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Original Research

Factors Influencing Umbilical Arterial Blood Gas Parameters in Newborns Born to Tibetan Mothers in High-Altitude Regions: A Retrospective Study

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Abstract

Background: Umbilical artery blood gas (UABG) parameters serve as critical indicators of metabolic and oxygenation status in newborns at birth, including base excess (BE), pH, and lactate (LAC). In high-altitude hypoxic environments, the factors that influence these parameters in indigenous populations may be unique. This study aimed to identify the factors affecting UABG parameters among a low-risk, physiological Tibetan population at high altitude. **Methods**: This retrospective study analyzed data from 524 Tibetan women and their newborn babies who gave birth vaginally at a high-altitude hospital between January 1, 2024, and December 31, 2024. BE was the primary outcome, while pH and LAC were exploratory outcomes. Maternal and neonatal characteristics were categorized according to median pH, BE, and LAC values. Statistical methods, including *t*-tests, Mann-Whitney U tests, chi-squared tests, and linear regression models, were employed to identify factors influencing UABG. **Results**: The median (interquartile range [IQR]) values for UABG were pH: 7.28 (7.22, 7.33), BE: –8.00 (–10.00, –7.00) mmol/L, and LAC: 4.37 (3.47, 5.40) mmol/L. In univariate analyses, a lower pH ($\leq$7.28) was associated with primiparity, shorter maternal height, longer second and third stage of labor, and neonatal length. A lower BE ($\leq$–8.00 mmol/L) was associated with primiparity and longer first and second stages of labor. A lower LAC ($\leq$4.37 mmol/L) was associated with multiparity, less frequent premature rupture of membranes, shorter second and third stages of labor, lower immediate blood loss, and total blood loss within 2 hours postpartum. Multivariable linear regression revealed maternal height as a positive predictor for pH (β = 0.002, p = 0.016), while the second stage duration was a negative predictor for pH (β = –0.001, p = 0.001) and BE (β = –0.017, $p < 0.001$), and a positive predictor for LAC (β = 0.003, p = 0.003). Neonatal length was a negative predictor for pH (β = –0.037, p = 0.005). Parity was a positive predictor for BE (β = 0.500, p = 0.045). Robust regression validated these associations. Significant differences were observed in pH, BE, and LAC between primiparous and multiparous women ($p < 0.05$). Significant differences were observed in BE between epidural anesthesia and non-anesthesia groups ($p < 0.05$). **Conclusions**: In this low-risk Tibetan population, pH was influenced by maternal height, the duration of the second stage of labor, and neonatal length. BE was influenced by parity and the duration of the second stage of labor. The duration of the second stage of labor is a factor influencing LAC. These results should not be generalized to high-risk pregnancies or complex delivery scenarios, as the study cohort was restricted to women with physiologically normal pregnancies who delivered vaginally.

Keywords: high-altitude pregnancy; Tibetan; umbilical artery blood gas

1. Introduction

The distinctive hypoxic environment of high-altitude regions has long been a key focus in perinatal medicine due to its impact on pregnancy and childbirth [1]. Prolonged exposure to low-pressure, low-oxygen environments at altitudes above 2500 meters can affect the mother, fetus, and newborn [2]. In the mother, this can lead to compensatory physiological changes, such as erythrocytosis and placental vascular remodeling. In the fetus, intrauterine growth patterns adapt, and the hypoxic environment may affect its development and health after birth [3]. As indigenous inhabitants of high-altitude regions, Tibetans have developed remarkable hypoxic adaptation capabilities through long-term natural selection and physiological adjustments [4]. However, it is not fully elucidated whether this adaptive mechanism affects the characteristics of their labor process during delivery (e.g., number of deliveries, duration of labor) and influences neonatal outcomes (e.g., birth weight, asphyxia).

Umbilical artery blood gas analysis (UABGA) is used to assess the oxygenation and acid-base status of neonates, as well as their respiratory response capacity. It has predictive value for adverse outcomes, including early identification of complications such as hypoxic injury and respiratory distress syndrome [5]. Key indicators of acid-base balance and oxygenation status in neonates include pH, base excess (BE), and lactate (LAC). A significant decrease in pH, a large negative BE deviation, and a significant increase in LAC levels suggest that the neonate may be experiencing acidosis [6]. Studies have shown that severe acidosis is strongly associated with increased neonatal mortality and neurological complications, while mild metabolic imbalance can also raise the risk of adverse outcomes in term neonates [7,8]. Low [9] demonstrated that severe intrapartum hypoxic-ischemic events, reflected by marked metabolic acidosis at birth, strongly predict fetal brain injury. In high-altitude regions, the hypoxic environment can have a greater impact on these indicators and, consequently, on neonatal health [10]. Previous studies have primarily focused on complications of high-altitude pregnancy, such as preeclampsia and fetal growth restriction (FGR), with little attention given to the relationship between physiological labor processes, labor characteristics, and neonatal UABGA, particularly in indigenous Tibetan populations that have developed a hypoxic adaptation phenotype.

This study aims to systematically investigate the association between the delivery characteristics of Tibetan women in plateau regions, including parity, epidural analgesia, and the duration of the second stage of labor, and the blood gas parameters (pH, BE, and LAC) of their term newborns, through a retrospective analysis. This research will provide scientific evidence to inform obstetric clinical practice in plateau regions.

2. Materials and Methods

2.1 Study Design

This retrospective study analyzed perinatal data from all eligible Tibetan mothers from high-altitude regions who delivered at our hospital (at an elevation of 3658 meters) between January 1, 2024, and December 31, 2024. A double-checking system was implemented to ensure data accuracy and completeness, in which two independent researchers cross-verified all extracted data against the original medical records.

Inclusion criteria were as follows: (1) local residents with permanent residency and at least one year of continuous local residence; (2) vaginal delivery with singleton pregnancy; (3) neonates with a 1-minute Apgar score of 7 or above; (4) term neonates with a gestational age of 37–42 weeks and birth weight of 2500–4000 grams; and (5) complete clinical data for both mother and infant.

Exclusion criteria included: (1) cesarean section or breech delivery; (2) maternal diabetes; (3) maternal drug use, sedative use, smoking, or alcohol consumption during pregnancy; (4) pregnancy-induced hypertension or preeclampsia; (5) previous cesarean section; (6) FGR; (7) oligohydramnios or meconium-stained amniotic fluid; (8) neonatal organ dysfunction, congenital anomalies, or severe malformations; (9) outliers: interquartile range (IQR) method: this non-parametric method identifies outliers as data points falling below Q1 – 1.5 × IQR or above Q3 + 1.5 × IQR, where Q1 is the first quartile, Q3 is the third quartile, and IQR = Q3 – Q1; Mean ± standard deviation (SD) method: applicable to approximately normal data, this method defines outliers as values lying outside the range of mean ± 3×SD.

2.2 Measurement of UABGA

Immediately after fetal delivery, a rapid assessment was conducted. If the newborn was breathing or crying, it was placed prone with its head turned to one side, and skin-to-skin contact with the mother was initiated. To ensure the sample was arterial blood, the umbilical artery was identified by its thicker, more muscular wall and typically single appearance compared with the two thinner-walled veins. UABGA blood samples were collected either during delayed cord clamping (60 seconds after birth) or before cord pulsations ceased (1~3 minutes postpartum) using a heparinized syringe to puncture the umbilical artery. For newborns requiring immediate resuscitation, samples were collected by a midwife not involved in resuscitation, within minutes of placental delivery. If immediate sampling was not possible, the umbilical cord segment was clamped, refrigerated, and analyzed within 60 minutes. The UABGA indicators (pH, residual base BE, and LAC) were measured using the Abbott i-STAT1 handheld blood gas analyzer (model 300; manufacturer: Abbott Point of Care Inc.; country of origin: Singapore) with CG4+ cartridges (manufacturer: Abbott Point of Care Inc.).

2.3 Data Collection

The baseline maternal data collected included age, height, gestational age, gravidity, pre-pregnancy weight, intrapartum weight, epidural anesthesia use, premature rupture of membranes, duration of each stage of labor, blood loss, total blood loss within two hours postpartum, and placental weight. The neonatal characteristics assessed were neonatal sex, weight, length, and head circumference. This information was sourced from medical records and electronic delivery registers. The UABGA indicators measured were pH, BE, and LAC, obtained from the blood gas analyzer results. High-risk threshold values for UABGA were defined as pH $<$7.00, LAC $\geq$6 mmol/L, and BE $<$–12 mmol/L, based on sea-level standards. Normal ranges were pH: 7.24~7.27, BE: –5.60~2.70 mmol/L, and LAC $<$6 mmol/L [11]. Classified by pH into normal ($\geq$7.20), mild acidosis (7.11~7.19), acidosis (7.00~7.10), and severe acidosis ($\leq$7.00). The primary outcome of this study was umbilical artery BE. Umbilical artery pH and LAC were considered exploratory outcomes.

2.4 Statistical Analysis

Statistical analysis was conducted on the collected data. The normality of all continuous variables was evaluated using both the Kolmogorov-Smirnov test and visual in-

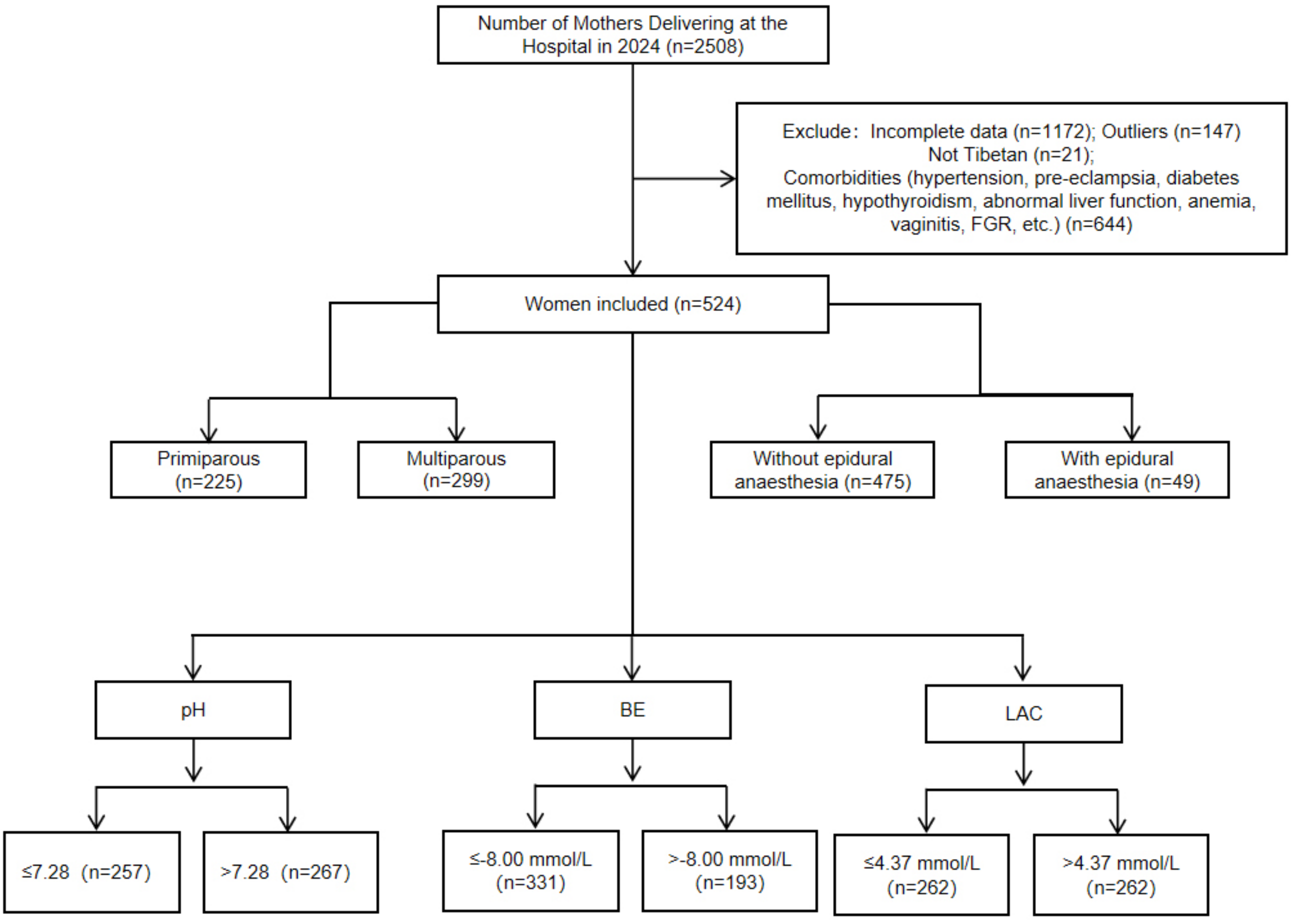

Fig. 1. Participant flowchart. BE, base excess; LAC, lactate; FGR, fetal growth restriction.

spection of Quantile-Quantile (Q-Q) plots. Given the large sample size (n = 524), primary reliance was placed on the Kolmogorov-Smirnov test results. For variables subjected to group comparisons, homogeneity of variances was assessed using Levene's test. Variables with approximately normal distribution and homogeneous variances were analyzed using the independent samples *t*-test. Variables with approximately normal distribution but heterogeneous variances were analyzed using Welch's *t*-test, which does not assume equal variances. Variables significantly deviating from a normal distribution were analyzed using the non-parametric Mann-Whitney U test, which does not require variance homogeneity. For qualitative variables, the chi-square test was used for analysis. Linear regression analysis was employed to identify factors independently associated with UABG parameters (pH, BE, LAC). Variables with a p-value < 0.05 in univariate analyses or those deemed clinically relevant were included as independent variables in the multivariate models. Specifically, pH served as the dependent variable, with parity, maternal height, and the duration of the second and third stages of labor as independent variables. For BE values as the dependent variable, parity and the duration of the first and second stages of labor were the independent variables. For LAC, parity, premature rupture of membranes, the duration of the second and third stages of labor, and immediate blood loss were the independent variables. Robust regression was further applied primarily to address potential outliers in the data or deviations from ideal assumptions in the data distribution. The results are presented as unstandardized regression coefficients (β) with their 95% confidence intervals (95% CI). The overall model fit was assessed using the adjusted R-squared (R^2) value and the F-statistic. A two-tailed p-value < 0.05 was considered statistically significant. Scatter plots for pH, BE, and LAC were generated. All analyses were performed using IBM SPSS Statistics software (version 27.0; IBM Corp., Armonk, NY, USA).

3. Results

3.1 Collection Process

The initial cohort consisted of 2508 mothers who gave birth at the hospital in 2024. After applying exclusion criteria, including incomplete (n = 1172) or abnormal (n = 147) data, non-Tibetan ethnicity (n = 21), and the presence of various comorbidities (n = 644), a total of 524 mothers were included in the analysis (Fig. 1). Of these, 225 were primiparous, and 299 were multiparous. Regarding anesthesia, 49 individuals received it, while 475 did not. The pH level

Table 1. Analysis of factors affecting pH, BE, and LAC of the UABG.

Variable	pH		$t/\chi^2/U$	p	BE		$t/\chi^2/U$	p	LAC		$t/\chi^2/U$	p
	≤7.28 (n = 257)	>7.28 (n = 267)			≤–8.00 mmol/L (n = 331)	>–8.00 mmol/L (n = 193)			≤4.37 mmol/L (n = 262)	>4.37 mmol/L (n = 262)		
Parity			6.686	0.010			29.874	0.001			20.259	0.001
Primiparous women	125 (48.64)	100 (37.35)			172 (51.96)	53 (27.46)			87 (33.21)	138 (52.67)		
Multiparous women	132 (51.36)	167 (62.55)			159 (48.04)	140 (72.54)			175 (66.79)	124 (47.33)		
Age (years)	28.93 ± 4.42	29.22 ± 4.74	–0.726	0.468	28.95 ± 4.36	29.30 ± 4.95	–0.832	0.406	29.16 ± 4.77	29.01 ± 4.42	0.371	0.711
Maternal Height (cm)	160.69 ± 5.03	161.56 ± 4.99	–1.990	0.047	160.99 ± 4.98	161.38 ± 5.10	–0.872	0.383	161.28 ± 5.19	160.99 ± 4.86	0.674	0.501
Gestational week (week)	39.65 ± 1.08	39.47 ± 1.04	1.884	0.060	39.60 ± 1.05	39.49 ± 1.08	1.158	0.247	39.58 ± 1.05	39.53 ± 1.07	0.577	0.564
Pre-pregnancy weight (kg)	55.65 ± 7.23	55.42 ± 7.70	0.351	0.726	55.49 ± 7.34	55.61 ± 7.70	–0.177	0.859	55.39 ± 7.79	55.66 ± 7.14	–0.413	0.680
Weight at delivery (kg)	67.35 ± 8.84	66.72 ± 8.60	0.823	0.411	67.24 ± 8.64	66.67 ± 8.86	0.718	0.473	66.60 ± 9.17	67.46 ± 8.23	–1.129	0.259
Premature rupture of membranes			0.257	0.612			1.935	0.164			5.893	0.015
No	203 (78.99)	206 (77.15)			252 (76.13)	157 (81.35)			216 (82.44)	193 (73.66)		
Yes	54 (21.01)	61 (22.85)			79 (23.87)	36 (15.63)			46 (17.56)	69 (26.34)		
Epidural anesthesia			0.349	0.555			3.539	0.060			1.103	0.294
No	231 (89.88)	244 (91.39)			294 (88.82)	181 (93.78)			241 (91.98)	234 (89.31)		
Yes	26 (10.12)	23 (8.61)			37 (11.17)	12 (6.21)			21 (8.01)	28 (10.69)		
Duration of the first stage of labor (min)	300.00 (189.00, 460.00)	280.00 (180.00, 428.00)	31,990.500	0.181	320.00 (202.50, 487.50)	240.00 (178.75, 390.00)	25,875.500	<0.001	290.00 (190.00, 426.00)	300.00 (180.00, 463.75)	33,450.000	0.615
Duration of the second stage of labor (min)	29.00 (17.00, 56.00)	22.00 (13.00, 41.00)	28,998.000	0.002	32.00 (18.00, 59.00)	19.00 (11.00, 30.00)	21,053.000	<0.001	20.00 (12.00, 37.00)	32.50 (19.00, 59.00)	24,088.000	<0.001
Duration of the third stage of labor (min)	6.00 (5.00, 9.00)	6.00 (5.00, 8.00)	30,497.500	0.026	6.00 (5.00, 9.00)	6.00 (5.00, 8.00)	29,801.000	0.196	6.00 (5.00, 8.00)	6.00 (5.00, 9.00)	29,712.500	0.009
Immediate blood loss (mL)	150.00 (118.75, 220.00)	150.00 (110.00, 200.00)	31,463.000	0.100	150.00 (110.00, 210.00)	150.00 (113.75, 210.00)	31,373.000	0.733	150.00 (100.00, 200.00)	150.00 (120.00, 220.00)	30,336.500	0.027
Total blood loss within 2 hours postpartum (mL)	230.00 (180.00, 295.00)	220.00 (180.00, 280.00)	31,276.500	0.080	220.00 (180.00, 280.50)	220.00 (180.00, 280.00)	31,554.000	0.817	220.00 (170.00, 280.00)	230.00 (180.00, 300.00)	30,107.500	0.019
Placental weight (g)	645.49 ± 101.12	633.75 ± 99.06	1.342	0.180	640.79 ± 99.26	637.30 ± 101.87	0.385	0.701	635.73 ± 94.49	643.28 ± 105.56	–0.862	0.389
Neonatal sex			1.950	0.163			0.042	0.838			1.718	0.190
male	136 (52.92)	125 (46.82)			166 (50.15)	95 (49.22)			123 (46.95)	138 (52.67)		
female	121 (47.80)	142 (53.18)			165 (49.84)	98 (50.78)			139 (53.05)	124 (47.33)		
Neonatal weight (g)	3229.83 ± 342.69	3185.15 ± 340.19	1.498	0.135	3217.65 ± 341.44	3188.91 ± 342.62	0.928	0.354	3203.49 ± 323.67	3210.64 ± 359.65	–0.239	0.811
Neonatal length (cm)	50.17 ± 1.52	49.90 ± 1.43	2.071	0.039	50.06 ± 1.52	49.99 ± 1.41	0.540	0.590	49.98 ± 1.46	50.08 ± 1.51	–0.694	0.488
Neonatal head circumference (cm)	33.96 ± 1.07	33.85 ± 1.04	1.225	0.221	33.92 ± 1.06	33.89 ± 1.05	0.280	0.779	33.86 ± 1.03	33.94 ± 1.08	–0.932	0.352

Data are presented as n (%), mean ± SD, or median (IQR). Group comparisons were made using independent samples *t*-test (for normally distributed data), Mann-Whitney U test (for non-normally distributed data), chi-square test (for categorical variables). UABG, umbilical artery blood gas; SD, standard deviation; IQR, interquartile range.

Table 2. Collinearity test results for pH, BE, and LAC.

Dependent variable	Independent variable	Tolerance	VIF
pH	Parity	0.602	1.660
	Height	0.968	1.033
	Duration of the second stage of labor	0.611	1.636
	Duration of the third stage of labor	0.991	1.009
	Neonatal length	0.948	1.055
BE	Parity	0.615	1.625
	Duration of the first stage of labor	0.826	1.211
	Duration of the second stage of labor	0.573	1.745
LAC	Parity	0.611	1.637
	Premature rupture of membranes	0.981	1.020
	Duration of the second stage of labor	0.611	1.636
	Duration of the third stage of labor	0.980	1.020
	Immediate blood loss	0.196	5.113
	Total blood loss within 2 hours postpartum	0.196	5.110

VIF, variance inflation factor.

was 7.28 (7.22, 7.33), the BE level was –8.00 (–10.00, –7.00) mmol/L, and the LAC level was 4.37 (3.47, 5.40) mmol/L. The UABG parameters of these 524 mothers were then categorized into groups based on cut-off values for pH ($\leq$7.28 vs. $>$7.28), BE ($\leq$–8.00 mmol/L vs. $>$–8.00 mmol/L), and LAC ($\leq$4.37 mmol/L vs. $>$4.37 mmol/L), to enable subsequent comparative analyses. In subsequent analyses, the median values of pH, BE, and LAC were selected as cut-off points for binary comparisons because the median serves as an objective and robust measure of central tendency [12]. This analysis is exploratory in nature, aiming to provide an initial description of the association trends.

3.2 Analysis of Factors Affecting pH, BE, and LAC of the UABG

Comparison of maternal and neonatal characteristics by UABGs groups is shown in Table 1. Compared with pH $>$7.28, pH $\leq$7.28 exhibited significantly shorter maternal height, longer duration of the second stage of labor, longer duration of the third stage of labor, and longer average body length (all $p < 0.05$).

Compared with BE $>$–8.00 mmol/L, BE $\leq$–8.00 mmol/L was associated with significantly different parity (primiparous: 172 vs. 53, multiparous: 159 vs. 140, p = 0.001), longer duration of the first stage of labor (320.00 min vs. 240.00 min, p = 0.000), and longer duration of the second stage of labor (all $p < 0.05$).

Compared with LAC $>$4.37 mmol/L, LAC $\leq$4.37 mmol/L was associated with significantly different parity, less frequent premature rupture of membranes, shorter duration of the second stage of labor, shorter duration of the third stage of labor, lower immediate blood loss, and lower total blood loss within 2 hours postpartum (all p <0.05).

3.3 Multicollinearity Diagnostics for pH, BE, and LAC

A variance inflation factor (VIF) value $>$5 indicates multicollinearity, while a tolerance value $<$0.2 also suggests multicollinearity. The collinearity test results are shown in Table 2. For pH, parity, maternal height, and the duration of the second and third stages of labor can be considered free of multicollinearity. For BE, parity, and the duration of the first and second stages of labor can be considered free of multicollinearity. For LAC, parity, preterm rupture of membranes, and duration of the second and third stages of labor cannot be considered free of multicollinearity. For immediate blood loss and total blood loss within 2 hours postpartum, VIF values $>$5 and tolerance values $<$0.2 indicate multicollinearity. In subsequent linear regression analyses, total blood loss within 2 hours postpartum and immediate blood loss were included separately. Results showed nearly identical R^2 values (0.077 vs. 0.076), adjusted R^2 values (0.068 vs 0.067), and F-values (both significant, p = 0.000) for both models, indicating comparable overall explanatory power. The VIF values for both "total blood loss within 2 hours postpartum" and "immediate blood loss" were approximately 1.02 (tolerance $\approx$ 0.98). Therefore, the inclusion of either variable in the analysis is unlikely to significantly impact the final results.

3.4 Linear Regression Models for pH, BE, and LAC

The linear regression model identified factors influencing UABG parameters (Table 3). For pH, the regression model explained 7.0% of the variance (adjusted R^2 = 0.061, F = 7.815, $p < 0.001$). Three factors showed significant associations. Maternal height was a positive predictor (β = 0.002, 95% CI: 0.000 to 0.003, p = 0.016), indicating that for each 1 cm increase in maternal height, the umbilical artery pH value increases by 0.002. Duration of the second stage of labor was a negative predictor (β = –

Table 3. Linear regression models for pH, BE, and LAC.

Dependent variable	Independent variable	β	95% CI	p	Regression model			
					R^2	Adjusted R^2	F	p
pH					0.070	0.061	7.815	<0.001
	Parity	0.011	–0.006∼0.027	0.202				
	Height	0.002	0.000∼0.003	0.016				
	Duration of the second stage of labor	–0.001	–0.001∼–0.000	0.001				
	Duration of the third stage of labor	–0.012	–0.003∼0.002	0.643				
	Neonatal length	–0.037	–0.011∼–0.002	0.005				
BE					0.102	0.096	19.594	<0.001
	Parity	0.500	0.012∼0.987	0.045				
	Duration of the first stage of labor	0.000	–0.001∼0.001	0.558				
	Duration of the second stage of labor	–0.017	–0.025∼–0.009	<0.001				
LAC					0.076	0.067	8.501	<0.001
	Parity	–0.080	–0.187∼0.027	0.143				
	Premature rupture of membranes	0.094	–0.007∼0.195	0.070				
	Duration of the second stage of labor	0.003	0.001∼0.004	0.003				
	Duration of the third stage of labor	0.013	–0.001∼0.028	0.061				
	Immediate blood loss	0.001	0.000∼0.001	0.060				

CI, confidence interval.

Table 4. Results of the robust regression validation analysis.

Dependent variable	Independent variable	β	95% CI	p	Robust Regression			
					R^2	Adjusted R^2	F	p
BE					0.100	0.095	19.319	<0.001
	Parity	0.572	0.111∼1.032	0.015				
	Duration of the first stage of labor	0.000	–0.001∼0.001	0.711				
	Duration of the second stage of labor	–0.017	–0.024∼–0.009	<0.001				
LAC					0.099	0.090	11.328	<0.001
	Parity	–0.222	–0.533∼0.088	0.161				
	Premature rupture of membranes	0.216	–0.078∼0.509	0.149				
	Duration of the second stage of labor	0.011	0.006∼0.016	<0.001				
	Duration of the third stage of labor	0.025	–0.017∼0.066	0.241				
	Immediate blood loss	0.001	–0.000∼0.003	0.151				

0.001, 95% CI: –0.001 to 0.000, p = 0.001), indicating that for each 1-minute increase in the duration of the second stage of labor, the umbilical artery pH decreases by 0.001. Neonatal length was a negative predictor (β = –0.037, 95% CI: –0.011 to –0.002, p = 0.005), meaning that for each 1 cm increase in neonatal length, the umbilical artery pH decreases by 0.037. For BE, the model explained 10.2% of the variance (adjusted R^2 = 0.096, F = 19.594, $p < 0.001$). Two factors showed associations, with one being significant: the duration of the second stage of labor was a negative predictor (β = –0.017, 95% CI: –0.025 to –0.009, $p <$ 0.001); specifically, each 1-minute increase in the duration of the second stage of labor reduced the umbilical artery BE by 0.017 mmol/L. Parity was a positive predictor approaching significance (β = 0.500, 95% CI: 0.012 to 0.987, p = 0.045), suggesting that multiparous women may have a 0.500 mmol/L higher umbilical artery BE compared with nulliparous women. For LAC, the model explained 7.6% of the variance (adjusted R^2 = 0.067, F = 8.501, $p < 0.001$). One factor was significantly associated, with two others approaching significance: the duration of the second stage of labor was a positive predictor (β = 0.003, 95% CI: 0.001 to 0.004, p = 0.003), meaning that each 1-minute increase in the duration of the second stage of labor increases the umbilical artery LAC by 0.003 mmol/L. Additionally, a scatter plot was created using the statistically significant indicators from the linear regression analysis (Fig. 2).

3.5 Robust Regression Validation Analysis for BE and LAC

Robust regression analysis (M-estimation method) was conducted with parity, duration of the first stage of labor, and duration of the second stage of labor as independent variables, and BE as the dependent variable. Results indicated that parity significantly positively influenced BE

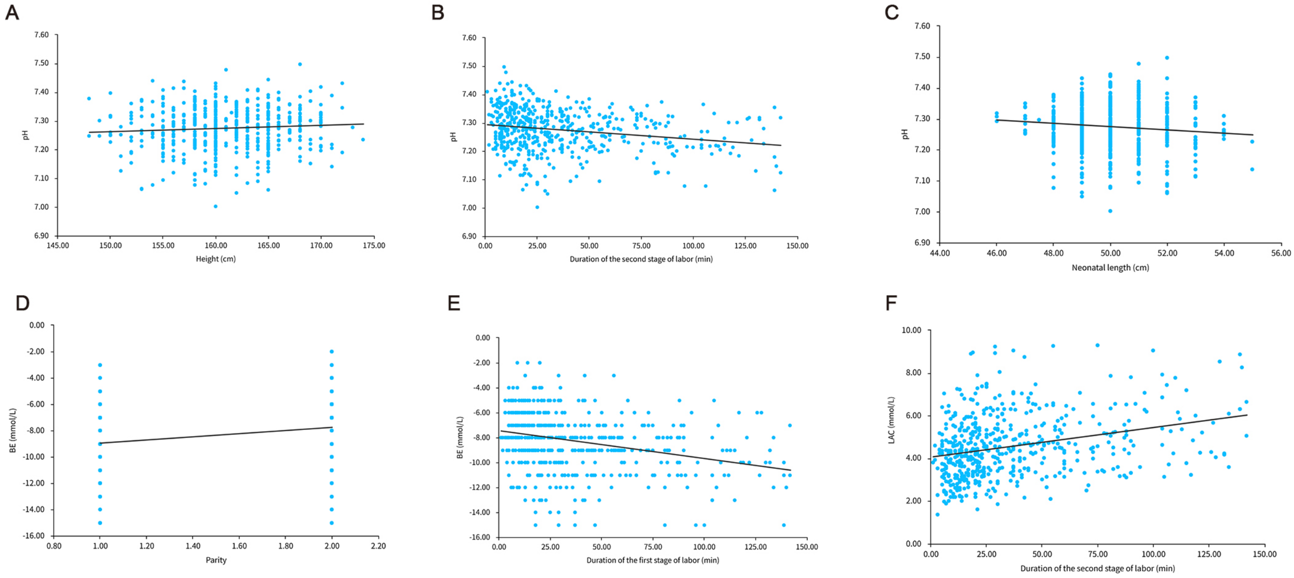

Fig. 2. Linear regression plot for pH, BE, and LAC. (A) Scatter plot of pH and maternal height and the linear regression formula for the scatter plot data is: pH = 6.958 + 0.002 × height, with an R^2 = 0.008. (B) Scatter plot of pH and duration of the second stage of labor, and the linear regression formula for the scatter plot data is: pH = 7.299 – 0.001 × duration of the second stage of labor, with an R^2 = 0.047. (C) Scatter plot of pH and neonatal length, and the linear regression formula for the scatter plot data is: pH = 9.131 – 0.037 × neonatal length, with an R^2 = 0.035. (D) Scatter plot of BE and parity, and the linear regression formula for the scatter plot data is: BE = –8.780 + 0.500 × parity, with an R^2 = 0.042. (E) Scatter plot of BE and duration of the second stage of labor, and the linear regression formula for the scatter plot data is: BE = –7.533 – 0.017 × duration of the second stage of labor, with an R^2 = 0.089. (F) Scatter plot of LAC and duration of the second stage of labor, and the linear regression formula for the scatter plot data is: LAC = 4.288 + 0.003 × duration of the second stage of labor, with an R^2 = 0.078.

(β = 0.572, p = 0.015), while the duration of the second stage of labor significantly negatively influenced BE (β = –0.017, $p < 0.001$) (Table 4).

Robust regression analysis (M-estimation method) was conducted using parity, premature rupture of membranes, duration of second stage of labor, duration of third stage of labor, and immediate blood loss as independent variables, with LAC as the dependent variable. Results indicated that only the duration of the second stage of labor was significantly positively correlated with LAC (β = 0.011, $p < 0.001$) (Table 4). In summary, both linear regression and robust regression analyses yielded consistent results.

3.6 Comparison of BE and LAC Values Between Primiparas and Multiparas, and Between the Epidural Anesthesia and No Anesthesia

Significant differences were observed in pH, BE and LAC between primiparous and multiparous women ($p < 0.05$). Significant differences in BE were observed between the epidural anesthesia and no-anesthesia groups ($p < 0.05$). No significant differences were observed in pH and LAC between the epidural anesthesia and no-anesthesia groups ($p > 0.05$, Fig. 3).

4. Discussion

This study identified significant associations between labor characteristics and neonatal UABG parameters in low-risk Tibetan populations at high altitude. Our core finding is that the duration of the second stage of labor serves as a key modifiable factor, with prolonged duration independently predicting lower BE and higher LAC levels. Additionally, primiparity emerged as a major factor influencing umbilical cord blood gas values. Maternal height also showed a positive correlation with neonatal pH levels, although its predictive capability remains limited.

In this study, the median pH value of 7.28 (IQR: 7.22, 7.33) aligns closely with previous studies. For instance, it is comparable to the pH value of 7.25 ± 0.07 reported in 296 term newborns in Weifang [13] and the pH value of 7.25 ± 0.13 observed in 2121 newborns in Hulunbuir [14], indicating that pH values in healthy term neonates remain within a narrow range. In this study, the BE value of –8 (–10, –7) mmol/L was similar to the multicenter report of –7.66 ± 5.02 mmol/L [15], but lower than the –5.08 ± 2.53 mmol/L observed in 182 term newborns in Hainan [16]. The LAC value of 4.37 (3.47, 5.40) mmol/L in this study was comparable to the 3.91 ± 2.47 mmol/L reported by Weifang [13]. Similarly, our findings align with a study of healthy term newborns at 3500 meters in

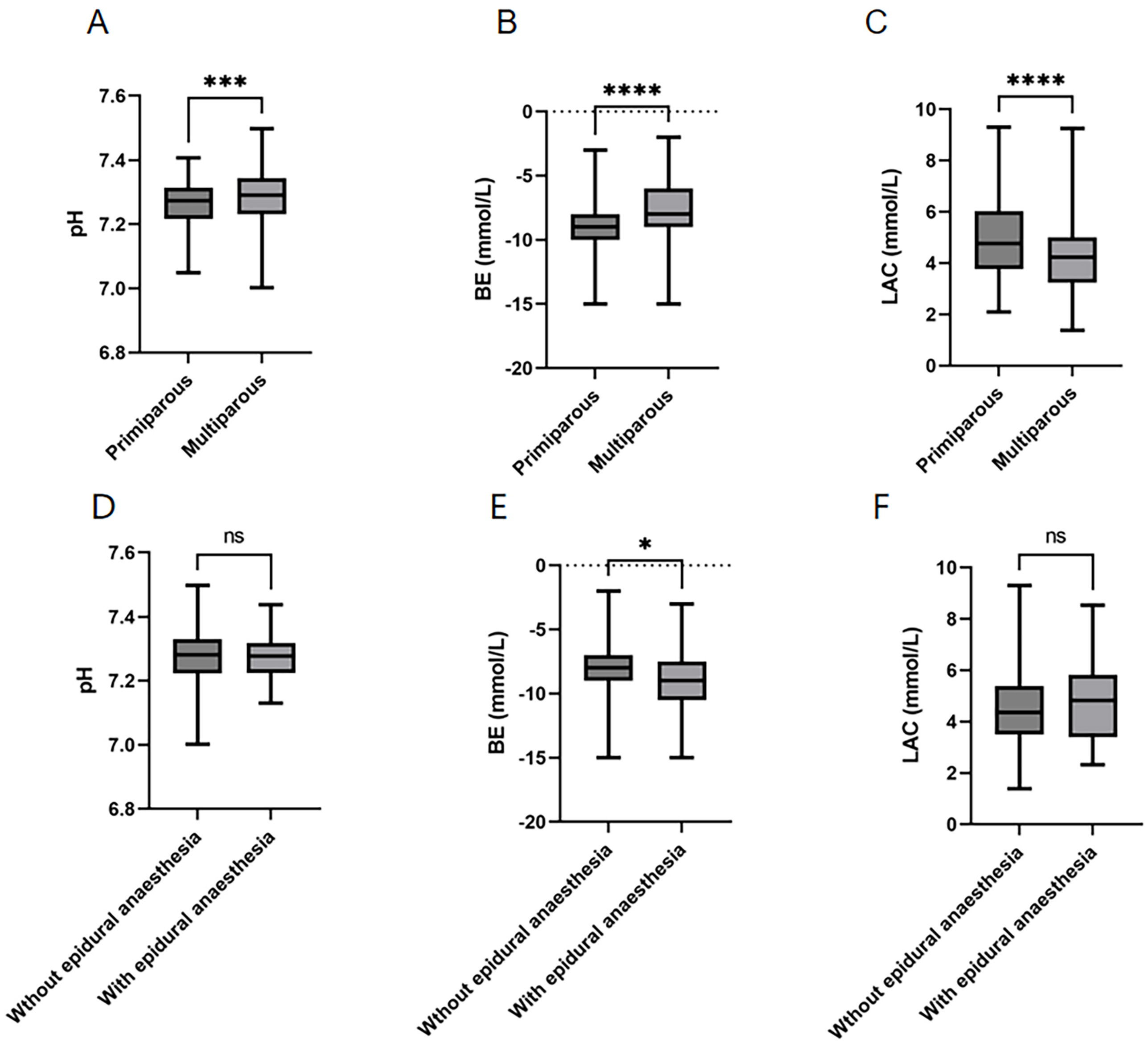

Fig. 3. Comparison of pH, BE, and LAC between primiparas and multiparas, and between anesthesia and no anesthesia. (A) Comparison of pH between primiparas and multiparas. (B) Comparison of BE between primiparas and multiparas. (C) Comparison of LAC between primiparas and multiparas. (D) Comparison of pH with and without anesthesia. (E) Comparison of BE with and without anesthesia. (F) Comparison of LAC with and without anesthesia. **** $p < 0.0001$, *** $p < 0.001$, * $p < 0.05$, ns: not significant.

Yunnan [17], which reported UABG parameters of pH 7.29 (7.17–7.35), LAC 4.50 (3.40–5.73) mmol/L, and BE –7.20 (–9.70 to –4.70) mmol/L. However, specific statistical differences will require evaluation in future studies that compare high-altitude regions with lowland or other plateau areas. In our study, all neonates had a 1-minute Apgar score of $\geq$7, which may have limited the variability in clinical condition at birth. Notably, even in populations with lower Apgar scores, prior studies have reported a weak correlation between Apgar scores and umbilical cord blood gas parameters. For example, a study of newborns with Apgar scores <8 found only weak, though statistically significant, correlations between Apgar scores and pH or bicarbonate levels in umbilical vein blood. This finding suggests that Apgar scores and blood gas analysis provide complementary, rather than interchangeable, assessments of neonatal condition at birth [18]. This aligns with our findings that, even within a low-risk cohort, factors such as labor duration and parity exert more consistent influences on UABG parameters than Apgar score alone.

Linear regression analysis indicates that the duration of the second stage of labor is an independent determinant of neonatal UABG parameters. Specifically, prolonged second stage of labor was significantly associated with lower BE and higher LAC levels, while exhibiting a negative correlation with pH. To assess the robustness of these associations, we further conducted robust regression analysis using the M-estimation method. The results confirmed that the duration of the second stage of labor remained significantly associated with BE and LAC, supporting the primary findings of the linear regression. At elevations above 2500 meters, the partial pressure of atmospheric oxygen decreases significantly, which affects umbilical artery blood gas levels [19]. Although the Tibetan population has developed adaptive features such as enhanced erythropoiesis and placental vascular remodeling, their fetuses remain in a state of relative hypoxia compared with those at sea level [20]. This hypoxic stress is exacerbated by the prolonged second stage of labor [21]. The increased frequency and intensity of uterine contractions reduce placental blood flow and thereby decrease oxygen delivery to the fetus. In order to sustain energy metabolism, fetal tissues shift towards anaerobic glycolysis, resulting in increased LAC production (manifested as an elevated LAC levels) and subsequent metabolic acidosis, reflected by more negative BE values [22]. Previous studies have found that healthy term newborns born at high altitude, up to 3600 meters above sea level, often exhibit pH and LAC levels in the UABGA that fall within the high-risk critical range [23,24]. This phenomenon may relate to the hypoxic intrauterine environment (oxygen partial pressure of 16–27 mmHg). Under these conditions, the fetus relies mainly on glucose oxidation to maintain physiological functions [25]. In addition, most of the LAC in fetal UABGA is produced during the second stage of labor [26]. Meanwhile, mothers undergo a series of compensatory physiological adaptations to the chronic low-pressure hypoxic environment of high-altitude region. These changes may lead to an increase in placental blood flow [27], thus partially mitigating the effects of chronic hypoxia. Therefore, closer labor monitoring and neonatal assessment are needed for primiparous women in highland areas to identify and manage potential hypoxic and metabolic complications promptly, even during a physiologically normal labor period.

Additionally, this study found a weak positive association between maternal height and umbilical artery pH (β = 0.002, p = 0.016). The mean height of mothers in the lower pH group ($\leq$7.28) was 160.69 cm, significantly lower than the 161.56 cm observed in the higher pH group ($>$7.28) (p = 0.047). This effect may stem from shorter maternal stature being associated with smaller pelvic volumes, increasing resistance during fetal descent. In high-altitude environments, chronic hypoxia may modestly impair uterine contractions coordination [28]. This can further prolong labor duration (with a longer third stage duration in the lower pH group, p = 0.026), thereby exposing the fetus to intermittent hypoxia. Cumulative hypoxic stress disrupts fetal acid-base balance, leading to a modest yet measurable pH decrease. Notably, the adjusted coefficient of determination (R^2) for the pH regression model was only 0.061. This unexpected association may reflect increased oxygen demand in longer fetuses or changes in fetal position during labor; however, the underlying mechanism requires further investigation.

Primiparity and premature rupture of membranes are additional factors associated with UABG parameters. Primiparous women were more likely to exhibit decreased BE values (172/331 cases in the low BE group, vs. 53/193 in the high BE group, p = 0.001) and elevated LAC values (87/262 primiparas in the low LAC group vs. 138/262 in the high LAC group, p = 0.001). In both linear and robust regression analyses, parity showed a significant association with BE levels. Linear regression revealed parity as a positive predictor. Primiparas exhibit poorer uterine contraction coordination and slower cervical dilation [29], leading to prolonged first and second stages of labor. The median duration of the first stage was 320.00 minutes in the low BE group, significantly longer than 240.00 minutes in the high BE group ($p < 0.001$). Prolonged labor exacerbates fetal hypoxia, resulting in LAC accumulation and reduced BE values [30]. Premature rupture of membranes correlates with elevated LAC levels, observed in 69 of 262 cases in the high LAC group compared with 46 of 262 in the lower LAC group (p = 0.015). This effect occurs because premature rupture of membranes compromises the integrity of the amniotic cavity, potentially reducing amniotic fluid volume and impairing both fetal buffering capacity and placental oxygen exchange efficiency [31]. In the oxygen-limited environment of high altitude, premature rupture of membranes may further exacerbate fetal hypoxic stress, leading to elevated LAC levels.

This study identified significant differences in umbilical artery blood pH, BE, and LAC levels between newborns of primiparous and multiparous mothers in high-altitude regions. These findings are consistent with multiple studies conducted in lowland areas, indicating that parity is an important determinant of UABG parameters. A large-scale, multicenter study conducted across six Chinese hospitals, comprising 20,191 newborns, demonstrated that parity significantly impacts UABG values [15]. Notably, in this study, epidural anesthesia affected only BE values, without significantly altering pH or LAC levels. This suggests that the acid-base balance changes induced by epidural anesthesia are primarily metabolic in nature and relatively mild, not reaching the threshold required to cause significant alterations in pH and LAC levels. This study exhibits both similarities and differences compared with the Tehran, Iran study regarding the effects of epidural anesthesia on neonatal acid-base balance [32]. Both studies observed a shift toward more negative BE values in the epidural group. However, a key discrepancy lies in the impact on pH: the Iranian study reported a significant pH decrease in the epidural group, whereas no such change was observed in the high-altitude setting of the present study. This discrepancy may result from variations in anesthetic management strategies between locations (e.g., blood pressure maintenance, oxygen therapy application). Additionally, differences in study population characteristics or statistical power may also be contributing factors. Overall, these findings suggest that although epidural anesthesia exerts a relatively consistent effect on fetal metabolic status, its impact on overall acid-base balance may be modulated by regional environmental factors, clinical practices, and population characteristics.

Limitations

This study presents some limitations. Our findings are based on a rigorously selected, low-risk, physiologically normal Tibetan population. We intentionally excluded pregnant women with comorbidities or complications, resulting in a highly homogeneous sample with limited variability in key blood gas parameters (pH, BE, and LAC). Therefore, while this study design facilitates the identification of relevant factors within normal physiological ranges, it inherently limits the generalizability of our findings to broader, more heterogeneous obstetric populations encompassing high-risk pregnancies. Future studies incorporating a wider spectrum of risk profiles are needed to validate and extend these findings. The present study employed a single-center, retrospective design may, which may have introduced selection bias and did not include stratified analyses based on altitudes (e.g., above 250 m vs. 4000 m) or pre-pregnancy comorbidities (e.g., gestational hypertension). Future studies could adopt a prospective cohort design to expand the sample size and further validate these findings. In addition, future studies could explore how varying altitudes in highland regions affect labor, delivery, and neonatal outcomes.

5. Conclusions

In conclusion, the present study revealed the relationship between labor and delivery characteristics and neonatal UABGs in secular Tibetan mothers living in the plateau region. In this low-risk population, factors influencing pH include maternal height, the duration of the second stage of labor, and neonatal length. Factors influencing BE include parity and the duration of the second stage of labor. The duration of the second stage of labor is a factor influencing LAC.

Availability of Data and Materials

All data reported in this paper will be shared by the corresponding author upon request.

Author Contributions

ZDo: conceptualization, investigation, formal analysis, data curation, writing—original draft preparation. BC: conceptualization, methodology, investigation, writing—original draft preparation. QG: investigation, data curation, writing—review and editing. LY, ZDa, LC, and ZC: investigation, writing—review and editing. PZ: formal analysis, writing—review and editing. ZY: data curation, writing—review and editing. JF: conceptualization, methodology, investigation, supervision, writing—original draft preparation, writing—review and editing. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

The research adheres to the Declaration of Helsinki. Ethical approval was obtained from the medical ethics committee of Lhasa People's Hospital (No. SYLL22250108). This is a retrospective study utilising anonymised routine clinical data; no interventions were performed on patients, nor was there any contact with individual patients. Given the retrospective design of this study and the analysis of anonymised data, the Ethics Committee has waived the requirement for informed consent.

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Conflict of Interest

The authors declare no conflict of interest.

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