



Pediatrics

Presented at the Academic Surgical Congress 2018

## The disproportionate cost of operation and congenital anomalies in infancy



Jordan C. Apfeld, MD<sup>a,b,\*</sup>, Zachary J. Kastenber, MD<sup>a,c</sup>, Alexander T. Gibbons, MD<sup>b</sup>, Ciaran S. Phibbs, PhD<sup>d,e</sup>, Henry C. Lee, MD<sup>d,f</sup>, Karl G. Sylvester, MD<sup>a,d,g</sup>

<sup>a</sup> Department of Surgery, Stanford University School of Medicine, CA, USA

<sup>b</sup> Department of Surgery, Cleveland Clinic Foundation, OH, USA

<sup>c</sup> Center for Health Policy/Center for Primary Care and Outcomes Research, Stanford University School of Medicine, CA, USA

<sup>d</sup> Department of Pediatrics, Stanford University School of Medicine, CA, USA

<sup>e</sup> Health Economics Resource Center and Center for Implementation to Innovation, Veterans Affairs Palo Alto Healthcare System, Menlo Park, CA, USA

<sup>f</sup> California Perinatal Quality Care Collaborative (CPQCC), Stanford, USA

<sup>g</sup> Fetal and Pregnancy Health Program, Lucile Packard Children's Hospital, Stanford University School of Medicine, CA, USA

### ARTICLE INFO

#### Article history:

Accepted 27 December 2018

Available online 3 May 2019

### ABSTRACT

**Background:** Congenital anomalies are the leading cause of infant death and pediatric hospitalization, but existing estimates of the associated costs of health care are either cross-sectional surveys or economic projections. We sought to determine the percent of total hospital health care expenditures attributable to major anomalies requiring surgery within the first year of life.

**Methods:** Utilizing comprehensive California statewide data from 2008 to 2012, cohorts of infants undergoing major surgery, with birth defects and with surgical anomalies, were constructed alongside a referent group of newborns with no anomalies or operations. Cost-to-charge and physician fee ratios were used to estimate hospital and professional costs, respectively. For each cohort, costs were broken down according to admission, birth episode, and first year of life, with additional stratifications by birth weight, gestational age, and organ system.

**Results:** In total, 68,126 of 2,205,070 infants (3.1%) underwent major surgery ( $n = 32,614$ ) or had a diagnosis of a severe congenital anomaly ( $n = 57,793$ ). These accounted for \$7.7 billion of the \$18.9 billion (40.7%) of the total health care costs/expenditures of the first-year-of-life hospitalizations, \$7.0 billion (48.6%) of the costs for infants with comparatively long birth episodes, and \$5.2 billion (54.7%) of the total neonatal intensive care unit admission costs. Infants with surgical anomalies ( $n = 21,264$ ) totaled \$4.1 billion (21.7%) at \$80,872 per infant. Cardiovascular and gastrointestinal diseases accounted for most admission costs secondary to major surgery or congenital anomalies.

**Conclusion:** In a population-based cohort of infant births compared with other critically ill neonates, surgical congenital anomalies are disproportionately costly within the United States health care system. The care of these infants, half of whom are covered by Medi-Cal or Medicaid, stands as a particular focus in an age of reform of health care payments.

© 2019 Elsevier Inc. All rights reserved.

### Background

Two-thirds of infant deaths occur within the first month after birth, and in the United States, congenital anomalies are the leading cause of pediatric hospitalization and death during the first year of

life.<sup>1,2</sup> Of live births, 3% are associated with birth defects that account for 20% of infant deaths.<sup>3</sup> Birth defects are also the fifth-leading cause of years of potential life lost.<sup>4</sup> Depending on the complexity of the anomaly, perinatal medical or operative intervention may be required.<sup>5</sup>

Through continued innovation in neonatal intensive care throughout the past several decades, the number of liveborn, high-acuity congenital anomalies and associated first-year-of-life operations have increased substantially.<sup>6,7,8</sup> Complex birth defects are often accompanied by systemic health problems that represent a

\* Reprint requests: Jordan C. Apfeld, MD, Department of General Surgery, Cleveland Clinic Foundation, 9500 Euclid Ave, Cleveland, OH 44195, USA.

E-mail address: [apfeldj@ccf.org](mailto:apfeldj@ccf.org) (J.C. Apfeld).

substantial overall socioeconomic burden.<sup>9,10</sup> For example, major structural anomalies requiring immediate operation, such as gastroschisis, omphalocele, critical congenital heart disease (CHD), tracheoesophageal fistula (TEF), and congenital diaphragmatic hernia (CDH), are associated with frequent and expensive hospital stays.<sup>2,11</sup>

In 2003, overall newborn hospital costs were estimated at \$10 billion in the United States, and these costs have likely increased alongside the technologic advances in neonatal care.<sup>12</sup> For congenital anomalies, with less available data, costs were estimated at \$6.3 billion in 1980 (or 1% of the nation's total health care costs).<sup>13</sup> By 1992, the costs attributed to major birth defects increased to greater than \$8 billion.<sup>14</sup> In 2013, the costs for birth defects reached \$22.9 billion and accounted for 3% of all hospitalizations and 5% of total hospital costs.<sup>15</sup> Several cost studies have focused on individual birth defects. A 1995 study estimated the average cost-per-birth admissions for an infant with congenital diaphragmatic hernia was \$137,000, accounting for more than \$230 million total annually.<sup>16</sup> A 2015 study on gastroschisis calculated the average hospital charge per patient at greater than \$180,000.<sup>17</sup>

A recent report by the Centers for Disease Control and Prevention (CDC) on the costs of hospitalization for birth defects was large in scope but narrow in precision, reporting that the greatest proportion of total costs, but lowest median costs, of admission occurred within the first year of life.<sup>18</sup> These findings possibly reflect overinclusive selection criteria using the larger ICD-9-CM

code range for congenital anomalies. Furthermore, in an age of global payments, it has proven difficult to isolate the admission costs associated with infant surgery, birth defects, or surgical anomalies in particular. Earlier cost analyses of preterm and low birthweight infants excluded surgical anomalies as outliers. Similarly, debate continues around the relative medical costs versus surgical costs for premature infants with complex anomalies.<sup>9,19,20</sup>

Taken together, earlier literature documents the substantial and increasing cost burden of birth defects overall and for specific, complex anomalies requiring operation. Nevertheless, a modern population-based analysis of total, first-year-of-life hospital costs associated with congenital anomalies, operations, and more precisely, surgical anomalies is lacking. In this study, we provide a comprehensive analysis of hospital costs associated with surgical birth defects in the State of California, which accounts for greater than 12% of all US births. We hypothesized that infants with surgical anomalies would be the most costly in the first year in comparison with other sick infants, and that the costs of operation would be the main contributor to these disproportionately high costs.

**Methods**

We obtained a population-based cohort of all births in California for 2008–2012, using the most updated Vital Statistics-Patient Discharge Database collected by the California Office of Statewide Planning and Development (OSHPD). The records of infant birth

Cohort Group	SURGICAL PROCEDURE COHORTS		CONGENITAL ANOMALY COHORTS		SURGICAL ANOMALY <i>COMBINED</i> COHORTS	
Cohort Letter	Cohort A	Cohort B	Cohort C	Cohort D	Cohort E	Cohort F
Cohort Name	All Invasive Procedures / Surgeries	Major Invasive Procedures / Surgeries, (requiring an operating room)	All Surgical Congenital Anomalies	Major Surgical Congenital Anomalies (significant mortality risk)*	Major Anomaly OR Major Surgery**	Major Anomaly AND Major Surgery***
Cohort Definition	<b>Included:</b> All diagnostic or therapeutic procedures considered invasive, using consultation/expert opinion in pediatric surgery and neonatology  <b>Not Included:</b> All radiologic studies; infusions/transfusions; vaccinations; circumcisions; frenotomies; catheterizations; spinal taps; routine postnatal procedures; mech. ventilation	<b>Included:</b> Major diagnostic or therapeutic requiring an operating room, per the classification system used by the Agency for Healthcare Research & Quality Healthcare Cost and Utilization Project †  <b>Excluded:</b> minor diagnostic or therapeutic procedures according to the AHRQ-HCUP; circumcisions	<b>Included:</b> Major structural congenital anomalies, per the Metropolitan Atlanta Congenital Defects Program (MACDP) coding system ††  <b>Excluded:</b> minor/excluded anomalies in MACDP coding system, common non-severe skin anomalies, anomalies rarely requiring surgery in 1 <sup>st</sup> year of life	<b>Included:</b> Major structural congenital anomalies (MACDP) that have significant mortality risk, according to a 2007 NEJM publication using the same Californian patient sample. †††  <b>Excluded:</b> Same as Cohort C	<b>Included:</b> If infant was in either Cohort B or Cohort D  <b>Excluded:</b> None.	<b>Included:</b> If infant was in both Cohort B and Cohort D (i.e. linked through the same admission)  <b>Excluded:</b> Infant in either Cohort B or Cohort D, but not in both; infants in both but <i>not</i> linked through identical admissions
Top 10 most frequent qualifying diagnoses (if applicable)	• N/A	• N/A	• Patent ductus arteriosus • Ostium secundum type ASD • Ventricular septal defect • Vascular hamartomas • Undescended testis • Obstructive defects of kidney/ureter • Hypospadias • Other specified CHDs • Other anomalies of larynx, trachea, and bronchus • Anomalies of skull/face bones	• Obstructive defects of kidney/ureter • Other specified CHDs • Other anomalies of larynx, trachea, and bronchus • Anomalies of skull/face bones • Hypertrophic pyloric stenosis • Coarctation of aorta • Tetralogy of Fallot • Atresia/stenosis, large bowel • Congenital musculoskeletal deformities of skull/jaw • Congenital hydrocephalus	• Obstructive defects of kidney/ureter • Other specified CHDs • Coarctation of aorta • Anomalies of skull/face bones • Hypertrophic pyloric stenosis • Aortic coarctation • Tetralogy of Fallot • Atresia/stenosis, large bowel • Congenital musculoskeletal deformities of skull, face, jaw • Congenital hydrocephalus	• Hypertrophic pyloric stenosis • Other specified CHDs • Anomalies of skull/face bones • Coarctation of aorta • Atresia and stenosis of large bowel, rectum, and anal canal • Other anomalies of larynx, trachea, and bronchus • Obstructive defects of kidney/ureter • Tetralogy of Fallot • Atresia/stenosis of small bowel • Anomalies of intestinal fixation
Top 10 most frequent qualifying procedures / surgeries (if applicable)	• Surgical occlusion of vessels, thoracic vessels † • Extracorporeal circulation auxiliary to open heart surgery • Pyloromyotomy • Laryngoscopy / tracheoscopy • Intercostal catheter for drainage • Other gastrostomy • Incision/drainage of skin/tissue • Other bronchoscopy • Other resection of small bowel • Myringotomy / insertion of tube	• Surgical occlusion of vessels, thoracic vessels • Pyloromyotomy • Partial resection of small bowel • Myringotomy w/ tube insertion • Repair of gastrostomy • Repair of atrial septal defect • Systemic-pulmon. artery shunt • Repair of cleft lip • Ventricular shunt to abdominal cavity and organs • Laparoscopy	• N/A	• N/A	• Surgical occlusion of vessels, thoracic vessels • Pyloromyotomy • Partial resection of small bowel • Myringotomy w/ tube insertion • Repair of gastrostomy • Repair of atrial septal defect • Systemic-pulmonary artery shunt • Repair of cleft lip • Ventricular shunt to abdominal cavity and organs • Laparoscopy	• Pyloromyotomy • Surgical occlusion of vessels, thoracic vessels • Repair of gastrostomy • Myringotomy w/ tube insertion • Repair of atrial septal defect • Systemic-pulmonary artery shunt • Other repair of chest wall • Partial resection, small bowel • Correction of cleft palate/lip • Ventricular shunt to abdominal cavity/organs
ANALYSIS	* "Other congenital anomalies" was removed from the table as a common but nondescript diagnosis ** By definition, the most common diagnoses/surgeries in Cohort E are the same as in Cohorts B and D *** For Cohorts E/F, repair surgery for ASD/VSDs were included, but birth defect diagnoses of ASD/VSDs were not included, as only first-year surgery for these diagnoses would indicate a defect requiring medically-necessary care in the first year of life † HCUP Procedure Classes. Healthcare Cost and Utilization Project (HCUP). †† Metropolitan Atlanta Congenital Defects Program (MACDP). Birth Defects and Genetic Diseases Branch 6-Digit Code, For Reportable Congenital Anomalies, Version 08/07, 2007. ††† Phibbs et al. Level and Volume of Neonatal Intensive Care and Mortality in Very-Low-Birth-Weight Infants. Supplementary Appendices. New England Journal of Medicine, 2007;(21):2165-2175. ‡ Most likely coincided with open heart surgery					

**Fig 1.** Description of cohort selection criteria, with the most common qualifying diagnoses and operations and procedures.

certificates were linked probabilistically to their discharge data through each intrahospital or interhospital transfer and for subsequent readmissions. This represented approximately 95% successful linkage.<sup>21</sup> This approach allowed us to obtain near-complete information on infant demographics and corresponding administrative discharge data through the first year of life. This database was subsequently linked with data collected by the California Perinatal Quality Care Collaborative (CPQCC) to identify admissions to a neonatal intensive care unit (NICU).

A series of infant cohorts were collected according to admission-specific discharge codes, using the International Classification of Diseases, 9th edition, Clinical Modification (ICD-CM-9).<sup>22</sup> For the surgical admission cohort A, we included infants receiving invasive diagnostic or therapeutic procedures, excluding routine postnatal procedures and operations (ie, circumcisions, frenotomies, hearing tests), blood draws, catheterizations, radiologic studies, vaccinations, and spinal taps. For a more focused cohort B, we included only major procedures requiring an operating room, according to the classification system used by the Agency for Healthcare Research and Quality-Healthcare Cost and Utilization Project (AHRQ-HCUP).<sup>23</sup> As a quality check, the list of codes in our cohorts were tabulated from most to least frequent or costly, after which a

panel of pediatric surgeons and neonatologists reviewed and excluded codes that did not conform with or satisfy our research topic. The final results of this process are represented in the Figure 1 (for frequencies), showing the codes that in theory could skew the data.

For the larger congenital anomaly cohort C, we included all major structural birth defects, including most of the ICD-9 codes used for tracking by the Metropolitan Atlanta Congenital Defects Program (MACDP),<sup>24</sup> excluding skin anomalies and birth defects rarely requiring operative therapy in the first year. For a more focused cohort D, we only included MACDP anomalies that pose a substantial mortality risk, using validated methodology for excluding major birth defects.<sup>25</sup> The Figure presents a full description of inclusion and exclusion criteria for all cohorts alongside examples of the most frequent qualifying diagnoses and procedures. In Supplementary Figure 1, we include our list of anomalies made up of the focused anomaly cohort D. The longer list of HCUP major operations (cohort B) is publicly available.<sup>23</sup>

We additionally prepared two “combined” cohorts. The largest (cohort E) selected both infant admissions involving major surgical procedures in the operating room (cohort B) and admissions for major congenital anomalies with a mortality risk (cohort D). The

**Table 1**  
Infant demographic, admission, and cost data for surgical congenital anomaly cohorts in California, 2008–2012

	All infants	Isolated cohorts		Combined cohorts	
		Major surgical procedures (cohort B)	Major congenital anomalies (cohort D)	Major surgery or major congenital anomaly (cohort E)	Major surgery and major congenital anomaly (cohort F)
<b>Infant counts</b>					
Infants (total number)	2,205,070	32,614	57,793	68,126	21,264
Birth weight (%) <sup>*</sup>					
Normal birth weight	2,039,495 (93.2)	22,463 (73.3)	42,933 (77.1)	49,149 (75.1)	15,721 (79.1)
Low birth weight	124,058 (5.7)	4,372 (14.3)	8,022 (14.4)	8,989 (13.7)	2,700 (13.6)
Very low birth weight	23,955 (1.1)	3,792 (12.4)	4,715 (8.5)	7,280 (11.1)	1,452 (7.3)
Gestational age (%) <sup>*</sup>					
Full term	1,915,596 (89.7)	21,083 (69.9)	40,643 (74.2)	46,408 (72.1)	14,825 (75.7)
Preterm	186,509 (8.7)	4,521 (15.0)	9,003 (16.4)	10,168 (15.8)	3,222 (16.5)
Early preterm	34,493 (1.6)	4,541 (15.1)	5,094 (9.3)	7,749 (12.0)	1,524 (7.8)
<b>Admission data</b>					
Hospital presentations (total number) <sup>†</sup>	3,877,314	115,667	163,775	197,554	77,322
Other hospital presentations:					
Emergency department visits (no cost data)	1,368,959	30,685	46,489	56,181	19,907
Ambulatory surgery visits (no cost data)	32,315	4,255	5,820	6,885	3,011
Infant transfers (no cost data)	61,781	10,304	14,314	17,358	7,260
Admissions (row %) <sup>‡</sup>					
Indexed through birth episode	2,387,301	67,130	96,607	115,949	45,077
Indexed through first year of life	2,462,190	83,882	113,766	137,677	56,619
Indexed to admission (first year)	2,462,190	37,355	76,833	89,724	24,464
<b>Cost data</b>					
Total costs, indexed for: <sup>‡</sup>					
Birth episode (to admission; US\$ billion)	16.9	4.3	4.5	5.9	2.9
Birth episode (entire; US\$ billion)	16.9	5.1	5.0	6.5	3.3
First year of life (to admission; US\$ billion)	18.9	5.1	5.3	7.0	3.5
First year of life (entire; US\$ billion)	18.9	6.1	6.0	7.7	4.1
Total costs for MediCal admissions (total number of admissions; US\$ billion)	9.7 (n = 1,373,013)	2.5 (n = 19,621)	2.7 (n = 42,218)	3.5 (n = 48,878)	1.7 (n = 12,961)
Total costs, non-MediCal admissions (total number of admissions; US\$ billion)	9.2 (n = 1,089,177)	2.6 (n = 17,735)	2.6 (n = 34,615)	3.5 (n = 40,847)	1.8 (n = 11,503)
<b>Infant admission costs (US\$)</b>					
Mean cost/admission	7,870	145,403	72,258	81,197	150,525
Median cost/admission	1,298	43,794	13,583	14,984	55,900
Median cost/day/admission (median length-of-stay/birth episode)	630/day	6,335/day (10 days)	3,431/day (7 days)	3,819/day (6 days)	6,638/day (20 days)
Median cost per infant (birth episode)	1,238	44,781	13,292	14,764	53,621
Median cost/infant (first year)	1,290	70,982	21,574	14,983	80,872

<sup>\*</sup> Information for birth weight and gestational age presented is for infants with complete demographic information in either of the OSHPD or CPQCC databases.

<sup>†</sup> Includes total admissions, emergency department visits, and ambulatory surgery (AS) visits. These visits do not have available cost data, and thus were not analyzed.

<sup>‡</sup> For complete description on how admissions and costs are broken down, see Supplementary Fig 1.

smallest (cohort E) included only visits with corresponding major anomalies and major operations performed. Finally, a control cohort excluded all admissions coded for major anomalies or major operations. The makeup of all major birth defect cohorts were means tested through comparison with the more rigorous CPQCC coding for congenital anomalies in the NICU setting.

Birth weight (BW) and estimated gestational age (GA) were recorded from vital statistics records of each infant and hospital charges from administrative data. Admissions with missing charges were excluded. A total of 84% of admissions occurred at hospitals operated by the Kaiser Permanente health system, which does not report financial data to OSHPD. Facility costs were computed through implementation of OSHPD-validated, hospital-specific, cost-to-charge ratios.<sup>26</sup> Hospital physician fees were estimated through implementation of a professional fee ratio based on the diagnosis related group of the infant, modified for whether an infant was covered by a private payer or public insurance (ie, Medi-Cal in California). Total costs were adjusted for changes in the Consumer Price Index.<sup>27</sup>

For qualifying infants in each cohort, we computed total infant counts, hospital presentations, and hospital admissions. For each qualifying cohort, admissions were further categorized as being within the initial birth episode until death or discharge home or as readmissions. Total, mean, median, and daily admission costs were calculated specific to the indexing admission but also extrapolated through the birth episode and through the first year-of-life (Supplementary Fig 2). For each cohort, BWs and GAs were recorded. Costs were examined more closely after categorizing infants into the following three groups: (1) BW > 2,499 g and GA > 36 weeks; (2) 1,499 g < BW < 2,500 g or 31 weeks < GA < 37 weeks; and (3) BW < 1,500 g or GA < 32 weeks. Analysis was performed using SAS v 9.4 (SAS Institute, Cary, NC, USA).

**Results**

*Infant counts*

From 2008 to 2012 in California, 2,205,070 infants were treated, 93.2% of whom were normal BW >2,499 g, 5.7% low BW (1,500 g–2,499g), and 1.1% very low BW (<1,500 g). Infants were 89.7% full term (≥37 weeks), 8.7% preterm (32–36 weeks), and 1.6% early preterm (<32 weeks). The vast majority of infants never had an operation or a diagnosis of a congenital anomaly (97%, n = 2,136,867). Of the 45,778 infants who received an invasive surgical procedure (cohort A), we analyzed 32,614 who had major operations requiring an operating room (cohort B). Of the 28,082 infants who had potentially surgical congenital anomalies (cohort C), we analyzed 57,793 with birth defects associated with a substantial mortality risk (cohort D). A total of 68,126 infants had major operations or major congenital anomalies (cohort E), and 21,264 who had a coinciding major operation and a major anomaly in the same admission (ie, surgical anomalies, cohort F; Table 1).

*Admissions*

After removing emergency department visits (n = 1,368,959), ambulatory surgery visits (n = 32,315), and other admissions without administrative charge data (n = 437,915), there were a total of 2,462,190 hospital admissions, 97.0% of which (n = 2,387,301) were during the birth episode and 3.0% of which were readmissions (n = 74,889). There were a total of 61,781 interhospital transfers and 69,276 NICU admissions. There were 89,724 admissions for either major congenital anomalies or major operations (cohort E) and 24,464 admissions for both major congenital anomalies and

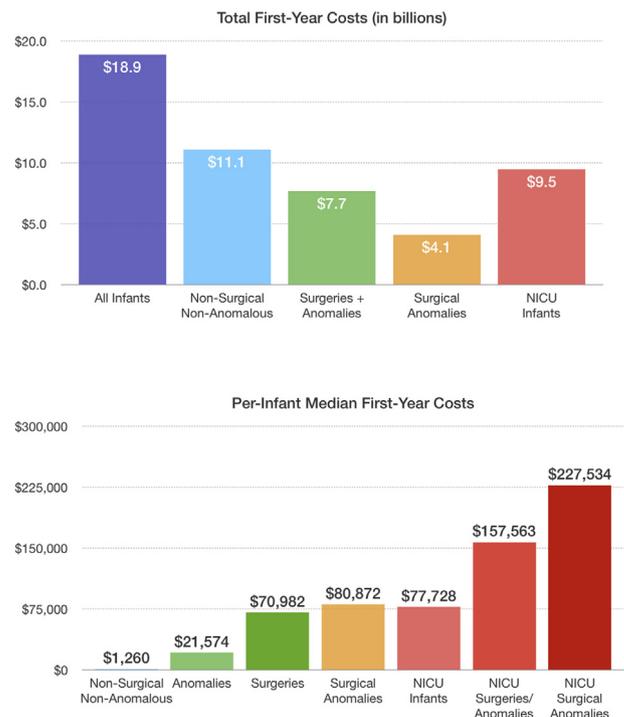
major operations (cohort F). Supplementary Table I includes data for the less-focused and NICU subcohorts.

*Overall costs*

Total hospital charges during 2008 to 2012 were \$56.2 billion, involving \$16.9 billion in birth-episode costs and \$18.9 billion in total first-year admission costs. Public-payer (ie, Medi-Cal) patients cost \$9.7 billion, and private or other payers cost \$9.2 billion. Infants never undergoing major operation or a major birth defect diagnosis totaled \$11.1 billion. Costs for infants with major operations (cohort B) totaled \$6.1 billion, at a median daily inpatient cost of \$6,335, median admission cost of \$43,794, and median first-year costs of \$70,982 per infant. Costs for major anomalies (cohort D) totaled \$6.0 billion, at \$3,431 per day, \$13,583 per admission, and \$21,574 per infant. For the combined surgery or anomaly group (cohort E), total costs were \$7.7 billion. For the combined surgery and anomaly group (cohort F), total costs were \$4.1 billion, at \$6,638 per day, \$55,900 per admission, and \$80,872 per infant. Figure 2 depicts total first-year costs as well as per-infant median first-year costs amongst the cohorts.

*Cost tabulation and comparisons*

Table II presents a breakdown of birth episode and first-year costs for the control cohort versus infants having major surgery or a major birth defect (cohorts E and F), additionally categorized by BW and GA. High-cost groups included full-term infants with BW > 2,500 g, no major operations, and no major anomalies, accounting for \$4.1 billion. Infants who were early-preterm or very-low BW had birth episode costs of \$3.2 billion in the control cohort (n = 29,377; \$72,165/infant) and \$3.1 billion in cohort E (ie, major surgery or anomaly; n = 8,410; \$289,445/infant). The most costly infants were very-low BW or early-preterm infants with surgical



**Fig 2.** Bar chart showing cumulative total first-year costs (in billions) across the different infant cohorts (top chart), and then the comparative first-year per-infant median costs (in dollars) across the wider series of cohorts (bottom chart).

**Table II**  
Tabulation of total infant costs and admission costs, according to birth weight and gestational age

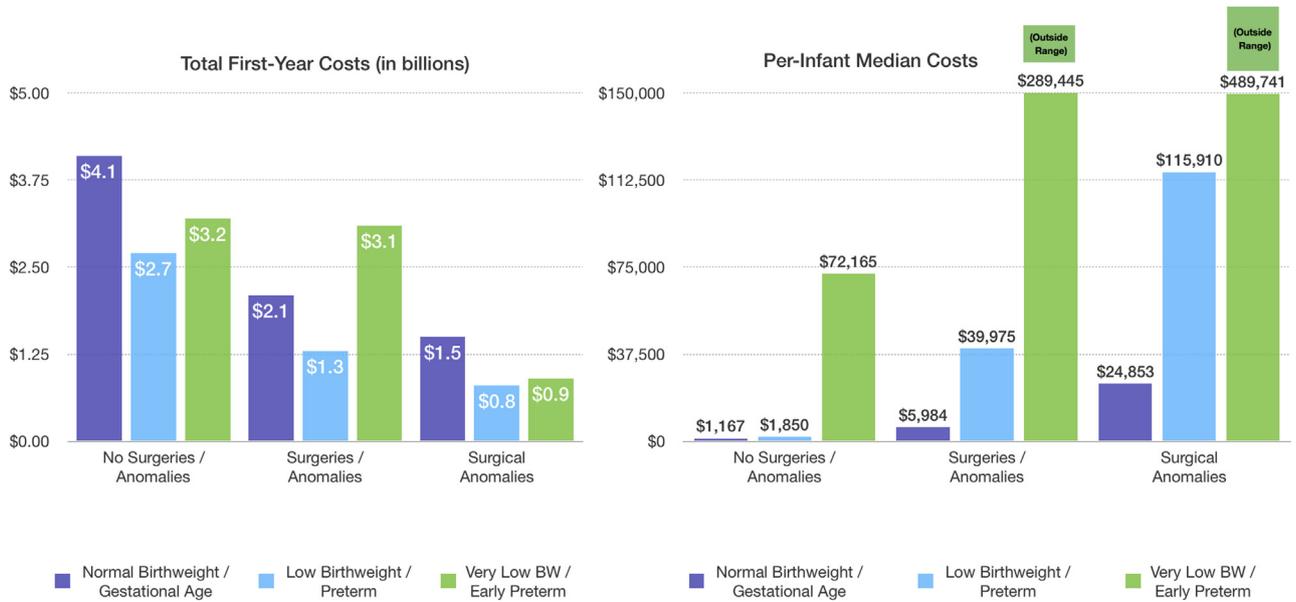
Birth episode costs by birth weight* / gestational age:	All infants <sup>†</sup> (indexed to diagnosis/procedure; US\$)			All admissions <sup>‡</sup> (isolated for diagnosis/procedure; US\$)		
	No major surgery and no major congenital anomaly (control)	Major surgery or major congenital anomaly (cohort E)	Major surgery and major congenital anomaly (cohort F)	No major surgery and no major congenital anomaly (control)	Major surgery or major congenital anomaly (cohort E)	Major surgery and major congenital anomaly (cohort F)
Birth weight >2499 g and Gestational age >36 weeks	<i>N</i> = 1,823,243 (88.0%) Total costs: 4.1 billion median cost: 1,167 daily cost: 582	<i>N</i> = 43,584 (67.8%) Total costs: 2.1 billion median cost: 5,984 daily cost: 1,606	<i>N</i> (%) = 13,960 (71.3%) Total costs: 1.5 billion median cost: 24,853 daily cost: 3,542	<i>N</i> = 1,915,343 (87.2%) Total costs: 4.2 billion median cost: 1,168 daily cost: 585	<i>N</i> = 42,368 (64.0%) Total costs: 1.9 billion median cost: 8,481 daily cost: 2,804	<i>N</i> = 10,172 (66.8%) Total costs: 1.3 billion median cost: 58,127 daily cost: 6,505
1499 g < birth weight < 2500 g or 31 weeks < EGA < 37 weeks	<i>N</i> = 219,623 (10.6%) Total costs: 2.7 billion median cost: 1,850 daily cost: 750	<i>N</i> = 12,282 (19.1%) Total costs: 1.3 billion median cost: 39,975 daily cost: 2,977	<i>N</i> (%) = 3,934 (20.1%) Total costs: 0.8 billion median cost: 115,910 daily cost: 4,263	<i>N</i> = 243,046 (11.1%) Total costs: 2.8 billion median cost: 1,811 daily cost: 769	<i>N</i> = 14,004 (21.2%) Total costs: 1.2 billion median cost: 27,147 daily cost: 3,622	<i>N</i> = 3,364 (22.1%) Total costs: 0.7 billion median cost: 123,043 daily cost: 5,486
Birth weight < 1,500 g or Gestational age < 32 weeks	<i>N</i> = 29,377 (1.4%) Total costs: 3.2 billion median cost: 72,165 daily cost: 2,411	<i>N</i> = 8,410 (13.1%) Total costs: 3.1 billion median cost: 289,445 daily cost: 4,203	<i>N</i> = 1,676 (8.6%) Total costs: 0.9 billion median cost: 489,741 daily cost: 4,886	<i>N</i> = 38,854 (1.8%) Total costs: 3.6 billion median cost: 50,763 daily cost: 2,559	<i>N</i> = 9,784 (14.8%) Total costs: 2.7 billion median cost: 183,406 daily cost: 4,658	<i>N</i> = 1,684 (11.1%) Total costs: 0.8 billion median cost: 383,434 daily cost: 5,514
Demographics missing	<i>N</i> = 64,624 infants Total costs: 0.2 billion	<i>N</i> = 3,850 infants Total costs: 0.2 billion	<i>N</i> = 1,694 infants Total costs: 0.1 billion	<i>N</i> = 68,575 admissions Total costs: 0.3 billion	<i>N</i> = 3,279 admissions Total costs: 0.2 billion	<i>N</i> = 1,265 admissions Total costs: 0.1 billion
Readmission costs	<i>N</i> = 91,995 infants Total costs: 0.9 billion	<i>N</i> = 15,860 infants Total costs: 1.1 billion	<i>N</i> = 7,939 infants Total costs: 0.7 billion	<i>N</i> = 101,129 admissions Total costs: 0.9 billion	<i>N</i> = 18,906 admissions Total costs: 1.0 billion	<i>N</i> = 7,979 admissions Total costs: 0.6 billion
<b>Cost totals</b>						
Birth episode US\$16.9 billion	10.4 billion (61.5%) ( <i>n</i> = 2,120,995)	6.5 billion (38.5%) ( <i>N</i> = 55,860)	3.3 billion (19.5%) ( <i>N</i> = 15,105)	11.0 billion (65.1%) ( <i>N</i> = 2,265,818)	5.9 billion (34.9%) ( <i>N</i> = 69,435)	2.9 billion (17.2%) ( <i>N</i> = 16,485)
First year US\$18.9 billion	11.2 billion (59.3%) ( <i>n</i> = 2,136,867)	7.7 billion (40.7%) ( <i>N</i> = 68,125)	4.1 billion (21.7%) ( <i>N</i> = 21,264)	11.9 billion (63.0%) ( <i>N</i> = 2,374,501)	7.0 billion (37.0%) ( <i>N</i> = 89,724)	3.5 billion (18.5%) ( <i>N</i> = 24,464)
Infants with long birth episode US\$14.4 billion	7.4 billion (51.4%) ( <i>n</i> = 173,193)	7.0 billion (48.6%) ( <i>n</i> = 35,645)	3.7 billion (25.7%) ( <i>n</i> = 14,230)	8.1 billion (56.2%) ( <i>n</i> = 266,797)	6.3 billion (43.8%) ( <i>n</i> = 53,238)	3.1 billion (21.5%) ( <i>n</i> = 16,905)
Totals (neonatal intensive care unit subset) US\$8.3 billion (admissions) US\$9.5 billion (first year)	4.3 billion (45.3%) ( <i>n</i> = 41,617)	5.2 billion (54.7%) ( <i>n</i> = 19,469)	2.3 billion (24.2%) ( <i>n</i> = 6,477)	4.0 billion (48.2%) ( <i>n</i> = 46,708)	4.3 billion (51.8%) ( <i>n</i> = 22,568)	1.9 billion (22.9%) ( <i>n</i> = 12,009)

Note: The number of infants (*first panel*) surpasses the number of admissions (*second panel*) when infants are counted in the birth episode after being indexed outside the birth episode. To avoid any potential inflation of costs using nonqualifying admissions for qualifying infants, the second panel represents costs for qualifying admissions.

\* We used 3 categorically-labeled groups using birthweight and gestational age, to represent babies that were not premature, premature, and very premature.

<sup>†</sup> Data (counts, costs) attributed to qualifying *infants*, extrapolated through the birth episode and through the first year (*n* = number of infants).

<sup>‡</sup> Data (counts, costs) attributed to only qualifying *admissions*, removing non-qualifying admission costs from qualifying infants in cohorts E and F, and placing in control cohort (*n* = number of admissions).



**Fig 3.** Bar chart comparing total first-year costs (in billions) for the cohorts of no surgeries/anomalies; combined major surgeries and major anomalies; and coinciding major surgeries and major anomalies (and further broken down by non-premature/premature/very premature) (left chart). The second chart shows comparative first-year per-infant median costs among the same cohorts, also broken down into non-premature / premature / very premature infants (right chart).

anomalies (ie, cohort F;  $n = 1,676$ ; \$489,741/infant; \$383,434/admission), but their total birth-episode costs of \$0.9 billion were surpassed by a larger group of full-term, normal BW infants with surgical anomalies ( $n = 13,960$ ; \$1.5 billion). Figure 3 depicts total first-year costs and per-infant median costs for the infants with and without major surgeries and/or anomalies, broken down by degree of prematurity.

In total, infants undergoing a major surgery or receiving a diagnosis of major birth defect (cohort E) accounted for \$7.7 billion of the \$18.9 billion first-year costs, or 40.7% for extrapolated data. Restricted to qualifying admissions only, cohort E accounted for \$7.0 billion or 37.0% of first-year costs. For infants receiving both a major surgery and a diagnosis of a major birth defect (cohort F), extrapolated costs were 21.7% of first-year costs (\$4.1 billion), and admission-restricted costs were 18.5% of total costs (\$3.5 billion). To examine only infants with long birth episodes, we removed newborns with initial hospital stays of less than 5 days (the 90th percentile), and costs for infants in cohort E increased to 48.6% (\$7.0 billion) and cohort F to 25.7% (\$3.7 billion) of total costs. For infants receiving NICU care, cohort E accounted for 54.7% (\$5.2 billion) and cohort F 24.3% (\$2.3 billion) of costs.

**Cost attribution**

Table III presents admission-level costs for cohort F of \$3.5 billion (ie, major surgery and anomaly;  $n = 24,464$ ) and admission-level costs of \$3.5 billion for cohort E after removing cohort F admissions (ie, isolated major operations or isolated major anomalies;  $n = 65,260$ ), totaling \$7.0 billion ( $n = 89,724$  admissions). Overall, the top quartile of admissions (by cost,  $n = 21,472$  admissions) accounted for 85.7% of the cost (\$6.0/\$7.0 billion) at \$174,386 per admission, 77.1% (\$2.7/\$3.5 billion) within the combined group at \$325,668 per admission, and 88.6% (\$3.1/\$3.5 billion) within the isolated groups for operation at \$302,973 per admission and for anomalies at \$144,342 per admission. Within the isolated group, costs were split evenly between admissions for operations and anomalies, respectively, with surgical admissions significantly less frequent but more costly.

Total admission costs are also broken out by surgical and congenital anomaly organ systems using ICD-9-CM version 1-2 and version 3 grouping, respectively. Admissions for cardiovascular diseases accounted for the greatest proportion of total costs ( $n = 20,093$  diagnoses, \$2.3 billion;  $n = 10,182$  operations, \$2.8 billion), with circulatory diseases leading in almost every category, even after our exclusion of common less-severe anomalies. Individual cardiovascular diagnosis and surgical codes accounted for nearly half of the top-10 lists for admission costs, most notably in the totals column and for cohort F (ie, surgical anomalies). Digestive diseases accounted for the second-greatest proportion of costs ( $n = 15,548$  diagnoses, \$1.3 billion;  $n = 15,927$  surgeries, \$2.4 billion), having less median costs compared with cardiovascular admissions. Individual gastrointestinal diagnosis and surgical codes, however, were also disproportionately featured on the top-10 lists for admission costs.

Other major cost contributors were diagnoses and procedures for thoracic or respiratory diseases, which had some of the greatest median costs but least frequencies ( $n = 8,379$  diagnoses, total \$1.1 billion;  $n = 3,110$  operations, \$1.0 billion); neurologic diseases, which featured “moderate” median costs at “moderate” frequencies ( $n = 8,729$  diagnoses, \$0.8 billion;  $n = 3,531$  operations, \$0.4 billion); and genitourinary diseases, which had low median costs but high frequency ( $n = 13,569$  diagnoses, \$0.8 billion;  $n = 2,171$  operations, \$0.2 billion).

**Discussion**

In this study, we assumed the perspective of the health system or payers to ask about the inpatient costs of newborns in the first year of life. We refrained from commenting on value or outcomes until more rigorous disease-specific population-level outcomes become available. Earlier research into the costs of newborns utilized the following two study designs: (1) tabulating costs by BW and GA, varying incorporating maternal costs;<sup>19,20</sup> and (2) tabulating newborn costs for healthy infants versus those requiring care in the NICU (ie, preterm, low BW).<sup>28,29</sup> Both approaches appropriately exclude infants with operations or congenital anomalies as

**Table III**  
Admissions coded for major operations or congenital anomalies, according to organ system and most costly admissions

	Totals	All admissions coded for major surgeries and major congenital anomalies	
		Major surgery + major anomaly (cohort F)	"Isolated" surgery or "isolated" anomaly (cohort E, after removing cohort F)
<b>Costs (US\$)</b>			
All admissions	<ul style="list-style-type: none"> <li>• N = 89,724</li> <li>• 7.0 billion</li> <li>• 14,984 (median)</li> </ul>	<ul style="list-style-type: none"> <li>• N = 24,464</li> <li>• 3.5 billion</li> <li>• 55,900 (median)</li> </ul>	<ul style="list-style-type: none"> <li>N = 65,260; 3.5 billion</li> <li>• N = 12,892</li> <li>• 1.7 billion</li> <li>N = 15,673; 3.1 billion</li> <li>• N = 5,281 surgeries</li> <li>• 1.6 billion</li> </ul>
Top one-quarter by cost (US\$)	<ul style="list-style-type: none"> <li>• N = 21,472</li> <li>• 6.0 billion</li> <li>• 174,386 (median)</li> </ul>	<ul style="list-style-type: none"> <li>• N = 5,799</li> <li>• 2.7 billion</li> <li>• 325,668 (median)</li> </ul>	<ul style="list-style-type: none"> <li>• N = 52,369 anomalies</li> <li>• 1.8 billion</li> <li>• N = 10,392 anomalies</li> <li>• 1.5 billion</li> </ul>
<b>By surgery (cost US\$)</b>			
All admissions (US\$):	1. Cardiovascular (2.8 billion; n = 10,182)	1. Cardiovascular (1.9 billion; n = 7,232)	1. Cardiovascular (0.9 billion; n = 2,950)
Top 10 operations by organ systems	2. Digestive (2.4 billion; n = 15,927)	2. Digestive (1.7 billion; n = 6,494)	2. Digestive (0.7 billion; n = 9,433)
	3. Respiratory (1.0 billion; n = 3,110)	3. Respiratory (0.8 billion; n = 2,216)	3. Nervous (0.2 billion; n = 1,817)
	4. Nervous (0.4 billion; n = 3,531)	4. Nervous (0.2 billion; n = 1,714)	4. Respiratory (0.2 billion; n = 894)
	5. Musculoskeletal (0.3 billion; n = 2,171)	5. Musculoskeletal (0.2 billion; n = 695)	5. HEENT (0.1 billion; n = 2,804)
	6. HEENT (0.2 billion; n = 3,155)	6. Genitourinary (0.1 billion; n = 1,074)	6. Musculoskeletal (0.1 billion; n = 1,476)
	7. Genitourinary (0.2 billion; n = 2,160)	7. Endocrine (0.07 billion; n = 342)	7. Genitourinary (0.1 billion; n = 1086)
	8. Lymphatic (0.1 billion; n = 288)	8. HEENT (0.07 billion; n = 351)	8. Miscellaneous (0.05 billion; n = 310)
	9. Endocrine (0.1 billion; n = 435)	9. Lymphatic (0.05 billion; n = 91)	9. Lymphatic (0.04 billion; n = 197)
	10. Miscellaneous (0.1 billion; n = 491)	10. Miscellaneous (0.04 billion; n = 181)	10. Endocrine (0.01 mill; n = 93)
Top one-quarter by cost (US\$):	1. Part small bowel resect NEC (n = 1,374)	1. Other chest wall repair (n = 661)	1. Part small bowel resect (n = 645)
Top 10 surgeries*	2. Other periton adhesiolysis (n = 811)	2. Systemic-pulmonary art shunt (n = 603)	2. Small bowel stoma closure (n = 369)
	3. Other chest wall repair (n = 1,084)	3. Part small bowel resect NEC (n = 512)	3. Other periton adhesiolysis (n = 339)
	4. Systemic-pulmonary art shunt (n = 1,115)	4. Other periton adhesiolysis (n = 413)	4. Repair of gastroschisis (n = 711)
	5. Repair of gastroschisis (n = 1,465)	5. Extracorporeal membrane oxygenation (n = 506)	5. Bilat ing hernia repair NOS (n = 227)
	6. Extracorporeal membrane oxygenation (n = 764)	6. Atria septa def repair NEC (n = 373)	6. Ileostomy NOS (n = 178)
	7. Small bowel stoma closure (n = 601)	7. Repair of gastroschisis (n = 354)	7. Temporary ileostomy (n = 147)
	8. Atria septa def repair NEC (n = 1,177)	8. Small bowel stoma closure (n = 236)	8. Ventricle shunt-abdomen (n = 237)
	9. Lap creat esoph sphinct (n = 434)	9. Lap creat esoph sphinct (n = 224)	9. Open bil ind ing hern (n = 125)
	10. Ventricle shunt-abdomen (n = 614)	10. Create cutanperiton fist (n = 195)	10. Incid appendectomy (n = 133)
<b>By diagnosis (cost US\$)</b>			
All admissions (US\$):	1. Cardiovascular (2.3 billion; n = 20,093)	1. Cardiac (1.7 billion; n = 7,472)	1. Circulatory (0.6 billion; n = 12,621)
Top 9 anomalies by organ system	2. Digestive (1.3 billion; n = 15,458)	2. Digestive (1.1 billion; n = 9,723)	2. Genitourinary (0.3 billion; n = 11,055)
	3. Respiratory (1.1 billion; n = 8,379)	3. Respiratory (0.8 billion; n = 2,509)	3. Respiratory (0.3 billion; n = 5,870)
	4. Genitourinary (0.8 billion; n = 13,569)	4. Genitourinary (0.5 billion; n = 2,514)	4. Nervous System (0.3 billion; n = 6,081)
	5. Nervous (0.8 billion; n = 8,729)	5. Nervous (0.5 billion; n = 2,648)	5. Digestive (0.2 billion; n = 5,735)
	6. HEENT (0.4 billion; n = 10,626)	6. Miscellaneous (0.3 billion; n = 1,086)	6. Musculoskeletal (0.2 billion; n = 5365)
	7. Miscellaneous (0.4 billion; n = 4,366)	7. HEENT (0.3 billion; n = 3,392)	7. Chromos. Anom's (0.1 billion; n = 2,394)
	8. Musculoskeletal (0.4 billion; n = 6,524)	8. Musculoskeletal (0.2 billion; n = 1,159)	8. Miscellaneous (0.1 billion; n = 3,280)
	9. Chromosomal (0.3 billion; n = 3,059)	9. Chromosomal (0.2 billion; n = 665)	9. HEENT (0.1 billion; n = 7,234)
Top one-quarter by cost (US\$):	1. Cong heart anomaly NEC (n = 2,030)	1. Laryngotrach anomaly NEC (n = 617)	1. Obst def ren plv&urt NEC (n = 1,220)
Top 10 anomalies†	2. Laryngotrach anomaly NEC (n = 1364)	2. Cong heart anomaly NEC (n = 739)	2. Cong heart anomaly NEC (n = 1,209)
	3. Obst def ren plv&urt NEC (n = 1,516)	3. Coarctation of aorta (n = 584)	3. Lung anomaly NOS (n = 633)
	4. Coarctation of aorta (n = 1,124)	4. Obst def ren plv&urt NEC (n = 497)	4. Laryngotrach anomaly NEC (n = 830)
	5. Hypoplas left heart synd (n = 736)	5. Hypoplas left heart synd (n = 467)	5. Ventricular sept defect (n = 991)
	6. Intestinal anomaly NEC (n = 758)	6. Intestinal fixation anom (n = 384)	6. Brain anomaly NEC (n = 585)
	7. Down syndrome (n = 1,115)	7. Atresia small bowel (n = 416)	7. Intestinal anomaly NEC (n = 416)
	8. Tetralogy of fallot (n = 913)	8. Agenesis of lung (n = 267)	8. Specified cong anomal NEC (n = 469)
	9. Atresia small bowel (n = 775)	9. Anomalies of diaphragm (n = 336)	9. Congenital hydrocephalus (n = 397)
	10. Intestinal fixation anom (n = 618)	10. Tetralogy of fallot (n = 368)	10. Musculoskel. anomaly NEC (n = 495)

HEENT, head, ear, eye, nose, & throat (i.e. otolaryngology); NEC, necrotizing enterocolitis; NOS, not otherwise specified.

Notes:

• Authors placed diagnoses and surgeries in analogous organ systems (ie, abdominal wall defects fall into diseases of the integument system, but repairs of defects fall into surgeries of the digestive system; a physician panel placed both diagnoses and repairs into the digestive or gastrointestinal organ system). However, only diagnosis organ systems included chromosomal abnormalities as a category and only surgical organ systems included endocrine and lymphatic surgeries.

• Within cohort F, counts and costs do not always match for surgical and anomaly organ systems, as we were selective in diagnoses and surgeries that were definitive qualifiers for the cohort (ie, atrial septal defect [ASD] repair qualifies as major surgery, but ASD diagnosis does not qualify as major anomaly unless accompanying a major heart defect).

• Within the isolated cohorts, there are expected to be a portion that would otherwise qualify (ie, isolated ASD repair qualifies only as an isolated major surgery when, in reality, the infant has a surgical anomaly).

• Infants with multiple qualifying diagnoses and operations across organ systems were counted in each organ system.

\* The top 10 most frequent surgeries were selected amongst the top quartile of admissions ordered by cost, in order to avoid more frequent but comparatively low cost surgical admissions for procedures like gastrostomy tube placement (which did not contribute sizable total costs compared to complex intrathoracic or intraabdominal surgeries).

† The top 10 most frequent birth defect diagnoses were selected amongst the top quartile of admissions ordered by cost, in order to avoid more frequent but comparatively low cost admissions such as short stays for nonoperative craniofacial anomalies (which did not contribute total costs compared to admissions for complex intrathoracic or intraabdominal anomalies).

effect modifiers for health outcomes and health care costs. To instead specifically target these costs, the most recent CDC report uses discharge diagnosis codes for congenital anomalies (ICD9-CM 740.00–759.9)<sup>18</sup> and associates costs using any qualifying admission (including duplicates): for any anomaly; for any patient age; for births in any hospital or state; and without accounting for infant characteristics or disease severities. A principal finding of this CDC report is that first-year admissions are an overwhelming contributor to inpatient costs for infants with congenital anomalies.

Our study addresses many of the aforementioned study limitations by focusing on this first-year cohort in California and, more precisely, by subsetting from the lists of invasive surgical procedures and birth defects used by HCUP and MADCP, respectively.<sup>23,24</sup> Our study included a broad spectrum of surgical conditions, ranging from those that have a high risk of mortality to conditions such as hypospadias, which may be an isolated finding and not requiring surgery at the time of birth. Our intent was to conduct a comprehensive analysis of surgical conditions and congenital anomalies detected in the first year of life. Because we were able to link hospital discharge data to that from the CPQCC, which includes only patients cared for in NICUs, we were able to isolate those infants who most likely had a serious surgical condition or congenital anomaly.

Out of the total newborn costs of \$18.9 billion, we report costs specifically for the following: infants requiring “major” surgery (\$6.1 billion;  $n = 32,614$ ; 1.5% of all infants); infants with life-threatening congenital anomalies (\$6.0 billion;  $n = 57,793$ ; 2.6%); infants having a major surgery or a major anomaly (\$7.7 billion;  $n = 68,126$ ; 3.1%)<sup>25</sup>; and infants with coinciding major operations or anomalies (\$4.1 billion;  $n = 21,264$ , <1.0%). Finally, admissions specific to major operations or anomalies accounted for \$7.0 billion (37.0%) of newborn costs, and admissions for major operations and anomalies accounted for almost half of these costs (\$3.5 billion, 18.5%). These percentages increased after excluding infants with short birth episodes (<5 days), and even further as a percentage of total NICU costs. This study is the first to show that infants with surgical anomalies are the most costly neonates and strongly points toward operative therapy contributing more costs than an isolated major birth defect diagnosis.

Furthermore, our study tabulates how sick infants with long birth episodes account for nearly all first-year inpatient costs (\$14.4 billion, 85% birth episode costs, 76% first-year costs). Analysis of the data reveal the following cost drivers in newborn care: costs for early preterm or very-low BW infants without major anomalies or operations (\$3.2 billion;  $n = 29,377$ ) are almost equaled by a much smaller cohort of early-preterm or very-low BW infants with major anomalies or operations (\$3.1 billion;  $n = 8,410$ ). Many of these costs come from NICU admissions (\$4.3 billion and 38.4% for infants without major operations or anomalies; \$5.2 billion and 67.5% for major operations or anomalies); and the top quartile in each major anomaly or surgery cohort accounts for more than three-quarters of the total costs, which is remarkable given the severity of diseases meeting our selection criteria. Particularly expensive admissions included those in the top quartile for surgical anomalies ( $n = 5,799$ ; \$2.7 billion; median \$325,668/admission) or for early-preterm or very-low BW surgical anomalies ( $n = 1,684$ ; \$0.8 billion; \$383,434/admission).

A limitation of the present study is the reliance on admission and discharge coding to isolate cases. To avoid oversampling, we used only diagnostic codes that would reasonably be the main indication for admission. The credibility of our data is evidenced by the individual operations or anomalies most highly represented in total frequency (Figure 1) and costs (Table III). Our most conservative estimate examines only surgical admissions for major

anomalies (cohort F, \$3.5 billion), although the most expensive “isolated anomaly” admissions (top quartile;  $n = 10,661$ ; \$1.6 billion) were likely nonsurgical admissions for surgical anomalies. The less frequent but more expensive “isolated” surgical admissions (top quartile;  $n = 6,292$ ; \$1.6 billion) were likely populated by the following 3 groups: truly “isolated” operations (eg, inguinal hernia repair), nonanomalous premature infants with acquired surgical conditions (eg, necrotizing enterocolitis), and operations for congenital anomalies not included in our focused cohort D (eg, severe atrial or ventricular septal defects that required surgical intervention).

We have shown that surgical anomalies are the most costly and that premature and very premature infants requiring surgery are vastly more costly than infants requiring NICU management of medical conditions alone. Ideally, future studies should seek to consistently and reliably attribute costs associated with prematurity, newborn surgery, and severe congenital anomalies, respectively. A case in point, we have shown that early-preterm or very-low BW infants within cohort E ( $n = 8,410$ ; \$3.1 billion) cost as much as their control-cohort counterparts ( $n = 29,377$ ; \$3.2 billion), and a similar relationship exists when examining only cohorts with long birth episodes ( $n = 35,645$ /\$7.0 billion vs  $n = 173,193$ /\$7.4 billion). These high-cost infants have similarly disproportionate contributions from their most expensive admissions (ie, 25% of admissions produce >75% of the costs), suggesting the need for reinvestigation from a resource utilization and health care management perspective. In an era in which NICUs are designed to fundamentally manage prematurity, these data highlight the importance of recognizing the disproportionate fixed and variable costs associated with congenital and acquired neonatal surgical disease.

## Funding

Funded by the Stanford Medical Scholars Research Program. Study performed at the Stanford University School of Medicine and Lucile Packard Children’s Hospital.

## Conflict of interest

The authors have no financial conflicts of interest to disclose.

## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at <https://doi.org/10.1016/j.surg.2018.12.022>.

## References

- Petrini J, Damus K, Johnston RB. An overview of infant mortality and birth defects in the United States. *Teratology*. 1997;56:8–10.
- Stays H, Charges H. Hospital stays, hospital charges, and in-hospital deaths among infants with selected birth defects—United States, 2003. *MMWR Morb Mortal Wkly Rep*. 2007;56:25–29.
- Higashi H, Barendregt JJ, Kassebaum NJ, Weiser TG, Bickler SW, Vos T. The burden of selected congenital anomalies amenable to surgery in low and middle-income regions: Cleft lip and palate, congenital heart anomalies and neural tube defects. *Arch Dis Child*. 2015;100:233–238.
- Centers for Disease Control and Prevention (CDC). Economic costs of birth defects and cerebral palsy—United States, 1992. *MMWR Morb Mortal Wkly Rep*. 1995;44:694–699.
- Russo CA, Elixhauser A. *Hospitalizations for birth defects, 2004*. Rockville, MD: US Agency for Healthcare Research and Quality; 2007.
- McCann ME, Soriano SG. Progress in anesthesia and management of the newborn surgical patient. *Semin Pediatr Surg*. 2014;23:244–248.
- Burns KH, Casey PH, Lyle RE, Bird TM, Fussell JJ, Robbins JM. Increasing prevalence of medically complex children in US hospitals. *Pediatrics*. 2010;126:638–646.

8. Catré D, Lopes MF, Viana JS, Cabrita AS. Perioperative morbidity and mortality in the first year of life: A systematic review (1997–2012) Perioperative morbidity and mortality in the first year of life. *Braz J Anesthesiol*. 2015;65:384–394.
9. Rogowski J. Measuring the cost of neonatal and perinatal care. *Pediatrics*. 1999;103:329–335.
10. Connor JA, Kline NE, Mott S, Harris SK, Jenkins KJ. The meaning of cost for families of children with congenital heart disease. *J Pediatr Heal Care*. 2010;24:318–325.
11. Sitkin NA, Farmer DL. Congenital anomalies in the context of global surgery. *Semin Pediatr Surg*. 2016;25:15–18.
12. Badalà F, Nouri-mahdavi K, Raoof DA. Hospital charges at birth and frequency of rehospitalizations and acute care visits over the first year of life: A comparison by age and birth weight. *Am J Nurs*. 2005;105:56–65.
13. Yoon PW, Olney RS, Khoury MJ, Sappenfield WM, Chavez GF, Taylor D. Contribution of birth defects and genetic diseases to pediatric hospitalizations. A population-based study. *Arch Pediatr Adolesc Med*. 1997;151:1096–1103.
14. Harris JA, James L. State-by-state cost of birth defects—1992. *Teratology*. 1997;56:11–16.
15. Waitzman NJ, Romano PS, Scheffler RM, Waitzman J. Estimates of the economic costs of birth defects. *Inquiry*. 1994;31:188–205.
16. Metkus BAP, Esserman L, Sola A, Harrison MR, Adzick NS. Cost per anomaly: What does a diaphragmatic hernia cost? *J Pediatr Surg*. 1995;30:226–230.
17. Hook-Dufresne DM, Yu X, Bandla V, Imseis E, Moore-Olufemi SD. The economic burden of gastroschisis: Costs of a birth defect. *J Surg Res*. 2015;195:16–20.
18. Arth AC, Tinker SC, Simeone RM, Ailes EC, Cragan JD, Grosse SD. Inpatient hospitalization costs associated with birth defects among persons of all ages—United States, 2013. *MMWR Morb Mortal Wkly Rep*. 2017;66:41–46.
19. Schmitt SK, Sneed L, Phibbs CS. Costs of newborn care in California: A population-based study. *Pediatrics*. 2006;117:154–160.
20. Phibbs CS, Schmitt SK, Cooper M, Gould JB, Lee HC, Profit J. A population-based estimate of the costs of maternal and newborn care. Presented at: Pediatric Academic Societies meeting; May 9, 2017; San Francisco, CA.
21. Herrchen B, Gould JB, Nesbitt TS. Vital statistics linked birth/infant death and hospital discharge record linkage for epidemiological studies. *Comput Biomed Res*. 1997;30:290–305.
22. Medicode (Firm). *ICD-9-CM: International classification of diseases, 9th revision, clinical modification*. Salt Lake City, UT: Medicode; 1996.
23. HCUP procedure classes. Healthcare Cost and Utilization Project Web site. [www.hcup-us.ahrq.gov/toolssoftware/procedure/procedure.jsp](http://www.hcup-us.ahrq.gov/toolssoftware/procedure/procedure.jsp). Accessed May 1, 2017.
24. Metropolitan Atlanta Congenital Defects Program (MACDP). Birth Defects and Genetic Diseases Branch 6-Digit Code, For Reportable Congenital Anomalies, Version 08/07, 2007.
25. Phibbs CS, Baker LC, Caughey AB, Danielsen B, Schmitt SK, Phibbs RH. Level and volume of neonatal intensive care and mortality in very-low-birth-weight infants. *N Engl J Med*. 2007;356:2165–2175.
26. State of California Office of Statewide Planning & Development (OSHPD). 2008 hospital annual financial disclosure report, documentation Web site. [https://www.oshpd.ca.gov/documents/HID/HospitalFinancial/HADR\\_Documentation.pdf](https://www.oshpd.ca.gov/documents/HID/HospitalFinancial/HADR_Documentation.pdf). Accessed May 1, 2017.
27. Crawford M, Church J, Akin B. Bureau of Labor Statistics. CPI detailed report data for December 2015 Web site. <https://www.bls.gov/cpi/cpid1512.pdf>. Accessed May 1, 2017.
28. Boyle MH, Torrance GW, Sinclair JC, Horwood SP. Economic evaluation of neonatal intensive care of very-low-birth-weight infants. *N Engl J Med*. 1983;308:1330–1337.
29. Bhutta ZA, Das JK, Bahl R, et al. Can available interventions end preventable deaths in mothers, newborn babies, and stillbirths, and at what cost? *Lancet*. July 2014;384:347–370.