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ARTICLE

Clinical deterioration during neonatal transport in California

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Abstract

Objective Identify clinical factors, transport characteristics and transport time intervals associated with clinical deterioration during neonatal transport in California.

Study design Population-based database was used to evaluate 47,794 infants transported before 7 days after birth from 2007 to 2016. Log binomial regression was used to estimate relative risks.

Results 30.8% of infants had clinical deterioration. Clinical deterioration was associated with prematurity, delivery room resuscitation, severe birth defects, emergent transports, transports by helicopter and requests for delivery room attendance. When evaluating transport time intervals, time required for evaluation by the transport team was associated with increased risk of clinical deterioration. Modifiable transport intervals were not associated with increased risk.

Conclusion Our results suggest that high-risk infants are more likely to be unstable during transport. Coordination and timing of neonatal transport in California appears to be effective and does not seem to contribute to clinical deterioration despite variation in the duration of these processes.

Introduction

The inter-facility transport of critically ill newborns is an integral component of regionalized perinatal care in the United States [1]. Treatment of sick neonates in higher-level neonatal intensive care units (NICUs) has been shown to be associated with decreased morbidity and mortality when compared to those cared for in lower-level NICUs [2–6]. For this reason, mothers who are anticipated to have high-risk deliveries should be transferred to more specialized centers when feasible. Unfortunately, not every high-risk delivery can be predicted, and transport is often imperative when neonates are born in hospitals that may not be equipped to deliver higher-level neonatal intensive care. In addition, sick neonates who need more advanced care but are not transported may have higher risk of death [2].

Although transport to higher-level NICUs is often necessary for critically ill neonates to receive specialized care, the transport environment is not without risks. Compared to inborn neonates or those born after maternal transfer, neonates who require acute postnatal transport have increased risk of morbidities such as hypoxemia, glucose abnormalities, intraventricular hemorrhage and death [7–10]. Several factors have been associated with adverse neonatal outcomes after transport: the condition of an infant around the time of transport and provision of intensive care during transport have both been linked to increased morbidity and mortality [11, 12]. Duration of transport may also impact outcomes. Studies of acute transports involving older children have shown that remoteness of the referral hospital and longer duration of transport are associated with increased hospital lengths of stay, higher illness acuity scores and increased mortality rates [13]. A retrospective study in Japan of neonatal transports demonstrated that inter-facility transport longer than 1 h was associated with a higher risk of neonatal death compared to transports of shorter duration [14].

During transport, neonates may be exposed to significant physiologic stressors that can lead to clinical deterioration. In addition, identification and management of patient deterioration may be more difficult while transport is occurring.

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Although it has been demonstrated that certain clinical characteristics are associated with adverse outcomes after transport [11, 12], little is known about factors associated with clinical deterioration during transport. In addition, it is unknown how certain time intervals during the transport process may affect the likelihood to deteriorate during transport. The goal of this study was to identify maternal and neonatal risk factors, transport characteristics and transport time intervals that are associated with increased risk of clinical deterioration during transport. It is crucial to understand which infants are likely to deteriorate during transport so that transport teams can prepare and respond appropriately. In addition, understanding the association of transport time intervals with deterioration during transport provides information on the quality of the neonatal transport process and may lead to opportunities for improvement.

Methods

Study population and data source

In California, the California Perinatal Quality Care Collaborative (CPQCC) collects clinical prospective data on infants admitted to 139 NICUs in California. Standard definitions align with those used by the Vermont Oxford Network. Eligibility for the database includes gestational age less than 32 weeks, birthweight between 401 and 1500 g, whether transport occurred into or out of a NICU, need for intubated or non-intubated assisted ventilation for greater than 4 h, early sepsis, major surgery, severe hyperbilirubinemia, suspected encephalopathy or active therapeutic hypothermia [15]. The majority of neonatal transports in California are conducted by members of the California Perinatal Transport System (CPeTS), a network of over 100 specialized NICUs and 57 transport teams, who conduct ~7000 acute neonatal transports each year. This network serves to facilitate the transport of critically ill infants to NICUs offering a higher level of care that are better able to meet their needs [12]. These transports are extremely heterogeneous with respect to gestational age at birth, postnatal age at transport and clinical status [16]. The CPeTS collects comprehensive neonatal transport data that are linked to the CPQCC database. Acute transfer makes an infant eligible for data collection for CPQCC, therefore this dataset accounts for all infants who were transported for care to one of the CPQCC NICUs. This study was based on data collected on infants born from January 2007 to December 2016 who were transported within 7 days after birth. This study was approved by the California Committee for the Protection of Human Subjects and the Stanford University Institutional Review Board.

Measures

The Canadian Transport Risk Index of Physiologic Stability (TRIPS) score is a physiology-based assessment developed by Lee et al. [11]. The TRIPS score can be used to calculate the risk of death of an infant within seven days of transport and an increase or decrease in TRIPS scores after transport has been shown to be associated with increased or decreased mortality, respectively [11]. This scoring system has been optimized and validated for the California neonatal population by Gould and colleagues (Ca-TRIPS) [12]. The Ca-TRIPS score comprises temperature, blood pressure, response to noxious stimuli, respiratory status, use of vasopressors to support blood pressure and use of a ventilator [12]. Ca-TRIPS scores are evaluated at the point at which the transport team arrives at the bedside (pre-transport score) and again when the infant begins care at the receiving NICU (post-transport score). Infants with clinical deterioration during transport were defined as those who had a post-transport score greater than pre-transport score. This definition was chosen because any increase in score after transport has been shown to be associated with higher mortality [11].

Covariates were selected a priori and evaluated from CPQCC and CPeTS. We included relevant covariates that would be known about the infant either prior to or shortly after birth. Maternal and neonatal clinical covariates included infant sex (male or female), gestational age (weeks), birthweight (grams), maternal age (years), maternal race/ethnicity (African American, Hispanic, White, Asian/Pacific Islander, or other/unknown), prenatal care, multiple birth, birth defect severity, delivery room resuscitation and 5-min Apgar score less than or equal to 5. Birth defect severity was divided into six levels, as is defined in CPQCC: Level 0 (no birth defect), Level 1 (not severe, i.e. hemangioma, atrial or ventricular septal defects), Level 2 (moderately severe, i.e. gastrointestinal atresias, imperforate anus, trisomy 21), Level 3 (severe, i.e. encephalocele, abdominal wall defect, complete atrio-ventricular canal), Level 4 (very severe, i.e. congenital diaphragmatic hernia, hydrops fetalis), Level 5 (most severe, i.e. ancencephaly, hypoplastic left heart syndrome, bilateral renal agenesis, trisomy 13 or 18).

Transport characteristics included: age at transport, hour and day of transport, type of transport, mode of transport, indication for transport and team leader composition. Transport type was defined as delivery attendance (transport team was requested to attend the delivery), emergent transport (immediate transport was requested), urgent transport (transport requested within 6 h), and scheduled transport (transport was planned for an infant who required eventual transfer but who was currently in stable condition).

Time (in minutes or hours) between key periods of neonatal transport were calculated from the CPeTS data and were divided into clinically relevant intervals. These time periods included: time from birth to when the referral call was made, time from the referral call to admission acceptance by the accepting NICU, time from admission acceptance to departure of the transport team, time from departure of the transport team to arrival at the referring NICU, time from start of evaluation by the transport team to admission at the accepting NICU. Total time of transport was calculated from time of referral to admission at the accepting NICU.

Analysis

Infants who experienced clinical deterioration during transport were compared to those who remained stable or improved during transport. Student's *t*-test compared means and standard deviations of Ca-TRIPS scores before and after transport in these infants. Infants were compared according to maternal, neonatal clinical, transport and timing factors. Relative risks and 95% confidence intervals for the association between each covariate and clinical deterioration during transport were estimated using log-binomial regression models. Models included variables that may influence the practice of transport, including year of transport, mode of transport, and transport type. As the intent of our study was to identify neonates at risk for clinical deterioration, specific neonatal and maternal characteristics were not included in the models. Significance was defined as $p < 0.05$ or a confidence interval that excludes 1.0. Statistical analyses were computed using SAS 9.3 (SAS Institute, Cary, North Carolina).

Results

Of 147,135 CPQCC-eligible infants born from 2007 to 2016, 62,541 infants required acute transport with 56,271 (38.4%) transported within 7 days after birth and 6270 (4.3%) transported later than 7 days after birth. 455 (0.3%) infants were excluded because of missing birthdate, birth time, accepting NICU evaluation date or evaluation time. 47,794 infants had valid Ca-TRIPS scores documented and were included in the analysis. Of these infants, 14,722 (30.8%) had clinical deterioration during transport. 33,072 (69.2%) infants remained stable with either no change or an improvement in Ca-TRIPS score.

Pre-transport, infants with clinical deterioration had a Ca-TRIPS score of 10.5 ± 14.0; infants who remained stable had a score of 10.8 ± 14.5 ($p = 0.02$). Post transport, infants with clinical deterioration had a mean score of 17.1 ± 16.0; those who remained stable had a score of 8.5 ± 13.2 ($p < 0.0001$).

Table 1 displays the association of maternal and neonatal characteristics with risk of clinical deterioration. Early gestational age was associated with increased risk of clinical deterioration during transport with the highest risk at the earliest gestational ages. This pattern was similar for birthweight. Increased risk of clinical deterioration was also associated with a low Apgar score at 5 min, the need for delivery room resuscitation and greater birth defect severity (Levels 4 and 5).

Transport characteristics are displayed in Table 2. There was no association between hour of transport or day of the week with risk of deterioration. Transports by helicopter, emergent transports and transports requested for delivery attendance were all associated with increased risk. Transports with a nurse or nurse practitioner as the team leader were associated with decreased risk.

Table 3 displays time intervals during the transport process and their association with risk of clinical deterioration. Compared to infants who were referred for transport within 2 h after birth, those who were referred later had lower risk of clinical deterioration. Transport teams that took more than 60 min to arrive at referring NICUs were associated with an increased risk of clinical deterioration. The longer the total time for the transport process and the longer the time period from initial evaluation by the transport team to NICU admission, the greater the risk of clinical deterioration.

Discussion

This is a large population-based study evaluating the relationship between clinical deterioration during transport and various clinical factors, transport characteristics and time intervals during the transport process. Our goal was twofold: (1) identify risk factors associated with clinical deterioration that might aid transport teams in appropriately preparing for transport, and (2) describe the relationship between time intervals during the transport process and clinical deterioration since particular intervals may be modifiable, providing opportunities to improve transport quality.

We found that high-risk infants were most at risk for deterioration during transport; this includes the smallest and most premature infants, infants requiring delivery room resuscitation, and those with more severe birth defects. This finding is not unexpected given that these infants are likely to be more ill. Other variables associated with illness severity, such as transports by helicopter and emergent transports, were also associated with increased risk of clinical deterioration. A recent study of neonates in Sweden found no significant change in Ca-TRIPS scores

Table 1 Maternal and neonatal factors associated with clinical deterioration during transport

Characteristic	Clinical deterioration *N* (%) 14,722 (30.8%)	No clinical deterioration *N* (%) 33,072 (69.2%)	Crude RR	Adjusted RR	Missing
Male sex	8568 (58)	18,978 (57)	1.02 (0.99–1.06)	1.02 (0.99–1.06)	35
Gestational age (weeks)					0
≤23	168 (1)	175 (1)	1.71 (1.47–1.99)	1.64 (1.41–1.92)	
24–27	1230 (8)	1444 (4)	1.61 (1.51–1.71)	1.55 (1.46–1.65)	
28–31	1451 (10)	2423 (7)	1.31 (1.24–1.38)	1.27 (1.20–1.35)	
32–36	4372 (30)	10,329 (31)	1.04 (1.00–1.08)	1.03 (0.99–1.07)	
≥37	7501 (51)	18,701 (57)	Ref.	Ref.	
Birthweight (g)		2777 (927)			0
<500	51 (0.3)	47 (0.1)	1.78 (1.35–2.34)	1.71 (1.30–2.25)	
500–749	554 (4)	625 (2)	1.60 (1.47–1.75)	1.54 (1.41–1.68)	
750–999	683 (5)	844 (3)	1.53 (1.41–1.65)	1.47 (1.36–1.59)	
1000–1249	558 (4)	895 (3)	1.31 (1.20–1.43)	1.27 (1.17–1.39)	
1250–1499	584 (4)	1010 (3)	1.25 (1.15–1.36)	1.21 (1.12–1.32)	
≥1500	12,292 (84)	29,651 (90)	Ref.	Ref.	
Maternal age (years)					118
≤20	1424 (10)	3154 (10)	1.01 (0.95–1.06)	0.98 (0.93–1.04)	
20–29	7195 (49)	16,071 (49)	Ref.	Ref.	
30–39	5437 (37)	12,291 (37)	0.99 (0.96–1.03)	1.00 (0.97–1.04)	
≥40	639 (4)	1465 (4)	0.98 (0.91–1.06)	0.99 (0.92–1.08)	
Maternal race/ethnicity					447
African American	975 (7)	2246 7)	0.97 (0.90–1.04)	0.98 (0.92–1.05)	
Hispanic	7395 (51)	16,676 (51)	0.98 (0.95–1.02)	0.98 (0.95–1.02)	
White	4770 (33)	10,484 (32)	Ref.	Ref.	
Asian/Pacific Islander	1044 (7)	2308 (7)	1.00 (0.93–1.06)	1.02 (0.95–1.09)	
Other/Unknown	401 (3)	1048 (3)	0.88 (0.80–0.98)	0.83 (0.60–1.16)	
Received Prenatal Care	14,081 (96)	31,582 (96)	1.03 (0.95–1.12)	1.03 (0.94–1.12)	199
Multiple Birth	1372 (9)	2805 (9)	1.07 (1.02–1.13)	1.04 (0.99–1.10)	39
Birth defect severity					0
Level 0	10,626 (72)	23,926 (72)	Ref.	Ref.	
Level 1	606 (4)	1399 (4)	0.98 (0.91–1.07)	0.98 (0.91–1.07)	
Level 2	2026 (14)	4944 (15)	0.95 (0.90–0.99)	0.95 (0.91–1.00)	
Level 3	962 (7)	1990 (6)	1.06 (0.99–1.13)	1.06 (0.99–1.13)	
Level 4	290 (2)	452 (1)	1.27 (1.13–1.43)	1.25 (1.11–1.40)	
Level 5	212 (1)	361 (1)	1.20 (1.05–1.38)	1.18 (1.03–1.35)	
Delivery room resuscitation					0
Bag/Mask	5447 (37)	10,231 (31)	1.20 (1.16–1.24)	1.18 (1.14–1.22)	
Compressions/ Epinephrine	937 (6)	1776 (5)	1.13 (1.06–1.21)	1.11 (1.04–1.19)	
Intubation	3273 (22)	5238 (16)	1.32 (1.27–1.37)	1.27 (1.22–1.32)	
5-minute Apgar score ≤5	1700 (12)	3180 (10)	1.15 (1.09–1.20)	1.13 (1.07–1.19)	10

before and after acute airborne transports [17], which contrasts with our findings. This difference may reflect differences in our study population and illness severity, in addition to a larger transport volume. We also found that transports led by a nurse or nurse practitioner were associated with decreased risk of clinical deterioration. A study of transport outcomes in the Canadian population, similarly showed that infants traveling with transport teams led by nurses showed the greatest decrease in TRIPS score compared to transport teams lead by emergency medical technicians [18]; however, that analysis did not differentiate between teams that contained physicians

Table 2 Transport characteristics associated with clinical deterioration during transport

Characteristic	Clinical deterioration *N* (%) 14,722 (30.8%)	No clinical deterioration *N* (%) 33,072 (69.2%)	Crude RR	Adjusted RR	Missing
Age at transport					0
<24 h	10,738 (73)	23,529 (71)	Ref.	Ref.	
≥24 h	3984 (27)	9543 (29)	0.94 (0.91–0.97)	0.97 (0.94–1.02)	
Hour of transport					0
Daytime (7am–10pm)	10,932 (74)	24,785 (75)	Ref.	Ref.	
Overnight (11pm–6am)	3790 (26)	8287 (25)	1.03 (0.99–1.06)	1.02 (0.98–1.05)	
Day of the week					0
Weekday	10,951 (74)	24,845 (75)	Ref.	Ref.	
Weekend	3771 (26)	8227 (25)	1.03 (0.99–1.07)	1.03 (0.99–1.07)	
Mode of transport					4
Ground	12,735 (87)	29,314 (89)	Ref.	Ref.	
Helicopter	1498 (10)	2741 (8)	1.17 (1.11–1.23)	1.16 (1.10–1.22)	
Fixed wing	486 (3)	1016 (3)	1.07 (0.98–1.17)	1.06 (0.97–1.16)	
Transport type					4
Requested delivery attendance	1328 (9)	2397 (7)	1.26 (1.19–1.34)	1.25 (1.18–1.33)	
Emergent	7520 (51)	15,746 (48)	1.15 (1.11–1.19)	1.12 (1.08–1.16)	
Scheduled	654 (4)	1658 (5)	1.00 (0.92–1.09)	1.00 (0.92–1.08)	
Urgent	5182 (35)	13,189 (40)	Ref.	Ref.	
Other	37 (0.3)	79 (0.2)	1.13 (0.82–1.56)	1.11 (0.80–1.53)	
Indication for transport					2
Medical service	13,784 (94)	31,044 (94)	Ref.	Ref.	
Surgery	937 (6)	2027 (6)	1.03 (0.96–1.10)	1.05 (0.99–1.13)	
Team leader					33
Neonatologist	2863 (19.5)	6124 (18.5)	1.01 (0.97–1.05)	1.00 (0.96–1.05)	
Pediatrician	464 (3.2)	1059 (3.2)	0.97 (0.88–1.06)	0.96 (0.87–1.05)	
Other MD/resident	981 (6.7)	2122 (6.4)	1.00 (0.94–1.07)	1.01 (0.95–1.08)	
Nurse practitioner	784 (5.3)	1893 (5.7)	0.93 (0.86–1.00)	0.92 (0.85–0.99)	
Transport specialist	7705 (52.4)	16,736 (50.6)	Ref.	Ref.	
Nurse	1915 (13.0)	5115 (15.5)	0.86 (0.82–0.91)	0.90 (0.86–0.95)	

or advanced transport specialists. We hypothesize that nurses and nurse practitioners may lead transports that are lower acuity where a provider with advanced neonatal resuscitation skills may not be needed. Transports requested for delivery attendance were found to be associated with increased risk; this reinforces that mothers who are anticipated to have high-risk deliveries should be transferred to more specialized centers when feasible to avoid infants being born in centers that may not be equipped to deliver advanced care. When feasible, antenatal transfer of high-risk patients has been shown to improve outcomes for both the mother and infant [2].

Despite the association of clinical deterioration with high-risk clinical factors, the mean pre-transport Ca-TRIPS score was similar among infants with and without clinical deterioration; in fact, infants without clinical deterioration had a slightly higher baseline Ca-TRIPS score. Although our results demonstrate a statistically significant difference due to the large sample size, from a clinical perspective, this minor difference in scores is likely not relevant. This contrasts with the study of transport outcomes in the Canadian population by Eliason et al. that showed that baseline pre-transport TRIPS score correlated to the change in TRIPS score [18]. Our data suggest that an infant's history, rather than physical exam, may be more indicative of the likelihood for deterioration during transport.

An important finding of this study is that there was no relationship between modifiable transport time intervals and the risk of clinical deterioration. These include the time required for a NICU to accept a patient after a referral call is made and the time required to mobilize a transport team after a patient is accepted. These intervals correspond to the time required for the transport team to be organized. This suggests that the process of facilitating and dispatching a

Table 3 Timing variables associated with clinical deterioration during transport

Timing characteristic	Clinical deterioration *N* (%) 14,722 (30.8%)	No deterioration *N* (%) 33,072 (69.2%)	Crude RR	Adjusted RR	Missing
Birth to referral call					62
Prior to or less than 2 h after delivery	6171 (42.0)	12,604 (38.2)	Ref.	Ref.	
2–12 h	3765 (25.6)	8799 (26.6)	0.91 (0.88–0.95)	0.94 (0.90–0.98)	
12–48 h	3036 (20.7)	7253 (22.0)	0.90 (0.86–0.94)	0.93 (0.89–0.98)	
More than 48 h	1728 (11.8)	4376 (13.2)	0.86 (0.82–0.91)	0.90 (0.85–0.95)	
Referral call to acceptance					192
Less than 10 min	11587 (79)	25,874 (78)	Ref.	Ref.	
10 + min	3072 (21)	7069 (22)	0.98 (0.94–1.02)	1.01 (0.97–1.05)	
Acceptance to transport team departure for referring NICU					559
Less than 30 mins	3208 (22)	7228 (22)	Ref.	Ref.	
30–45 min	4140 (28)	8942 (27)	1.03 (0.98–1.08)	1.02 (0.97–1.07)	
45–60 min	2720 (19)	6131 (19)	1.00 (0.95–1.05)	0.99 (0.94–1.04)	
More than 60 min	4491 (31)	10,375 (32)	0.98 (0.94–1.03)	0.99 (0.94–1.04)	
Transport team departure to arrival at referring NICU					142
Less than 20 min	2851 (19)	6695 (20)	Ref.	Ref.	
20–40 min	5240 (36)	11,873 (36)	1.03 (0.98–1.07)	1.04 (0.99–1.09)	
40–60 min	2963 (20)	6553 (20)	1.04 (0.99–1.10)	1.05 (1.00–1.11)	
More than 60 min	3619 (25)	7858 (24)	1.06 (1.01–1.11)	1.07 (1.02–1.13)	
Transport team evaluation to accepting NICU admission					97
Less than 60 min	1985 (14)	5748 (17)	Ref.	Ref.	
60–90 min	3599 (25)	9436 (29)	1.08 (1.02–1.14)	1.08 (1.03–1.15)	
90–120 min	3424 (23)	7946 (24)	1.17 (1.11–1.24)	1.17 (1.11–1.24)	
More than 120 min	5682 (39)	9877 (30)	1.42 (1.35–1.50)	1.40 (1.33–1.47)	
Total time of transport process (referral to NICU admission)					62
Prior to or less than 2 h after delivery	1092 (7.4)	3037 (9.2)	Ref.	Ref.	
2–4 h	7429 (50.5)	18,075 (54.7)	1.10 (1.03–1.17)	1.11 (1.04–1.18)	
4–6 h min	4126 (28.1)	8079 (24.5)	1.28 (1.20–1.37)	1.26 (1.18–1.35)	
More than 6 h	2053 (14.0)	3841 (11.6)	1.32 (1.22–1.42)	1.33 (1.23–1.43)	

transport team appears to be effective and that despite variation in the duration of these intervals, there was no association with risk of clinical deterioration. Our study is in the context of a relatively efficient statewide transport system where in 79% of transports, the time from initial referral call to acceptance of the transfer occurred in less than 10 min, and the large majority of transports occurred expeditiously in regard to initiation of transport and arrival at the referring NICU (Table 3). Standards do not exist for appropriate lengths of components of the transport process; however, the time intervals in our study are similar to those in an analysis of neonatal transports in Australia that demonstrated a median discussion time after the initial referral call to be 10 (interquartile range 7–15) min [19].

We did not find that the time interval of acceptance to transport team departure was associated with clinical deterioration. This time interval could be considered as one that may be most modifiable from the standpoint of the transport team in order to optimize outcomes. A delay in response of the transport team could presumably lead to further clinical deterioration in a sick infant at a facility without appropriate resources. This is likely to be true to some extent, and our finding of no association in time and clinical deterioration may be due to several reasons, First, the response times were generally quick, with 69% occurring in less than 1 h. Second, it may be the case that those response times which occurred later were ones in which the transport team leader appreciated that the clinical

scenario and the referring hospital situation was one in which a later departure time would be safe. Our findings suggest that in California, the response times of transport teams are generally appropriate. We did find that transports teams that take longer than 60 min to arrive at the referring NICU were associated with increased risk of clinical deterioration. Although we were unable to evaluate physical distance and weather-related limitations that may impact transit time, transfer of pediatric patients from more remote healthcare centers has been shown to be associated with adverse outcomes [13].

In general, the time intervals during transport that were most associated with risk of deterioration are likely related to the condition of the infant being transported, and not related to the transport process itself. We found that the longer it took for the referral call to be made after birth, the lower likelihood of clinical deterioration. This is potentially because infants who are referred later after birth may be less ill. Risk of deterioration during transport was associated with longer total transport times; however, when evaluating the individual intervals of the transport process, this risk was associated with longer evaluation periods by the transport team. This is likely to reflect the situation when transport teams may need more time to stabilize sicker infants either prior to or during transport. This is a key finding since the need for intensive care during transport is associated with adverse outcomes [11]. Prior research has similarly found that longer transport times are associated with increased neonatal mortality [13, 14]; however, this study further elucidates which specific components of the transport process may be associated with increased risk of deterioration.

One limitation of this study is that there was missing data. Of the 56,271 infants transported within 7 days after birth, 455 had missing transport information and 8477 had missing Ca-TRIPS scores. However, in the final analysis of 47,794 infants, no more than 2% had missing information for any given clinical factor or transport timing period. The large sample size is a significant strength of this study. We utilized a population-based dataset encompassing more than 60,000 infants who required acute transport in California. The combined CPQCC and CPETS network encompass more than 90% of newborns born in California, which is a strength of this analysis. The size and scope of this database allows the ability to provide a comprehensive analysis of neonatal transport and evaluate how components of the transport process are associated with clinical deterioration during transport in California.

In summary, this study provides evidence that the process of organizing and facilitating neonatal transport is effective in California and that there is no increased risk of clinical deterioration despite variation in the duration of these processes. Clinical deterioration during transport instead appears to be associated with certain groups of high-risk infants. Understanding the clinical factors associated with deterioration is crucial to ensure transport teams are adequately prepared to manage these infants. It is notable that a large number of transports continue to occur for infants in California, which may have a potential impact on both short-term and long-term outcomes of these infants. Quality improvement efforts focusing on antenatal maternal transfer when appropriate may reduce the need for neonatal transport. In addition, exploring the impact of the transport process on specific high-risk populations, such as extremely premature and very-low birthweight infants, is a priority for future research.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Lupton BA, Pendray MR. Regionalized neonatal emergency transport. Semin Neonatol. 2004;9:125–33.
2. Marlow N, Bennett C, Draper ES, Hennessy EM, Morgan AS, Costeloe KL. Perinatal outcomes for extremely preterm babies in relation to place of birth in England: the EPICure 2 study. Arch Dis Child Fetal Neonatal Ed. 2014;99:F181–188.
3. Warner B, Musial MJ, Chenier T, Donovan E. The effect of birth hospital type on the outcome of very low birth weight infants. Pediatrics. 2004;113(1 Pt 1):35–41.
4. Apfeld JC, Kastenberg ZJ, Sylvester KG, Lee HC. The effect of level of care on gastroschisis outcomes. J Pediatr. 2017; 190:79–84.e1.
5. Kastenberg ZJ, Lee HC, Profit J, Gould JB, Sylvester KG. Effect of deregionalized care on mortality in very low-birth-weight infants with necrotizing enterocolitis. JAMA Pediatr. 2015;169:26–32.
6. Lapcharoensap W, Gage SC, Kan P, Profit J, Shaw GM, Gould JB, et al. Hospital variation and risk factors for bronchopulmonary dysplasia in a population-based cohort. JAMA Pediatr. 2015;169: e143676.
7. Hohlagschwandtner M, Husslein P, Klebermass K, Weninger M, Nardi A, Langer M. Perinatal mortality and morbidity. Comparison between maternal transport, neonatal transport and inpatient antenatal treatment. Arch Gynecol Obstet. 2001;265:113–8.
8. Araújo BF, Zatti H, Oliveira Filho PF, Coelho MB, Olmi FB, Guaresi TB, et al. Effect of place of birth and transport on morbidity and mortality of preterm newborns. J Pediatr. 2011; 87:257–62.
9. Mohamed MA, Aly H. Transport of premature infants is associated with increased risk for intraventricular haemorrhage. Arch Dis Child Fetal Neonatal Ed. 2010;95:F403–407.

10. Towers CV, Bonebrake R, Padilla G, Rumney P. The effect of transport on the rate of severe intraventricular hemorrhage in very low birth weight infants. Obstet Gynecol. 2000;95:291–5.
11. Lee SK, Zupancic JA, Pendray M, Thiessen P, Schmidt B, Whyte R, et al. Transport risk index of physiologic stability: a practical system for assessing infant transport care. J Pediatr. 2001;139:220–6.
12. Gould JB, Danielsen BH, Bollman L, Hackel A, Murphy B. Estimating the quality of neonatal transport in California. J Perinatol. 2013;33:964–70.
13. Sample M, Acharya A, O'Hearn K, Livingstone S, Menon K. The relationship between remoteness and outcomes in critically ill children. Pediatr Crit Care Med. 2017;18:e514–20.
14. Mori R, Fujimura M, Shiraishi J, Evans B, Corkett M, Negishi H, et al. Duration of inter-facility neonatal transport and neonatal mortality: systematic review and cohort study. Pediatr Int. 2007;49:452–8.
15. CPQCC Manual of Definitions For Infants Born in 2018. California Care Quality Care Collaborative, Stanford, CA; 2018.
16. Akula VP, Gould JB, Kan P, Bollman L, Profit J, Lee HC. Characteristics of neonatal transports in California. J Perinatol. 2016;36:1122–7.
17. Frid I, Ågren J, Kjellberg M, Normann E, Sindelar R. Critically ill neonates displayed stable vital parameters and reduced metabolic acidosis during neonatal emergency airborne transport in Sweden. Acta Paediatr. 2018;107:1357–61.
18. Eliason SH, Whyte H, Dow K, Cronin CM, Lee S, Network CN. Variations in transport outcomes of outborn infants among Canadian neonatal intensive care units. Am J Perinatol. 2013;30:377–82.
19. Abdel-Latif ME, Berry A. Analysis of the retrieval times of a centralised transport service, New South Wales, Australia. Arch Dis Child. 2009;94:282–6.