Received: 22 September 2022 | Revised: 23 November 2022 | Accepted: 23 November 2022

DOI: 10.1111/aogs.14494

ORIGINAL RESEARCH ARTICLE

Neonatal outcome of infants with umbilical cord arterial pH less than 7

So Ling Lau[1] | Zara Lin Zau Lok[2] | Shuk Yi Annie Hui[1] | Genevieve Po Gee Fung[3] | Hugh Simon Lam[3] | Tak Yeung Leung[1]

[1]Department of Obstetrics and Gynecology, The Chinese University of Hong Kong, Prince of Wales Hospital, Hong Kong, China

[2]OT&P Healthcare, Hong Kong, China

[3]Department of Pediatrics, The Chinese University of Hong Kong, Hong Kong, China

Correspondence
Tak Yeung Leung, Department of Obstetrics and Gynecology, The Chinese University of Hong Kong, Prince of Wales Hospital, 30–32 Ngan Shing Street, Shatin, Hong Kong, China.
Email: tyleung@cuhk.edu.hk

Abstract

Introduction: Umbilical arterial pH of less than 7 is often used as the threshold below which the risks of neonatal death and adverse long-term neurological outcomes are considered to be higher. Yet within the group with pH <7, the risks have not been further stratified. Here, we aimed to investigate the predictors of adverse long-term outcomes of this group of infants.

Material and methods: This was a retrospective study of 248 infants born after 34 weeks of gestation in a tertiary obstetric unit, between 2003 and 2017, with cord arterial pH <7 or base excess ≤−12 mmol/L at birth. The infants were categorized into two groups: (1) intact survivors, or (2) neonatal/infant deaths or cerebral palsy or developmental delay. The umbilical arterial pH and base excess levels, Apgar scores, mode of delivery, gestational age, small for gestational age, birth in the era before the implementation of neonatal hypothermic therapy, and the presence of a known sentinel event, were compared between the groups using univariate analysis followed by multivariate analysis.

Results: Among the 248 infants, there were 222 intact survivors (89.5%) and 26 infants with poor outcomes (10.5%), including eight deaths (3.2%) and 18 (7.3%) with cerebral palsy and/or developmental delay. Univariate analysis showed that infants with adverse outcomes had significantly lower cord arterial pH (6.85 vs 6.95, with $p < 0.001$), lower cord arterial base excess (−19.95 vs −15.90 mmol/L, $p < 0.001$), a higher proportion of having AS at 5 min <7 (65.4% vs 13.1%, $p < 0.001$), and a higher proportion of having a sentinel event (34.6% vs 16.7%, $p = 0.034$). Multivariate analysis confirmed cord arterial pH of <6.9 and an Apgar score at 5 min <7 as independent prognostic factors (the adjusted odds ratios were 4.64 and 6.62, respectively). The risk of adverse outcome increased from 4.3% when the arterial pH was between 6.9 and <7, to 30% when the pH was <6.9.

Conclusions: Infants born with umbilical artery pH <7 still have a high chance of 89.5% to become intact survivors. A cord arterial pH of <6.9 and an Apgar score at 5 min <7

Abbreviations: ACOG, American College of Obstetricians & Gynecologists; AS5, Apgar score at fifth minute; HIE, hypoxic ischemic encephalopathy; SGA, small for gestational age.

are independent prognostic factors for neonatal/infant death or adverse long-term neurological outcomes.

KEYWORDS
cerebral palsy, fetal academia, infant death, neonatal death, neonatal outcome, umbilical arterial pH

1 | INTRODUCTION

Significant birth asphyxia is one of the major causes of stillbirths, neonatal death, infant death and adverse long-term outcomes such as cerebral palsy and developmental delay.[1–4] Acute intrapartum hypoxic events such as placental abruption, uterine rupture, cord prolapse, and shoulder dystocia cause anaerobic metabolism, which can lead to rapid deterioration of umbilical cord arterial pH within a short period.[5–8] The effects of fetal acidosis have been associated with hypoxic ischemic encephalopathy (HIE), the need for cardiopulmonary resuscitation, intubation, seizures, cerebral palsy, developmental delay, and mortality.[9–11] In a systematic review of seven publications consisting of 386 cases with pH <7, the incidence of neonatal death and chronic neurological morbidity was 5.9 and 17.2% respectively.[12] Hence obstetric units and medico-legal claims rely on umbilical cord pH as an objective marker of adverse outcomes.[13] The American College of Obstetricians & Gynecologists (ACOG) and The American Academy of Pediatrics have also jointly set up the four essential criteria for establishing a causal link between intrapartum hypoxic events and cerebral palsy and included significantly low cord arterial pH (<7), early onset of moderate or severe HIE in infants born at 34 weeks of gestation or more, cerebral palsy of the spastic quadriplegic or dyskinetic type, and exclusion of other identifiable etiologies.[14]

Yet not all neonates with a cord arterial pH of less than 7 suffer from adverse long-term outcomes or die. Information on the prognostic factors of this group of babies is limited. At present, only a single study has reported that the risk of adverse outcomes correlated with pH. In this report, 506 neonates born at or after 35 gestational weeks, with an arterial pH of less than 7 which was either sampled from the umbilical cord at birth, or from the neonates within 1 h of life, were analyzed. The risk of adverse outcomes increased from 3% when the pH was between 6.9 and <7, to 10% and 40% when the pH dropped to 6.8– <6.9 and <6.8, respectively.[15] However, 37 neonates (7.3%) of their cohort did not have umbilical samples, and blood was only taken from their bodies some time later. Hence their results may not truly reflect the outcome of intrapartum hypoxia. Second, the effect of other potential prognostic factors such as Apgar scores, mode of delivery, gestational age, small for gestational age (SGA), implementation of neonatal hypothermic therapy, and the presence of a known sentinel event was not assessed. Hence, we conducted a retrospective cohort study to investigate the predictors of neonatal death and adverse long-term neurological outcomes among neonates born with umbilical arterial pH lower than 7.

Key message

Cord arterial pH of <6.9 and Apgar score at 5 min <7 are independent prognostic factors for neonatal/infant death or adverse long-term neurological outcomes. The risk increased from 4.3% to 30% when the pH dropped from 6.9 to <7 to below 6.9.

2 | MATERIAL AND METHODS

This retrospective study was conducted in a tertiary referral center in Hong Kong with an annual delivery of more than 6000. All live-births born between 2003 and 2017 with maturity of 34 gestational weeks or above, and an umbilical cord pH of less than 7, or base excess at, or lower than, −12 mmol/L, were included (ACOG).[16] Their case records were retrieved for review of the antenatal and intrapartum management, as well as neonatal management. Infant data was obtained jointly from obstetric delivery records and pediatric files via the hospital centralized computer system. Cases were excluded if they were found to have pre-existing syndromes such as trisomy 13, 18, or 21. Based on their long-term outcomes, they were then classified into either one of the two groups: (1) intact survivors, or (2) adverse long-term outcomes. Adverse long-term outcomes includes neonatal or infant death or cerebral palsy or developmental delay. The umbilical artery pH and base excess levels, and other potential prognostic factors including Apgar scores, mode of delivery, gestational age, SGA, birth before or since 2007 (when neonatal systemic hypothermic therapy was implemented), and the presence of a known sentinel event such as cord prolapse, shoulder dystocia, placental abruption, uterine rupture and failed instrumental delivery, were compared between the groups. SGA was defined as a birthweight of less than 10th centile for gestation age according to our published local gestational age specific birthweight reference.[17]

During the study period, the umbilical cord arterial and venous blood were sampled routinely after the birth of every newborn following a standard protocol: the umbilical cord was double clamped immediately after birth, and blood were sampled from the vessels routinely before the delivery of the placenta in the event of vaginal delivery, or immediately after delivery of the placenta in the event of cesarean section.[18,19] Umbilical cord arterial and venous pH, base deficit, $PaCO_2$, and PaO_2 were measured using Siemens RAPIDpoint®

400/405 Systems, which was regularly calibrated to maintain quality control. All newborns were also assessed at the first and the fifth minute of life with Apgar scores, which were assigned by the attending obstetrician, midwife, or pediatrician. In case fetal distress was suspected before birth, a pediatrician was summoned to stand by for resuscitation. Newborns were also assigned an Apgar score at the 10th minute of life by pediatricians if the Apgar score at the fifth minute (AS5) was less than 7. The neonates were admitted to the neonatal intensive care unit if they required continuous life support. Starting in the year 2007, neonates born at gestation 36 weeks of above with HIE were treated with hypothermic therapy commenced according to the selection criteria in the Shankaran et al. study.[20] Neurodevelopmental follow-up was offered to all surviving infants diagnosed with HIE, as these infants are at the highest risk of neurodevelopmental problems. Follow-up was also offered to infants with birthweight less than 1.5 kg, who had significant hypoxemia in the neonatal period, or with any intracranial abnormality. The survivors' records for at least 4 years were reviewed for any cerebral palsy or developmental delay. Development was classified as normal in infants in whom there was no concern about developmental delay and delayed in any infant with ongoing concerns. Physical examinations and assessments with motion function were done during follow-up with pediatricians. Clinical notes were reviewed and checked if infants were diagnosed with cerebral palsy.

2.1 | Statistical analyses

Statistical analysis was performed with IBM SPSS Statistics version 22.0 (IBM Inc.). Univariate analysis was performed using an independent sample *t*-test or Mann–Whitney U test, respectively for parametric and nonparametric continuous variables. Categorical variables were compared using the chi-square test or Fisher's exact test where appropriate. A *p*-value of 0.05 or less was considered statistically significant. Variables with a *p*-value less than 0.2 were selected for multivariate analysis using logistic regression.

2.2 | Ethics statement

Ethical approval was obtained from The Joint Chinese University of Hong Kong–New Territories East Cluster Clinical Research Ethics Committee (Ref CRE 2017.442) on September 19, 2017. Patient consent was waived.

3 | RESULTS

During the study period, we identified 279 neonates with cord arterial pH <7 or base excess ≤−12 mmol/L from a total of 98 844 neonates. Hence the overall incidence of severe acidosis (cord arterial pH <7) was 2.82 per 1000 deliveries. A total of 29 were then excluded as they were less than 34 gestational weeks, and one infant was also excluded for trisomy 13. The outcome was missing in one of the remaining 249 neonates. The baby was born by cesarean section for placental abruption at 40 weeks of gestation, with umbilical artery pH of 6.631 and base excess of −31 mmol/L. The neonate developed seizures during his stay in the neonatal intensive care unit which were controlled with anticonvulsants. He was discharged on day 30 of life and provided with a follow-up appointment; however, subsequently, he was lost to follow-up. Hence the final cohort consisted of 248 births, of which seven were from seven different twin sets and all of which were the second twin.

The median gestation at delivery of these 248 cases was 39.1 (interquartile range 38.00–40.2), and 230 (92.7%) were born at term (i.e., ≥37 weeks). The mean birthweight was 3.05 ± 0.46 kg. The maternal age at delivery ranged from 17–43 years, with a median age of 31 years, and 22.9% of the mothers were of advanced maternal age (≥35 years old at the time of delivery), and 65.7% were primiparous at the time of delivery. A total of 148 (59.7%) neonates were delivered vaginally, including 83 (33.5%) spontaneous and 65 (26.2%) instrumental delivery. The remaining 100 (40.3%) were delivered by cesarean section. In 46 of them, a sentinel event was identified, including 16 cases with placental abruption, 15 failed instrumental deliveries requiring urgent cesarean sections, 12 cases of cord prolapse, and three cases of shoulder dystocia. There were 188 (75.8%) neonates with umbilical artery pH between 6.9 and <7.0, 41 (16.5%) neonates with pH between 6.8 and <6.9, and 19 (7.7%) neonates with pH <6.8.

There were 222 intact survivors (89.5%) and 26 infants with adverse long-term neurological outcomes (10.5%). These included three (1.2%) with early neonatal death and five (2.0%) who died after day 7 of life secondary to severe hypoxic brain damage. Four infants developed cerebral palsy (1.6%), and 14 were found to have developmental delay (5.6%). The risk of adverse long-term outcomes was significantly lower in the group with pH between 6.9 and <7.0 (4.3%; 8/188; $p < 0.001$), than in the group with pH between 6.8 and <6.9 (29.3%; 12/41), and that below 6.8 (31.6%; 6/19). Compared with the intact survivors, infants with adverse outcomes had significantly lower cord arterial pH (6.854 vs 6.953, with $p < 0.001$), lower cord arterial base excess (−19.95 vs −15.90 mmol/L, $p < 0.001$), and a higher proportion of having AS at 5 min <7 (65.4% vs 13.1%, $p < 0.001$). Infants who suffered from adverse outcomes were associated with deliveries complicated with a sentinel event (34.6% vs 16.7%, $p = 0.034$). Concerning the mode of delivery and the year of delivery, there was no statistical difference between the two groups. The gestational age, proportion of preterm deliveries, and proportion of SGA were comparable between intact survivors and cases with adverse outcomes (Table 1). On multivariate analysis, only cord arterial pH of <6.9 and AS5 of <7 remained to be significant predictors of the occurrence of adverse long-term outcomes, and their respective adjusted odds ratio were 4.64 and 6.62 (Table 2).

TABLE 1 Comparison of perinatal factors between the intact survivors and those with adverse long-term neurological outcomes (including neonatal or infant death/cerebral palsy/developmental delay) in neonates with umbilical cord pH <7 or base excess ≤−12 mmol/L

	Intact survivors		Adverse long-term outcomes		
	N = 222		*N* = 26		
Perinatal factors	**Median or *n***	**(IQR or %)**	**Median or *n***	**(IQR or %)**	***p*-value**
Cord arterial pH					
Median (IQR)	6.953	(6.910–6.980)	6.854	(6.794–6.934)	<0.001
<6.8	13	(5.8)	6	(23.1)	<0.001
6.8–<6.9	29	(13.1)	12	(46.1)	
6.9–<7.0	180	(81.1)	8	(30.8)	
Cord arterial base excess (mmol/L)					
Median (IQR)	−15.90	(−18.60 to −13.50)	−19.95	(−22.65 to −16.37)	<0.001
≤−20	34	(15.3)	13	(50.0)	<0.001
>−20 to ≤−16	71	(32.0)	9	(34.6)	
>−16	106	(47.7)	4	(15.4)	
Apgar score at 5 min					
<7	29	(13.1)	17	(65.4)	<0.001
≥7	193	(86.9)	9	(34.6)	
Sentinel event identified					
Yes	37	(16.7)	9	(34.6)	0.034
No	185	(83.3)	17	(65.4)	
Mode of delivery					
Cesarean	84	(37.8)	16	(61.5)	0.065
Instrumental	61	(27.5)	4	(15.4)	
Normal vaginal delivery	77	(34.7)	6	(23.1)	
Gestational weeks					
Median (IQR)	39.2	(38.0–40.2)	39.0	(37.0–40.0)	0.206
34–36 weeks	15	(6.8)	4	(15.4)	0.123
≥37 weeks	207	(93.2)	22	(84.6)	
Year of birth					
Before 2007	157	(70.7)	16	(61.5)	0.335
In 2007 and after	65	(29.3)	10	(38.5)	
Small for gestational age					
Below 10th percentile	37	(16.7)	6	(23.1)	0.414
At or above the 10th percentile	185	(83.3)	20	(76.9)	

4 | DISCUSSION

The incidence of severe birth asphyxia, defined by an umbilical cord arterial pH <7 in our study, was 2.82 per 1000 births, which is slightly lower than the incidence of 3.7 per 1000 births reported in the systematic review by Graham et al.[12] Our overall death rate was also less than that of the systematic review (3.2% vs 5.9%) by Graham et al. Our incidence of severe acidosis is also lower than another recent single-center study by Kelly et al., which reported an incidence of 8.9 in 1000 births.[15] Yet, our proportion of different degree of severe acidosis (7.7% for pH <6.8; 16.5% for pH 6.8–<6.9; 75.8% for pH 6.9–<7) was similar to that of Kelly et al (10.5%, 18.1% and 71.4%, respectively). The lower incidence in our cohort could be related to the routine use of continuous fetal hear monitoring, early diagnosis of intrapartum fetal distress, and most importantly the high efficiency of arranging urgent delivery. As reported previously, we were able to achieve a median decision-to-delivery interval of 15 min.[7,8] As a result, our rates of adverse neonatal outcomes were low. Similarly, we have also previously reported a low intrapartum stillbirth rate of 0.2 per 1000 births.[2]

Our study demonstrated that the majority of neonates (89.5%) who were born with severe acidemia (pH <7) did not go on to experience any long-term neurological deficits or death. Similar to the report of Kelly et al., we also found a low risk of adverse long-term outcomes when the arterial pH was between 6.9 and <7 (4.3% vs 3% from our cohort and Kelly et al., respectively), and a significantly

TABLE 2 Multivariate analysis for prognostic factors of adverse long-term outcomes in neonates with umbilical cord pH <7 or base excess ≤−12 mmol/L

	Univariate Odds ratio			Multivariate Odds ratio		
Perinatal factors	**OR**	**95% CI**	***p*-value**	**aOR**	**95% CI**	***p*-value**
Cord arterial pH						
≥6.9	1		<0.001	1		0.003
<6.9	9.64	3.93–23.67		4.64	1.70–12.66	
Cord arterial base excess (mmol/L)						
≤−16	5.81	1.94–17.40	0.002	N.A.		
<−16	1					
Apgar score at 5 min						
≥7	1		<0.001	1		<0.001
<7	12.57	5.13–30.84		6.62	2.46–17.80	
Sentinel event identified						
Yes	2.65	1.10–6.39	0.030	N.A.		
No	1					
Mode of delivery						
Cesarean	1			N.A.		
Instrumental	0.34	0.11–1.08	0.068			
Normal vaginal delivery	0.41	0.15–1.10	0.076			
Gestational weeks						
34–36 weeks	2.51	0.77–8.23	0.129	N.A.		
≥37 weeks	1					

Abbreviations: aOR, adjusted odds ratio; OR, odds ratio.

higher risk of 30% when the pH was lower than 6.9. However, while Kelly et al. demonstrated a stepwise increase from 10% in the group with pH 6.8–<6.9 and 40% in the group with pH <6.8, our results shows a similarly high risk in these two groups (29.3% and 31.6%, respectively). The underlying reasons for our difference is not clear. Both our unit and that in the study by Kelly et al. had similar annual delivery rates (around 6000–8000), and the study periods were similar (2003–2017 vs 2005–2013). The inclusion criteria were also the same (pH <7; base excess ≤−12 mmol/L; gestation ≥34 weeks), but the spectrum of diseases and clinical practice might vary. In addition, while our blood gas results were all based on umbilical arterial samples, 7.3% of the cases in the Kelly et al. report did not have umbilical samples, so their pH results were based on blood samples taken from the neonates' bodies within 1 h of birth.

Unlike the study by Kelly et al., we performed multivariate analysis and found that besides umbilical arterial pH, AS5 was also an independent prognostic factor. The adjusted odds ratio of AS5 was slightly higher than that of pH <6.9 (6.62 vs 4.64). Iliodromiti et al., in their large Scottish population cohort study of 1 million deliveries, found that a low AS5 was associated with a higher infant mortality rate. Yet, umbilical blood gas data was not included in this study.[21] While umbilical arterial pH reflects the severity of acute intrapartum fetal hypoxia, AS5 reflects the neonatal response to postnatal resuscitation.[22] Our results indicate that a timely and successful resuscitation, as indicated by an improved Apgar score at 5 min, may halt an acute hypoxic insult progressing to an irreversible brain damage. On the other hand, neonates who respond poorly to resuscitation (indicated by a low AS5) or those who do not receive sufficient resuscitation at birth are at risk of adverse long-term outcomes. In this regard, the presence of neonatologists or midwives well trained in neonatal resuscitation at the time of birth is crucial in reducing the risk of adverse outcomes.[23,24]

Although ACOG included a sentinel event as an essential criterion for establishing a causal linkage between intrapartum hypoxia and cerebral palsy,[14] our study shows that the presence of such a sentinel event is not an independent factor. It is not surprising for several reasons: first, quick delivery with a short bradycardia-to-delivery interval reduces the chance of severe acidosis.[5–7] Second, some causes of fetal hypoxia such as compound umbilical cord presentation (the former term "occult cord prolapse" was a misnomer) are difficult to diagnose.[25] Some fetuses may have late onset growth restriction with reduced reserve and tolerance to the stress of labor. However, they are not differentiable from constitutionally small fetuses based on birthweight alone.[26] To diagnose late-onset fetal growth restriction prenatally, Doppler assessment of the umbilical and cerebral blood flow is necessary, yet it is not a routine practice.[27] One point of note is that in our cohort with pH <7, there were a total of 43 neonates (17.3%) with a birthweight below the 10th percentile of our population. This indicates that SGA is at a higher risk of developing severe acidosis. Furthermore, the proportion of SGA was also higher in the

adverse outcomes group than in the intact group (23.1% vs 16.7%) although the difference did not reach a statistical significance.

The strength of our study was that all neonates born in our unit had both the umbilical cord arterial and venous blood samples for blood gas analysis. A single center study also ensures a standardized protocol of obstetric and pediatric management, a single standard, and expertise in diagnosis classification, neonatal resuscitation, care, and follow-up. Yet our study was mainly limited by its retrospective nature. Due to the limited number of adverse events, we were unable to demonstrate any beneficial effect with the implementation of the hypothermic therapy. A larger cohort would be needed to further determine a numerical limit that corresponds to a risk of an event.

5 | CONCLUSION

The incidence of severe umbilical acidosis (pH <7) at birth is 2.82 per 1000 births. The overall intact survival among these infants is high (89.5%). Cord arterial pH of <6.9 and an Apgar score at 5 min <7 are independent prognostic factors for neonatal or infant death or adverse long-term neurological outcomes.

AUTHOR CONTRIBUTIONS

Concept or design and drafting of the manuscript: SLL, TYL. Acquisition of data: SLL, SYA H, GPGF, HSL, TYL. Analysis or interpretation of data: SLL, SYAH, TYL. All authors critically revised the manuscript for important intellectual content and had full access to the data, contributed to the study, approved the final version for publication, and take responsibility for its accuracy and integrity.

CONFLICT OF INTEREST

All authors have disclosed no conflicts of interest.

ORCID

So Ling Lau https://orcid.org/0000-0003-4198-1709
Shuk Yi Annie Hui https://orcid.org/0000-0001-5042-4731
Genevieve Po Gee Fung https://orcid.org/0000-0002-9526-1953
Hugh Simon Lam https://orcid.org/0000-0001-9912-0544
Tak Yeung Leung https://orcid.org/0000-0002-9153-0343

REFERENCES

1. Leung TY, Chung TK. Severe chronic morbidity of childbirth. *Best Pract Clin Res Obstet Gynaecol*. 2009;23:401-423.
2. Wong STK, Tse WT, Lau SL, Sahota DS, Leung TY. Stillbirth rate in singleton pregnancies: a 20-year retrospective study from a public obstetric unit in Hong Kong. *Hong Kong Med J*. 2022;28:285-293.
3. Lau SL, Wong STK, Tse WT, et al. Perinatal mortality rate in multiple pregnancies: a 20-year retrospective study from a tertiary obstetric unit in Hong Kong. *Hong Kong Med J*. 2022;28:347-356. doi:10.12809/hkmj2210153
4. Fung GPG, Lau SL, Hui SYA, et al. Neonatal mortality in singleton pregnancies: a 20-year retrospective study from a tertiary perinatal unit in Hong Kong. *Hong Kong Med J*. 2022. doi:10.12809/hkmj2210357 Epub ahead of print. PMID: 36442841.
5. Leung TY, Lao TT. Timing of caesarean section according to urgency. *Best Pract Res Clin Obstet Gynaecol*. 2013;27:251-267.
6. Leung TY, Chung PW, Rogers MS, Sahota DS, Lao TT, Chung TK. Urgent cesarean delivery for fetal bradycardia. *Obstet Gynecol*. 2009;114:1023-1028.
7. Leung TY, Stuart O, Sahota DS, Suen SS, Lau TK, Lao TT. Head-to-body delivery interval and risk of fetal acidosis and hypoxic ischaemic encephalopathy in shoulder dystocia: a retrospective review. *BJOG*. 2011;118:474-479.
8. Wong L, Tse WT, Lai CY, et al. Bradycardia-to-delivery interval and fetal outcomes in umbilical cord prolapse. *Acta Obstet Gynecol Scand*. 2021;100:170-177.
9. Goodwin TM, Belai I, Hernandez P, Durand M, Paul RH. Asphyxial complications in the term newborn with severe umbilical acidemia. *Am J Obstet Gynecol*. 1992;167:1506-1512.
10. Malin GL, Morris RK, Khan KS. Strength of association between umbilical cord pH and perinatal and long term outcomes: systematic review and meta-analysis. *BMJ*. 2010;340:c1471.
11. Andres RL, Saade G, Gilstrap LC, et al. Association between umbilical blood gas parameters and neonatal morbidity and death in neonates with pathologic fetal acidemia. *Am J Obstet Gynecol*. 1999;181:867-871.
12. Graham EM, Ruis KA, Hartman AL, Northington FJ, Fox HE. A systematic review of the role of intrapartum hypoxia-ischemia in the causation of neonatal encephalopathy. *Am J Obstet Gynecol*. 2008;199:587-595.
13. Greenwood C, Newman S, Impey L, Johnson A. Cerebral palsy and clinical negligence litigation: a cohort study. *BJOG*. 2003;110:6-11.
14. ACOG. Report of the American College of Obstetricians and Gynaecologists Task Force on neonatal encephalopathy. Neonatal encephalopathy and neurological outcome. *Obstet Gynecol*. 2014;123:896-901.
15. Kelly R, Ramaiah SM, Sheridan H, et al. Dose-dependent relationship between acidosis at birth and likelihood of death or cerebral palsy. *Arch Dis Child Fetal Neonatal Ed*. 2018;103:F567-F572.
16. ACOG Committee on Obstetric Practice. ACOG Committee Opinion No 348, November 2006: umbilical cord blood gas and acid-base analysis. *Obstet Gynecol*. 2006;108:1319-1322.
17. Fok TF, So HK, Wong E, et al. Hong Kong neonatal measurements working group. Updated gestational age specific birth weight, crown-heel length, and head circumference of Chinese newborns. *Arch Dis Child Fetal Neonatal Ed*. 2003;88:F229-F236.
18. Leung TY, Lok I, Tam WH, Leung TN, Lau TK. Deterioration in cord blood gas status during the second stage of labour is more rapid in the second twin than in the first twin. *BJOG*. 2004;111:546-549.
19. Leung TY, Tam WH, Leung TN, Lok I, Lau TK. Effect of twin-to-twin delivery interval on umbilical cord blood gas in the second twins. *BJOG*. 2002;109:63-67.
20. Shankaran S, Laptook AR, Ehrenkranz RA, et al. Whole-body hypothermia for neonates with hypoxic-ischemic encephalopathy. *N Engl J Med*. 2005;353:1574-1584.
21. Iliodromiti S, Mackay DF, Smith GCS, Pell JP, Nelson SM. Apgar score and the risk of cause-specific infant mortality: a population-based cohort study. *Lancet*. 2014;384:15-21.
22. Laptook AR. Neonatal and infant death: the Apgar score reassessed. *Lancet*. 2014;384:1727-1728.
23. American Heart Association. Guideline on Neonatal Resuscitation. 2020. Available online at: https://cpr.heart.org/en/resuscitation-science/cpr-and-ecc-guidelines/neonatal-resuscitation#ARN1 (Accessed Nov 21, 2022).
24. Ersdal HL, Mduma E, Svensen E, Perlman JM. Early initiation of basic resuscitation interventions including face mask ventilation may reduce birth asphyxia related mortality in low-income countries: a prospective descriptive observational study. *Resuscitation*. 2012;83:869-873.

25. Wong L, Kwan AHW, Lau SL, Sin WTA, Leung TY. Umbilical cord prolapse: revisiting its definition and management. *Am J Obstet Gynecol*. 2021;225:357-366.
26. Roeckner JT, Pressman K, Odibo L, Duncan JR, Odibo AO. Outcome-based comparison of SMFM and ISUOG definitions of fetal growth restriction. *Ultrasound Obstet Gynecol*. 2021;57:925-930.
27. Salomon LJ, Alfirevic Z, Da Silva CF, et al. ISUOG practice guidelines: ultrasound assessment of fetal biometry and growth. *Ultrasound Obstet Gynecol*. 2019;53:715-723.

How to cite this article: Lau SL, Lok ZLZ, Hui SYA, Fung GPG, Lam HS, Leung TY. Neonatal outcome of infants with umbilical cord arterial pH less than 7. *Acta Obstet Gynecol Scand*. 2023;102:174-180. doi:10.1111/aogs.14494