

Original Article



Hemoglobin Thresholds for Defining Anemia among Healthy Infants Aged 0–5 Months in China: A Population-based Study

Shuxia Wang¹, Shan Jiang¹, Xuehong Pang¹, Qian Zhang¹, Bowen Chen², Tao Xu³, Yuying Wang¹,
Wenhua Zhao¹, and Zhenyu Yang^{1,#}

1. National Institute for Nutrition and Health, Chinese Center for Disease Control and Prevention. Key Laboratory of Public Nutrition and Health, National Health Commission of the People's Republic of China. Key Laboratory of Human Breast Milk Science, Chinese Center for Disease Control and Prevention, Beijing 100050, China; 2. Capital Institute of Pediatrics, Beijing 100020, China; 3. National Center for Women and Children's Health, National Health Commission of the People's Republic of China, Beijing 100081, China

Abstract

Objective To develop hemoglobin (Hb) percentiles and thresholds for defining anemia among infants aged 0–5 months in China.

Methods The National Nutrition and Health Systematic Survey for children aged 0–17 years in China, a nationwide cross-sectional study, was conducted between 2019 and 2021. Hb levels were measured in infants using the HemoCue 201+ analyzer. Age- and sex-specific Hb distributions were constructed for “healthy infants”, defined as those with adequate iron reserves at birth, exclusive breastfeeding, normal weight-for-age Z-score and weight growth velocity, normal neuropsychological development, and absence of acute or chronic diseases. A generalized additive model for location, scale, and shape was applied to fit the Hb percentiles. The 5th percentile of the Hb distribution was defined as the threshold for anemia.

Results A total of 10,174 infants aged 0–5 months participated in the study, among whom 2,155 healthy infants were included in the analysis. Hb levels peaked at birth, gradually decreased to a nadir around 60 days after birth, and then rose to a plateau. The Hb thresholds defining anemia were 102.7 g/L, 96.3 g/L, 92.8 g/L, 95.4 g/L, 97.1 g/L, and 95.8 g/L for the 0-, 1-, 2-, 3-, 4-, and 5-month age groups, respectively.

Conclusion This study establishes hemoglobin thresholds for defining anemia in infants aged 0–5 months based on a nationwide, population-based dataset in China.

Key words: Infant; Hemoglobin; Anemia

Biomed Environ Sci, 2026; 39(4): 408-417

doi: [10.3967/bes2025.144](https://doi.org/10.3967/bes2025.144)

ISSN: 0895-3988

www.besjournal.com (full text)

CN: 11-2816/Q

Copyright ©2026 by China CDC

INTRODUCTION

Anemia is a condition characterized by an insufficient number of red blood cells and, consequently, a reduced oxygen-carrying capacity that fails to meet the body's physiological

needs^[1].

Anemia is one of the most significant public health problems worldwide, particularly in developing countries. The Global Burden of Disease 2021 Anemia Collaborators estimated that the global prevalence of anemia across all age groups was

[#]Correspondence should be addressed to Zhenyu Yang, PhD, Tel: 86-10-66237198, E-mail: yangzy@ninh.chinacdc.cn
Biographical note of the first author: Shuxia Wang, MS, majoring in maternal and child's nutrition, E-mail: wangsx@ninh.chinacdc.cn

24.3%, corresponding to approximately 1.92 billion cases^[2]. Children under five years of age, pregnant women, and the elderly are considered high-risk groups for anemia. In children, anemia is associated with impaired cognitive, motor, and behavioral development, as well as increased susceptibility to infections^[3]. Normal hemoglobin (Hb) levels vary according to age, sex, physiological status, and altitude. Peripheral blood Hb concentration is internationally recognized as the standard indicator for diagnosing anemia.

The World Health Organization (WHO) published the latest guideline on Hb cutoffs for defining anemia using a statistical approach in 2024. This guideline encompasses nearly all population groups, except for infants aged 0–5 months^[1]. In 2002, the WHO established anemia thresholds of 135 g/L at birth and 95 g/L for infants aged 2–6 months^[4]; however, these thresholds were not adopted in the 2024 guideline^[1]. Few studies have established anemia thresholds for infants younger than 6 months. Most of these studies either did not include “healthy infants”^[5] or included those who were not sufficiently healthy^[6]. Although some studies defined “healthy infants,” they did not account for the dynamic changes in Hb levels during the first six months of life. Instead, they proposed Hb cutoffs for the entire 0–6-month period or for specific age groups^[7]. At present, there is no universally accepted Hb cutoff for infants of specific monthly ages worldwide.

Infancy is a rapid and dynamic period of human growth and development. Anemia during this stage can exert long-term adverse effects on health and development. It is crucial to establish the critical Hb levels for diagnosing anemia in infants. Therefore, this study aimed to utilize data from the National Nutrition and Health Systematic Survey for Children Aged 0–17 Years in China (CNHSC) to develop Hb percentiles for infants aged 0–5 months. These findings will provide a foundation for further research and the establishment of reference Hb thresholds for diagnosing anemia in this age group.

METHODS

Study Design and Subjects

This study was part of CNHSC, a nationwide, population-based cross-sectional survey designed to collect representative data on the nutritional status, growth, and health of children aged 0–17 years across different regions of China between 2019 and

2021. Detailed descriptions of the survey design and methods have been published elsewhere^[8]. In brief, a multistage stratified randomized cluster sampling design was employed. Two provinces were randomly selected from each of the seven regions of China—eastern, northern, central, southern, southwestern, northwestern, and northeastern. From each selected province, one urban district and one rural county were further randomly chosen.

In this study, data from infants aged 0–5 months were extracted to examine Hb levels and to establish anemia thresholds for this age group in China. The inclusion criteria were healthy, locally born infants younger than six months. The exclusion criteria included infants with acute or chronic illnesses, such as acute respiratory tract infection, acute gastroenteritis, or congenital heart defects. “Healthy infants” were defined as those with adequate iron reserves at birth^[9], exclusive breastfeeding (EBF), normal physical and neuropsychological development, and absence of acute or chronic diseases. Specific definitions are provided in [Table 1](#). Infants aged 0–5 months were categorized into monthly groups: 0-month (0–30 days), 1-month (31–60 days), 2-month (61–90 days), 3-month (91–120 days), 4-month (121–150 days), and 5-month (151–180 days). The total sample comprised 11,088 infants from 14 provinces, with 1,848 infants per monthly group.

Procedures

Hb levels were measured using the HemoCue Hb 201+ system (HemoCue AB, Ängelholm, Sweden). A trained staff member disinfected the outer surface of the infant’s left middle finger, punctured it with a disposable lancet (STERILANCE, 26G, 1.8 mm), and gently pressed the finger using the left index finger and thumb to promote blood flow. The first two drops of blood were wiped away with a dry cotton ball, and the following large drop (more than 20 μ L) was collected to fill the entire HemoCue microcuvette. Another staff member wiped away any excess blood from the infant’s finger with a dry cotton ball and promptly (within 40 seconds) inserted the filled microcuvette into the analyzer for measurement. The Hb values were adjusted for altitude.

A structured questionnaire was administered to collect information on each infant, including date of birth, sex, ethnicity, gestational age, birth weight, birth length, feeding mode, and use of nutritional supplements. The infant’s date of birth, sex, ethnicity, gestational age, birth weight, and birth

length were obtained from the birth certificate by trained investigators. The infant's age was calculated by subtracting the date of birth from the date of the interview. The investigator asked the caregiver about the infant's feeding method. Infants aged 0–5 months were weighed in the morning using a Seca digital baby scale (Seca 335, Germany). The WHO Anthro Survey Analyzer was used to calculate the weight-for-age Z-score. Weight gain was calculated by subtracting birth weight from the weight measured during the survey. Weight velocity was expressed in 1-month increments up to 6 months. According to the WHO Child Growth Standards^[10], infants were classified as having normal or abnormal growth velocity based on weight. Because the WHO standards do not include data for the 4-month group, the value for 4 months was derived as the mean of the 3- and 5-month groups. EBF was defined as infants receiving only breast milk, without any additional food or liquid.

Neuropsychological and behavioral development was assessed using the Children Neuropsychological and Behavioral Scale – Revision 2016 (CNBS-R2016), which includes five domains: gross motor, personal-social, language, fine motor, and adaptive behavior^[11]. A trained developmental pediatrician administered the CNBS-R2016 using standardized procedures and assessment tools. The mean score of the CNBS-R2016 General Developmental Quotient is 100, with scores below 70 indicating developmental delay.

Quality Control (QC)

All investigators and laboratory personnel

completed national-level training before the initiation of the project. The training mainly included questionnaire survey and Hb testing. Personnel were certified and authorized to perform their respective duties only after passing a competency assessment that verified proficiency in assigned tasks.

A computer-aided survey system as a data collector was established, including a collection and storage data function, monitoring operations and control quality to ensure standardization and high quality of information collection.

Before each day's Hb analysis, a quality control (QC) panel consisting of both high- and low-level QC solutions was tested once. During the analysis, a QC slide was analyzed after every 30 samples. Test results were compared with the target values and allowable deviation ranges of the QC solutions, and data within these ranges were considered acceptable. The target value for the QC sample was 120 g/L, and the mean coefficient of variation was 1.47%.

Statistical Analysis

Differences in sociodemographic characteristics between the analytical and non-analytical samples were evaluated using chi-square (χ^2) tests or *t*-tests in SAS software (version 9.4). A generalized additive model for location, scale, and shape (GAMLSS) was applied to fit the Hb percentiles for infants aged 0–5 months in China using R software (version 4.3.1)^[12]. The GAMLSS model is suitable for analyses focusing not only on shifts in the mean (location) of the Hb distribution but also on its variance, skewness, kurtosis, and quantiles. Continuous distributions were employed because the response variable (Hb

Table 1. Definition of healthy infants

Indicators	Standards
	Singleton
Adequate iron reserves at birth ^[7]	Term delivery, 37 weeks ≤ gestational week ≤ 42 weeks No small-gestational-age (SGA) and large-gestational-age (LGA) No low-birthweight and macrosomia (2,500 g ≤ birthweight ≤ 4,000 g)
EBF	Breastfeeding after birth, not consuming complementary foods or formula Not consuming dietary supplements containing iron
Normal physical development	$2SD \leq WAZ \leq 2SD$ $-2SD \leq$ Growth velocity based on weight $\leq 2SD$
Normal neuropsychological development	Score of CNBS-R2016 ≥ 70
Disease status	No acute and chronic diseases reported

Note. SGA, Small-gestational-age; LGA, Lager-gestational-age; EBF, Exclusively breastfeeding; SD, Standard deviation; WAZ, Weight-for-age Z-score; CNBS-R2016, Children Neuropsychological and Behavioral Scale – Revision 2016.

concentration) was continuous. Based on the principle of minimizing the Akaike Information Criterion, the cubic spline transformation was applied to estimate the location, scale, and shape parameters using the GAMLSS package. The 5th percentile of the Hb distribution, adjusted for altitude, was defined as the threshold for diagnosing anemia. Selecting the 5th percentile provides greater sensitivity for identifying infants with potential underlying conditions associated with anemia, thereby facilitating timely intervention.

RESULTS

A total of 10,174 infants aged 0–5 months completed the CNHSC survey and had Hb measurements, including 1,695, 1,722, 1,661, 1,687, 1,739, and 1,670 infants in the 0-, 1-, 2-, 3-, 4-, and 5-month groups, respectively. After excluding infants whose mothers were younger than 18 years or older than 45 years, 9,712 infants were included in the analysis. Following the exclusion of individuals with insufficient iron stores, non-EBF, or physical development abnormalities (non-analytical samples),

2,155 infants remained in the analytical sample (Figure 1).

Basic Characteristics of the Study Infants

In the analytical sample, there were 190, 381, 413, 427, 403, and 341 infants in the 0-, 1-, 2-, 3-, 4-, and 5-month groups, respectively. The proportion of male infants was 47.9%, and 92.3% of the infants were of Han ethnicity. The mean birth weight was $3,222.0 \pm 259.5$ g. Statistically significant differences ($P < 0.001$) were observed between the analytical and non-analytical samples in terms of age in months, sex, ethnicity, gestational age at delivery, birth weight, age-specific weight, and Hb concentration (Table 2).

Distribution of Hb Values among Infants Aged 0–5 Months in the Analytical Sample

The median Hb values for the 0-, 1-, 2-, 3-, 4-, and 5-month groups were 128.0 g/L, 119.0 g/L, 115.0 g/L, 117.0 g/L, 118.0 g/L, and 117.0 g/L, respectively (Table 3). Hb levels decreased after birth, reached their nadir at approximately 2 months of age, and gradually increased thereafter in both

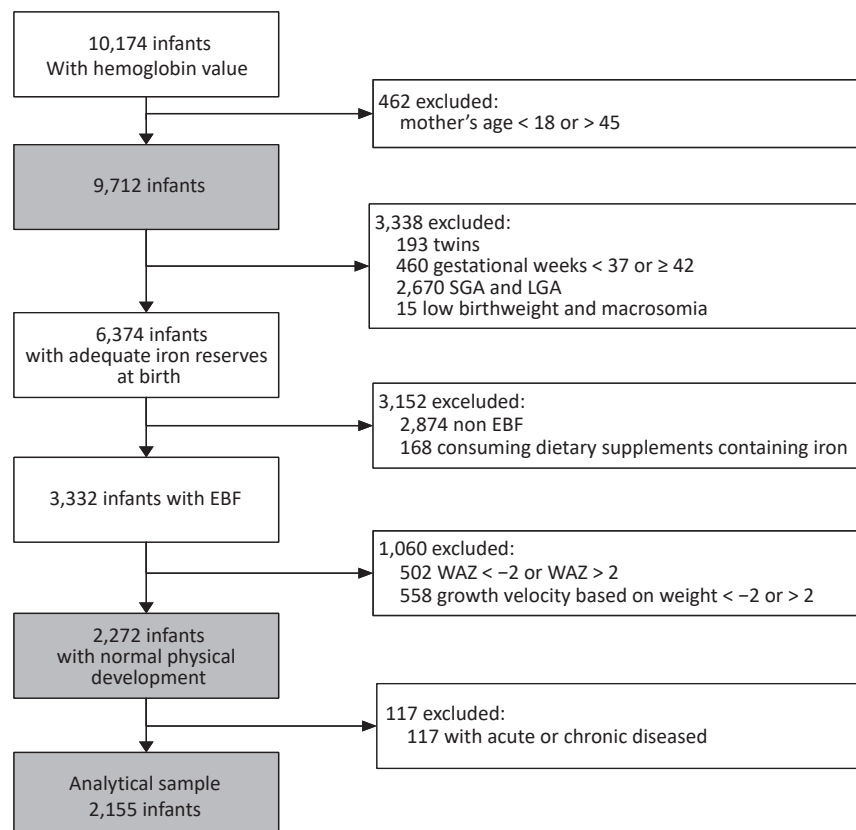


Figure 1. Flowchart of subject selection. EBF, Exclusively breastfeeding; SGA, Small-gestational-age; LGA, Larger-gestational-age; WAZ, Weight-for-age Z-score.

boys and girls.

Construction of the Hb Distribution Model for Infants Aged 0–5 Months

The median Hb values for infants aged 0, 1, 2, 3, 4, and 5 months were 127.8 g/L, 118.8 g/L,

115.5 g/L, 117.0 g/L, 117.6 g/L, and 115.8 g/L, respectively. The analysis results from the GAMLSS indicated that Hb levels peaked at birth and gradually decreased to a nadir at approximately 60 days after birth, representing a decline of about 12.3 g/L at the 50th percentile. Thereafter, Hb levels

Table 2. Comparison of basic characteristics between analytical samples and samples excluded

Characteristics	Analytical sample 1		Non-analytical sample		P
	n	Mean (SD) / %	n	Mean (SD) / %	
Months					< 0.001
0- month	190	8.8	1,373	18.6	
1- month	381	17.7	1,216	16.5	
2- month	413	19.2	1,109	15.1	
3- month	427	19.8	1,181	16.0	
4- month	403	18.7	1,249	17.0	
5- month	341	15.8	1,236	16.8	
Sex					0.022
Boy	1,033	47.9	3,737	50.8	
Girl	1,122	52.1	3,627	49.3	
Ethnicity					< 0.001
Han ethnicity	1,988	92.3	6,521	88.6	
Non Han ethnicity	167	7.8	843	11.5	
Region					< 0.001
Northeast China	348	16.2	1,196	16.2	
North China	296	13.7	1,227	16.7	
East China	352	16.3	1,142	15.5	
South China	213	9.9	697	9.5	
Central China	284	13.2	918	12.5	
Northwest China	310	14.4	1,274	17.3	
Southwest China	352	16.3	910	12.4	
Gestational week at delivery (wk)	2,155	39.2 (1.0)	6,745	39.0 (1.5)	< 0.001
Birthweight (g)	2,155	3,222.0 (259.5)	7,029	3,331.3 (474.4)	< 0.001
WAZ	2,155	0.4 (0.8)	7,162	0.5 (1.4)	< 0.001
Weight gain (g)					
0- month	190	775.2 (325.2)	1,326	1,023.2 (1,842.5)	< 0.001
1- month	381	1,906.3 (487.5)	1,176	1,856.8 (2,217.5)	0.666
2- month	413	2,880.6 (596.4)	1,064	2,916.1 (1,385.2)	0.615
3- month	427	3,460.4 (650.1)	1,120	3,669.6 (1,896.0)	0.001
4- month	403	3,960.0 (685.7)	1,176	4,197.2 (1,209.8)	< 0.001
5- month	341	4,458.4 (761.5)	1,166	4,822.4 (2,257.9)	< 0.001
Hb concentration (g/L)	2,155	118.0 (14.0)	7,364	118.9 (18.5)	0.039

Note. SD, Standard deviation; WAZ, Weight-for-age Z-score; Hb, Hemoglobin.

increased and reached a plateau. These trends were nearly identical for boys and girls. However, the median Hb concentrations at different months varied slightly by sex. The 50th percentile Hb level decreased by 11.9 g/L between 0 and 60 days for boys, whereas it decreased by 14.6 g/L for girls. Subsequently, Hb concentrations increased in both boys and girls from 60 days onward. The results are presented in Figures 2 and 3 and detailed in Table 4.

Threshold Values for Hb Determination of Anemia among Infants Aged 0–5 Months in China

The reference Hb ranges for infants aged 0, 1, 2, 3, 4, and 5 months were 102.7–153.6 g/L, 96.3–142.0 g/L, 92.8–138.8 g/L, 95.4–139.2 g/L, 97.1–138.6 g/L, and 95.8–136.3 g/L, respectively. In this study, the 5th percentile of Hb distribution was defined as the threshold for diagnosing anemia. The Hb thresholds corresponding to the 5th percentile were 102.7 g/L, 96.3 g/L, 92.8 g/L, 95.4 g/L, 97.1 g/L, and 95.8 g/L for the 0-, 1-, 2-, 3-, 4-, and 5-month groups, respectively. The 5th percentile threshold decreased by 9.0 g/L between 0 and 60 days for boys and by 12.6 g/L for girls. The anemia rates in the analytical and non-analytical samples were 4.6% and

5.9%, respectively.

DISCUSSION

Hb concentration exhibits a distinct postnatal pattern characterized by an initial peak at birth, followed by a gradual decline to a nadir around 60 days after birth. Subsequently, Hb levels increase and stabilize. These trends are generally consistent between male and female infants, although the median Hb concentrations at various months differ by sex. Specifically, the 50th percentile Hb level decreased by 11.9 g/L in male infants and by 14.6 g/L in female infants from birth to 60 days. After this period, Hb concentrations began to rise in both sexes. Similarly, the 5th percentile threshold decreased by 9.0 g/L in male infants and by 12.6 g/L in female infants during the same time frame.

The postnatal fluctuations in Hb levels are notable. In the present study, infants in the 0-month cohort exhibited the highest Hb values, which gradually declined from 1 to 2 months, followed by a steady increase from 3 to 5 months, ultimately reaching a plateau. These observed Hb patterns align with trends reported in previous research. Jopling

Table 3. Hb distribution by sex in infants aged 0–5 months in analytical sample (g/L)

Sex	Months	<i>n</i>	Mean	<i>SD</i>	<i>P</i> ₁	<i>P</i> ₅	<i>P</i> ₂₅	<i>P</i> ₅₀	<i>P</i> ₇₅	<i>P</i> ₉₅	<i>P</i> ₉₉
All	0– month	190	128.8	16.5	98.0	103.0	117.0	128.0	141.0	156.0	185.0
	1– month	381	118.5	13.5	82.0	97.0	109.0	119.0	127.0	141.0	152.0
	2– month	413	115.1	14.3	84.0	92.0	106.0	115.0	124.0	140.0	151.0
	3– month	427	117.4	13.2	87.0	96.0	109.0	117.0	125.0	142.0	151.0
	4– month	403	117.8	12.8	84.0	98.0	110.0	118.0	124.0	142.0	152.0
	5– month	341	115.9	12.0	87.0	94.0	109.0	117.0	122.0	135.0	143.0
Boy	0– month	101	129.7	16.8	103.0	108.0	117.0	131.0	139.0	156.0	185.0
	1– month	174	119.3	13.1	87.0	98.0	110.0	120.0	128.0	140.0	147.0
	2– month	207	115.8	14.9	86.0	94.0	104.0	115.0	126.0	140.0	151.0
	3– month	192	117.9	13.1	83.0	97.0	110.0	118.0	126.0	141.0	151.0
	4– month	185	118.8	13.5	84.0	99.0	111.0	119.0	124.0	142.0	158.0
	5– month	170	116.5	12.4	87.0	94.0	109.0	116.0	124.0	137.0	145.0
Girl	0– month	89	131.0	15.7	98.0	107.0	118.0	130.0	144.0	155.0	171.0
	1– month	207	119.5	13.0	90.0	100.0	110.0	119.0	128.0	141.0	152.0
	2– month	206	116.3	12.5	92.0	96.0	108.0	116.0	124.0	135.0	149.0
	3– month	235	119.4	12.4	94.0	100.0	110.0	120.0	127.0	142.0	152.0
	4– month	218	119.9	11.1	96.0	103.0	113.0	120.0	125.0	141.0	144.0
	5– month	171	118.2	10.7	88.0	98.0	112.0	119.0	123.0	135.0	144.0

Note. *SD*, Standard deviation; Hb, Hemoglobin.

and Christensen established reference ranges for Hb during the neonatal period, reporting a linear decrease from 180.0 g/L at birth to 130.0 g/L at 28 days postpartum, which continued to decline to 110.0 g/L at 90 days postpartum^[13,14]. Similarly, a Brazilian cohort study observed a decrease in mean Hb concentration among term infants ($n = 21$), from 159.6 g/L at birth to 119.5 g/L at 1 month and further to 105.5 g/L at 2 months^[15]. The rapid decline in Hb during the first month may be attributed to reduced erythropoietin production and mild transient hemolysis, particularly during the first week^[16,17]. From approximately 60 days after birth, Hb concentrations in infants begin to rise gradually. In a study involving infants in The Gambia ($n = 675$), Hb concentrations at the 2.5th and 97.5th

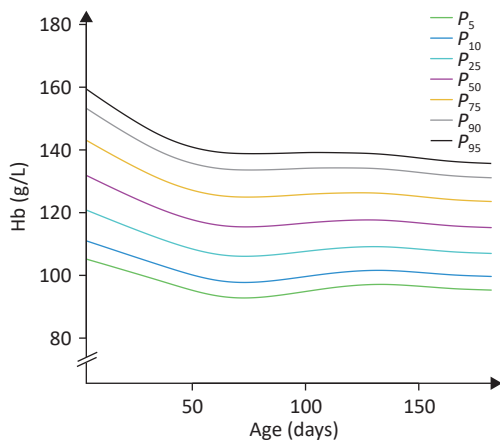
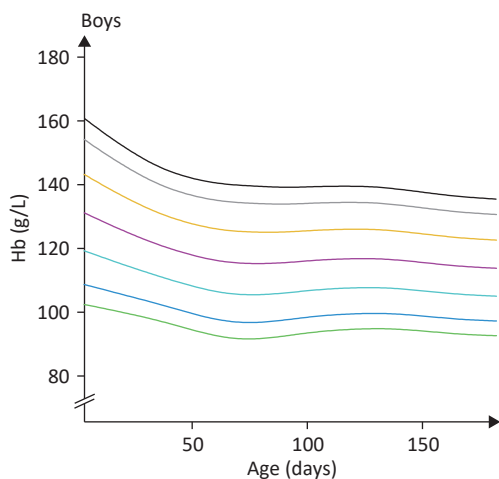


Figure 2. Smoothed hemoglobin percentile curves for infants aged 0–180 days in the analytical sample.



percentiles for infants aged 2 to 5 months were reported as 90.0–127.0 g/L for males and 93.0–129.0 g/L for females^[18]. Blouin and Marol reported Hb values of 104.0 g/L^[19] for infants aged 4 months and 97.0 g/L^[20] for those aged 3–5 months, respectively.

Notably, male infants tend to have lower Hb levels than their female counterparts. In Southeast Asia, male infants aged 4–6 months exhibited significantly lower Hb concentrations than females (108.7 g/L vs. 111.4 g/L, $P = 0.04$)^[21]. Similar findings were reported among Gambian infants aged 2–5 months ($P = 0.002$)^[18] and Turkish infants aged 5–7 months (105.0 g/L vs. 108.0 g/L, $P = 0.003$)^[5]. Some studies suggest that lower iron stores in male infants may contribute to their reduced Hb levels, possibly due to sex-based differences in fetal iron absorption or increased iron demands associated with faster growth rates^[21].

The reference values for Hb in infants at different ages—specifically 0, 1, 2, 3, 4, and 5 months—were as follows: 102.7–153.6 g/L, 96.3–142.0 g/L, 92.8–138.8 g/L, 95.4–139.2 g/L, 97.1–138.6 g/L, and 95.8–136.3 g/L, respectively. In Nigeria, normative Hb values for healthy infants have been established at 135.0–180.0 g/L for those aged 1–7 days, 130.0–160.0 g/L for infants aged 8–14 days, and 125.0–140.0 g/L for those between 1 month and 1 year^[7]. In another African context, Humberg et al. proposed a reference range of 84.0–128.0 g/L for Hb concentrations in infants aged 4 to 9 weeks^[22]. Troy et al. suggested reference values of 90.0–119.0 g/L and 90.0–121.0 g/L for infants aged 3 and 5 months, respectively^[23]. A study conducted in The Gambia corroborated the findings reported by Troy et al.^[18].

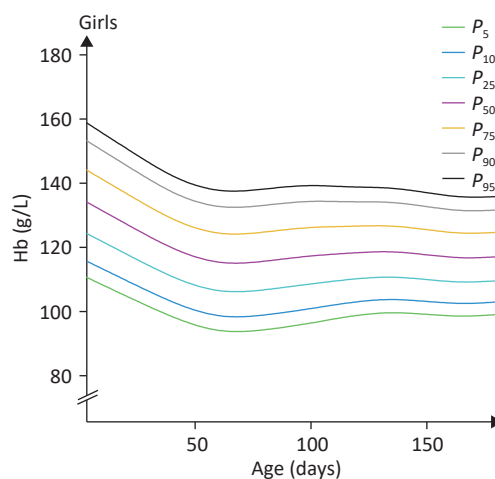


Figure 3. Sex-specific smoothed hemoglobin percentile curves for infants aged 0–180 days in the analytical sample.

Notably, the aforementioned studies did not account for iron stores at birth or feeding mode, which may have contributed to the lower reference values compared with those observed in the present study.

There is a paucity of research establishing Hb thresholds for diagnosing anemia in infants younger than 6 months. Magnus et al. identified an Hb concentration below 105.0 g/L as the cutoff value for anemia in 4-month-old infants with adequate iron stores^[6]. Yalcin et al. excluded infants with acute or chronic illnesses or a family history of thalassemia and reported a reference value of 92.0 g/L for infants aged 5–7 months^[5]. Using the 5th percentile as a diagnostic threshold among apparently healthy infants, we proposed Hb cutoff values of 102.7 g/L, 96.3 g/L, 92.8 g/L, 95.4 g/L, 97.1 g/L, and 95.8 g/L to define anemia in the 0-, 1-, 2-, 3-, 4-, and 5-month age groups, respectively. Factors such as ethnicity, timing of complementary food introduction, and disease status may influence Hb levels, which may partly explain the inconsistencies between the anemia thresholds identified in this study and those in the WHO guidelines and other studies.

This study has several limitations. First, the Hb

thresholds used to define anemia were derived from a statistical approach rather than from associations with health outcomes. Given that this was a cross-sectional study, longitudinal research is warranted to validate the proposed cutoff values. Second, biochemical indicators of the infants' iron nutritional status were not included. Previous studies have demonstrated that total fetal iron stores are positively correlated with birth weight and gestational age,^[9] and infants with abnormal birth weight were excluded from the present analysis. In addition, the malaria infection status of the infants was not assessed. However, the current malaria prevalence in China is extremely low, and the country received malaria-free certification from the WHO in 2021^[24]. The timing of umbilical cord clamping was also not recorded in this study. Research has shown that the timing of umbilical cord ligation during delivery directly affects the infant's Hb concentration, and this influence may persist for a certain period^[19]. China adopted the WHO's Early Essential Newborn Care (EENC) program in 2016, which has since been gradually implemented nationwide. Delayed cord clamping is one of the key recommended interventions under the EENC

Table 4. Hb distribution by sex in infants aged 0–5 months fitted by GAMLSS (g/L)

Sex	Months	Day-age (d)	P_1	P_5	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{95}	P_{99}
All	0- month	15	92.6	102.7	108.2	117.4	127.8	138.3	147.8	153.6	164.5
	1- month	45	87.2	96.3	101.2	109.5	118.8	128.2	136.8	142.0	151.8
	2- month	75	83.7	92.8	97.8	106.1	115.5	125.0	133.6	138.8	148.7
	3- month	105	86.7	95.4	100.1	108.0	117.0	126.0	134.2	139.2	148.5
	4- month	135	88.8	97.1	101.6	109.1	117.6	126.1	133.9	138.6	147.4
	5- month	165	87.7	95.8	100.1	107.5	115.8	124.1	131.7	136.3	145.0
Boy	0- month	15	89.9	100.6	106.4	116.2	127.2	138.3	148.4	154.5	166.0
	1- month	45	85.9	95.4	100.6	109.2	118.9	128.7	137.6	143.0	153.2
	2- month	75	82.0	91.6	96.8	105.5	115.3	125.2	134.2	139.6	149.9
	3- month	105	84.8	93.9	98.8	107.0	116.3	125.7	134.3	139.4	149.1
	4- month	135	85.9	94.8	99.5	107.6	116.6	125.7	133.9	138.9	148.3
	5- month	165	84.6	93.2	97.9	105.7	114.5	123.4	131.5	136.4	145.6
Girl	0- month	15	97.5	106.6	111.5	119.9	129.3	139.0	147.9	153.3	163.5
	1- month	45	88.5	97.0	101.6	109.4	118.3	127.4	135.7	140.7	150.3
	2- month	75	85.5	94.0	98.6	106.4	115.3	124.4	132.8	137.8	147.5
	3- month	105	88.8	97.0	101.5	109.0	117.6	126.3	134.3	139.2	148.4
	4- month	135	92.0	99.6	103.7	110.7	118.6	126.6	133.9	138.4	146.8
	5- month	165	91.3	98.6	102.5	109.2	116.8	124.5	131.5	135.7	143.8

Note. GAMLSS, Generalised additive model for location scale and shape. Hb, Hemoglobin.

framework^[25]. Although information on cord clamping timing was not collected, most participating hospitals reportedly follow the guidelines for delayed umbilical cord clamping. Finally, the sample size for each age group was relatively limited, particularly for the 0-month-old group. Nevertheless, the sample sizes in studies used by the WHO to define anemia cutoffs for infants aged 6–23 months were comparable or even smaller.

The thresholds for defining anemia in infants aged 0–5 months were established for the first time based on a nationwide, population-based study conducted in China. The Hb thresholds were 102.7 g/L, 96.3 g/L, 92.8 g/L, 95.4 g/L, 97.1 g/L, and 95.8 g/L for the 0-, 1-, 2-, 3-, 4-, and 5-month age groups, respectively. These thresholds are expected to facilitate the early identification of anemia in infants and to advance the timing of subsequent interventions at both national and global levels.

Funding This work was supported by the National Special Program for Science and Technology Basic Resources Investigation of China (Grant No. 2017FY101100). The funder had no role in the design, data collection, data analysis, interpretation, or reporting of this study.

Competing Interests The authors declare that they have no conflicts of interest.

Ethics This study protocol was reviewed and approved by the Medical Ethical Review Committee of the National Institute for Nutrition and Health, Chinese Center for Disease Control and Prevention (Approval No. 2019-009). All parents or legal guardians of the participants provided written informed consent.

Authors' Contributions Conceptualization: Zhenyu Yang and Wenhua Zhao. Analysis and Interpretation of Data, Manuscript Writing: Shuxia Wang. Manuscript Revision: Shuxia Wang and Zhenyu Yang. Data Collection and Supervision: Shan Jiang, Xuehong Pang, Qian Zhang, Bowen Chen, Tao Xu, and Yuying Wang. All the authors read and approved the final manuscript.

Acknowledgements The authors express their sincere gratitude to the field staff for their dedication and to all participating families for their valuable contributions to this study.

Data Sharing All data generated or analyzed during this study are included within this article.

Received: June 9, 2025;

Accepted: October 16, 2025

REFERENCES

1. WHO. Guideline on haemoglobin cutoffs to define anaemia in individuals and populations. WHO. 2024.
2. Gardner WM, Razo C, Mchugh TA, et al. Prevalence, years lived with disability, and trends in anaemia burden by severity and cause, 1990-2021: findings from the Global Burden of Disease Study 2021. *Lancet Haematol*, 2023; 10, e713–34.
3. Larson LM, Kubes JN, Ramirez-Luzuriaga MJ, et al. Effects of increased hemoglobin on child growth, development, and disease: a systematic review and meta-analysis. *Ann NY Acad Sci*, 2019; 1450, 83–104.
4. WHO. The clinical use of blood in medicine, obstetrics, pediatrics, surgery and anesthesia, trauma and burns. WHO. 2001.
5. Yalçın SS, Dut R, Yurdakök K, et al. Seasonal and gender differences in hemoglobin value in infants at 5-7 months of age. *Turk J Pediatr*, 2009; 51, 572–7.
6. Domellöf M, Hernell O, Dewey KG, et al. The diagnostic criteria for iron deficiency in infants should be reevaluated. *J Nutr*, 2002; 132, 3680–6.
7. Buseri FI, Siaminabo IJ, Jeremiah ZA. Reference values of hematological indices of infants, children, and adolescents in Port Harcourt, Nigeria. *Pathol Lab Med Int*, 2010; 2010, 65–70.
8. Yang ZY, Zhang Q, Zhai Y, et al. National nutrition and health systematic survey for children 0-17 years of age in China. *Biomed Environ Sci*, 2021; 34, 891–9.
9. Singla PN, Gupta VK, Agarwal KN. Storage iron in human foetal organs. *Acta Paediatrica*, 1985; 74, 701–6.
10. WHO. WHO child growth standards: growth velocity based on weight, length and head circumference: methods and development. WHO. 2009.
11. Jin CH. Children neuropsychological and behavior scale, revision 2016. Beijing Press. 2016. (In Chinese)
12. Cole TJ, Green PJ. Smoothing reference centile curves: the LMS method and penalized likelihood. *Stat Med*, 1992; 11, 1305–19.
13. Jopling J, Henry E, Wiedmeier SE, et al. Reference ranges for hematocrit and blood hemoglobin concentration during the neonatal period: data from a multihospital health care system. *Pediatrics*, 2009; 123, e333–7.
14. Christensen RD, Henry E, Bennett ST, et al. Reference intervals for reticulocyte parameters of infants during their first 90 days after birth. *J Perinatol*, 2016; 36, 61–6.
15. Yamada RT, Leone CR. Hematological and iron content evolution in exclusively breastfed late-preterm newborns. *Clinics*, 2014; 69, 792–8.
16. Kling PJ, Schmidt RL, Roberts RA, et al. Serum erythropoietin levels during infancy: associations with erythropoiesis. *J Pediatr*, 1996; 128, 791–6.
17. Christensen RD, Lambert DK, Henry E, et al. End-tidal carbon monoxide as an indicator of the hemolytic rate. *Blood Cells, Mol Dis*, 2015; 54, 292–6.
18. Odotola AA, Afolabi MO, Jafari J, et al. Haematological and biochemical reference values of Gambian infants. *Trop Med Int Health*, 2014; 19, 275–83.
19. Blouin B, Penny ME, Maheu-Giroux M, et al. Timing of umbilical cord-clamping and infant anaemia: the role of maternal anaemia. *Paediatr Int Child Health*, 2013; 33, 79–85.
20. Marol R, Marol R. Prevalence of anemia in exclusively breastfed full term babies between 3-6 months of age. *Int J Contemp Pediatr*, 2021; 8, 300–5.
21. Wieringa FT, Berger J, Dijkhuizen MA, et al. Sex differences in prevalence of anaemia and iron deficiency in infancy in a large multi-country trial in South-East Asia. *Br J Nutr*, 2007; 98, 1070–6.

22. Humberg A, Kammer J, Mordmüller B, et al. Haematological and biochemical reference intervals for infants and children in Gabon. [Trop Med Int Health](#), 2011; 16, 343–8.
23. Troy SB, Rowhani-Rahbar A, Dyer L, et al. Hematologic and immunologic parameters in Zimbabwean infants: a case for using local reference intervals to monitor toxicities in clinical trials. [J Trop Pediatr](#), 2012; 58, 59–62.
24. WHO. From 30 million cases to zero: China is certified malaria-free by WHO. WHO. 2021.
25. Xu T, Qu W, Wang Y, et al. Analysis of early essential newborn care capacities of rural health facilities - four provinces in western China, 2016. [China CDC Wkly](#), 2020; 2, 8–12.