

Feeding Patterns and Neonatal Sleep: A Multicenter Cross-Sectional Study

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Abstract

Objective

To examine the association between feeding patterns and neonatal sleep patterns and sleep-related behaviors.

Methods

In this multicenter cross-sectional study, caregivers of neonates aged < 28 days from seven tertiary hospitals in China were surveyed between October 2024 and September 2025. Neonatal sleep was assessed using a structured questionnaire. Propensity score overlap weighting was used to balance baseline characteristics across feeding groups, followed by weighted regression analyses.

Results

A total of 707 questionnaires were collected, and 634 were included, comprising 139 exclusively breastfed, 88 exclusively formula-fed, and 407 mixed-fed infants. Formula-fed infants had longer daytime sleep duration than exclusively breastfed infants by 0.69 hours (adjusted 95% CI, 0.09–1.29). Compared with mixed-fed infants, formula-fed infants had shorter nighttime sleep duration by 0.58 hours (95% CI, – 1.06 to – 0.10). Formula-fed infants also had more nighttime awakenings than exclusively breastfed infants, with an increase of 0.13 events per night (adjusted 95% CI, 0.03–0.23). In contrast, compared with mixed-fed infants, formula-fed infants had fewer nighttime awakenings, with a reduction of 0.09 events per night (95% CI, – 0.18 to – 0.01).

Conclusion

Feeding patterns were associated with neonatal sleep duration and nighttime awakenings. Longitudinal studies are needed to clarify developmental trajectories and underlying mechanisms.

Clinical trial registration

Not applicable.

Introduction

Sleep is critical for neonatal neurodevelopment, brain maturation, and synaptic plasticity, and may further influence the development of cognition, attention, and perceptual abilities¹. Sleep deprivation has been associated with impairments in higher-order and complex cognitive functions, as well as an

increased risk of psychiatric disorders and behavioral problems in children² Infants with more stable sleep states and smoother sleep transitions tend to exhibit better neurological maturation and emotional stability. They are also more likely to achieve enhanced cognitive development, including superior language expression and executive functioning later in life³. Therefore, improving neonatal sleep may contribute to enhanced neurodevelopment, reduced risk of disease, and overall promotion of healthy growth^{2,4,5}.

After birth, the circadian rhythm system in infants remains immature and relies on external environmental cues for regulation⁶. Among these environmental cues, breast milk — the predominant "chrononutrition" during early infancy — plays a pivotal role in the regulation of neonatal sleep–wake rhythms⁷. Increasing evidence suggests that breast milk plays a critical role in the postnatal establishment of the infant's circadian rhythms, largely attributed to the marked diurnal fluctuations of specific bioactive components within its composition⁸. A study analyzing 83 breast milk samples assessed the 24-hour concentration patterns of 71 components and found significant diurnal variations in tryptophan, lipids, triglycerides, cholesterol, iron, melatonin, cortisol, and cortisone⁹. Among the circadian fluctuations observed in breast milk components, cortisol, cortisone, and tyrosine peak during the daytime, promoting infant alertness, attention, and wakefulness. In contrast, melatonin, tryptophan, 5'-AMP, and 5'-GMP rise at night, contributing to neural regulation, facilitating sleep, and supporting the establishment of the infant's circadian rhythm¹⁰.

Moreover, these molecular-level findings have been corroborated by clinical studies, as demonstrated by the observed impacts of different feeding patterns on infant sleep. Evidence suggests that breastfeeding patterns are associated with infant sleep behaviors. The timing and rhythmicity of feeding may influence sleep quality and duration, thereby potentially affecting neonatal outcomes. A cross-sectional study found that exclusively breastfed infants exhibited longer nighttime and total sleep durations compared to those who were formula-fed¹¹. Another prospective cohort study involving 4,056 infants found that exclusive breastfeeding at 3 months of age was positively associated with longer sleep duration, with exclusively breastfed infants exhibiting longer sleep times throughout the first two years of life¹².

However, globally, fewer than half of infants achieve early initiation, exclusive breastfeeding, or sustained breastfeeding practices¹³. Even among exclusively breastfed populations, feeding practices that disrupt circadian rhythms are still prevalent. In the United States, 85% of breastfed infants consume milk that is not obtained directly from the mother's breast but rather expressed and stored in advance. As a result, infants may consume evening-expressed milk in the morning, leading to a potential mismatch between the milk's circadian phase and the time of feeding. This may disrupt the developing circadian rhythms of neonates, potentially leading to sleep disturbances and weakening physiological synchronization between the infant and the mother⁸. However, during rooming-in of mothers and newborns in the hospital, mothers typically practice responsive feeding under the guidance of healthcare professionals. This approach minimizes the use of stored expressed milk and better preserves the natural circadian variations in breast milk components. Therefore, in this study, exclusive breastfeeding was regarded as a

feeding pattern more closely aligned with the infant's natural circadian rhythm, whereas formula feeding and mixed feeding were considered more likely to involve disruptions to circadian timing.

This study aims to examine the association between feeding patterns and neonatal sleep patterns and sleep behaviors. We hypothesized that exclusive breastfeeding would be associated with more favorable sleep-related outcomes than other feeding patterns.

Methods

Study Design

This prospective multicenter cross-sectional study was designed and reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.

Participants

This study was a multicenter cross-sectional survey conducted between October 2024 and September 2025 across seven tertiary hospitals in eastern coastal China. A total of 707 mothers of hospitalized neonates under 28 days of age were recruited by nurses in postpartum wards and neonatal units. Preterm infants, as well as those with delayed neurological development, a history of prolonged hospitalization in the neonatal intensive care unit (NICU), seizure disorders, or long-term use of sedatives or caffeine, were excluded from the study.

Procedure

Following informed consent, the questionnaires were completed by the primary neonatal caregivers—mostly mothers—under the guidance of trained nurses. Participants were consecutively recruited at the time of maternal–infant discharge, and primary caregivers were required to be able to understand and complete the questionnaire. As recruitment was conducted exclusively in hospital settings, community-dwelling neonates were not included.

Feeding patterns were determined within the hospital setting from birth to assessment and followed routine clinical feeding practices. Because infants remained hospitalized during this period, feeding modes were considered stable. Infants who received any formula supplementation in addition to breast milk were classified as mixed feeding.

Measures

Questionnaire Development

Existing questionnaires predominantly target older infants. Moreover, they do not adequately address the impact of feeding patterns on sleep in a way that aligns with the objectives of this study. Therefore, the research team developed a specialized questionnaire to assess neonatal sleep.

The questionnaire was developed using the Delphi method to ensure both face validity and content validity. This process was informed by an extensive review of the literature on feeding patterns and sleep, combined with in-depth discussions with an expert panel. A total of 16 experts were invited to participate in the review, representing three professional categories: clinical nursing experts with a mid-level or higher professional title and over 10 years of relevant experience or advanced research in nursing theory; clinical medical experts with more than 10 years of neonatal clinical practice, a postgraduate degree or higher, and the title of attending physician or above; and sleep research experts with a postgraduate degree or higher and at least 10 years of experience in sleep research, assessment, or intervention, or notable achievements in developing sleep assessment tools and monitoring systems.

The research team contacted the experts by telephone and email to invite their participation. All potential participants received an explanation of the study and provided written informed consent. Upon enrollment, each expert was assigned a unique code to ensure anonymity within the research team. Reminder emails were sent after each round.

A total of three Delphi rounds were conducted. In each round, experts were given one week to complete the questionnaire, followed by one week for the research team to analyze the data. The second-round questionnaire was developed based on the results of the first round and sent again to the experts, and the third round followed the same process until consensus was reached.

All three rounds achieved a 100% valid response rate (16/16) and an expert engagement rate of 100%. In the first round, Cr values for individual items ranged from 0.6375 to 0.7875, with a mean of 0.716; in the second round, from 0.800 to 0.975, with a mean of 0.876; and in the third round, from 0.838 to 0.988, with a mean of 0.922. The authority level of the experts increased across rounds, exceeding 0.8 in all cases. Kendall's W coefficients for the three rounds were 0.163, 0.216, and 0.433 ($p < 0.05$), indicating a progressive increase in expert consensus. The final version of the questionnaire comprised four dimensions and 21 items, covering maternal and neonatal characteristics, feeding patterns, infant sleep duration, and sleep-related behaviors. Variables relevant to the present analysis are detailed in the Supplementary Table 1.

Exposure

The primary exposure was the infant feeding pattern, categorized into three groups: exclusive breastfeeding, exclusive formula feeding, and mixed feeding. Infants in the exclusive breastfeeding group were fed only human milk, while those in the exclusive formula feeding group received only commercial formula without any breast milk. Mixed feeding referred to the combined use of breast milk and formula during the same period.

Feeding pattern was chosen as the primary exposure because it may influence infant sleep through differences in nutrient composition, circadian bioactive factors in human milk, and feeding-related behavioral cues. Infants who did not meet the predefined feeding criteria or whose feeding information was incomplete were excluded from the analysis.

Covariates

We collected maternal and neonatal characteristics that were considered clinically and theoretically relevant to infant sleep outcomes. Maternal demographic variables included age, and educational attainment. Delivery-related variables comprised mode of delivery, parity, and preterm birth status. Neonatal information included sex, birth weight, and postnatal age at assessment.

These covariates were selected a priori based on previous literature and biological plausibility as potential confounders associated with both feeding patterns (exposure) and infant sleep characteristics (outcomes). In the subsequent analysis, these variables were incorporated into the overlap weighting model to adjust for confounding and achieve covariate balance between groups. Residual confounding due to unmeasured or imprecisely measured confounders may remain.

Outcomes

The study did not designate a single primary outcome. Instead, infant sleep was characterized through multiple complementary indicators derived from questionnaire responses. These included total daytime sleep duration, total nighttime sleep duration, frequency of nighttime awakenings, total duration of nighttime wakefulness, difficulty in soothing the infant to sleep, and time required to soothe the infant to sleep.

Multicenter quality control

To ensure consistency across centers, standardized study procedures were implemented at all participating hospitals. Nurses responsible for recruitment and questionnaire administration received centralized training prior to study initiation. A detailed study manual was provided to guide participant enrollment, questionnaire completion, and data recording.

Because data were collected within routine hospital settings, infants were cared for in relatively standardized ward environments, which helped reduce variability in environmental factors such as lighting, noise, and nursing schedules. Data quality was further ensured through centralized data management procedures. Completed questionnaires from all centers were reviewed for completeness and internal logical consistency. In cases of missing or inconsistent responses, queries were returned to the respective center for verification. Regular cross-center monitoring was conducted to ensure adherence to the standardized protocol and to maintain consistency in data collection procedures.

Statistical Analysis

We used descriptive data analysis techniques to examine the distribution of all covariates. Because the variables were not normally distributed, categorical variables were summarized as counts and percentages, and continuous variables were summarized as medians with interquartile ranges (IQR). Group comparisons were performed using the Kruskal–Wallis (K–W) test for continuous variables and the χ^2 test or Fisher’s exact test for categorical variables.

To reduce confounding bias caused by nonrandom group assignment, we applied propensity score overlap weighting (OW) based on a logistic regression model. The propensity score represented the probability of belonging to a given feeding pattern group (exclusive breastfeeding, exclusive formula feeding, or mixed feeding) conditional on the following covariates: maternal age, educational attainment, delivery mode, parity, preterm birth status, infant sex, birth weight, and postnatal age at assessment.

Given the three-group design, overlap weighting was applied in a pairwise manner—comparing exclusive breastfeeding with exclusive formula feeding, exclusive formula feeding with mixed feeding, and mixed feeding with exclusive breastfeeding—to estimate adjusted associations between feeding patterns and sleep outcomes.

Covariate balance between groups before and after weighting was evaluated using absolute standardized differences (ASD), with an ASD < 0.10 indicating adequate balance. A Love plot was used to visualize the improvement in covariate balance after weighting.

After confirming adequate balance, weighted regression models were fitted to estimate the association between feeding pattern and infant sleep outcomes, including total daytime sleep duration, total nighttime sleep duration, frequency and duration of nighttime awakenings, and difficulty and time required to soothe the infant to sleep. Point estimates and 95% confidence intervals were obtained using the robust sandwich variance estimator. All analyses were performed using R (version 4.5.1) with the *PSweight*, *survey*, and *ggplot2* packages. Two-sided p values < 0.05 were considered statistically significant.

Results

General features

A total of 707 questionnaires were initially collected. After excluding improperly completed responses through data cleaning, 634 participants remained for the final analysis, including 139 in the breastfeeding group, 88 in the formula-feeding group, and 407 in the mixed-feeding group. Table 1 presents the baseline characteristics of mothers and neonates across the three groups. A statistically significant difference was observed only in infant age and maternal education level, with all other baseline variables showing no meaningful between-group differences. More detailed maternal and neonatal baseline characteristics are provided in Supplementary Table 2.

Covariate Balance Before and After Overlap Weighting

Before applying overlap weighting, we conducted pairwise unadjusted comparisons with the Mann–Whitney U test; the results, illustrated by violin plots, are shown in Supplementary Figure 1. To address baseline imbalances in maternal and neonatal characteristics, we then applied propensity score overlap weighting. The propensity scores were estimated using logistic regression with maximum likelihood estimation. Figure 1 demonstrates that, after weighting, all absolute standardized differences (ASD) were reduced to below the commonly accepted threshold of 0.10 and approached zero, indicating excellent covariate balance across groups.

Neonatal Sleep Outcomes Across Feeding Groups

After applying overlap weighting to balance baseline covariates across feeding groups, we conducted weighted univariate and multivariable regression analyses to evaluate group differences in sleep duration and sleep behaviors, with detailed results presented in Tables 2–3.

For daytime sleep duration, infants in the formula-feeding group slept longer during the day than those in the breastfeeding group. In the unadjusted overlap-weighted model, daytime sleep duration was increased by 0.69 hours (95% CI, 0.06–1.32), and this association remained consistent after multivariable adjustment (0.69 hours; 95% CI, 0.09–1.29).

For nighttime sleep duration, formula-fed infants slept shorter at night compared with those in the mixed-feeding group. In both crude and adjusted models, nighttime sleep duration was reduced by 0.58 hours (95% CI, –1.06 to –0.10).

Sleep behavior outcomes are summarized in Tables 4–7. Formula-feeding group experienced more frequent nighttime awakenings than infants exclusively breastfed. Night-waking frequency increased by 0.13 events per night in both unadjusted (95% CI, 0.02–0.23) and adjusted analyses (95% CI, 0.03–0.23). Conversely, formula-fed infants woke less often during the night compared with those in the mixed-feeding group. Night-waking frequency was reduced by 0.09 events (95% CI, –0.18 to –0.01) in both crude and adjusted models.

Additionally, a trend toward easier soothing to sleep was observed in the breastfeeding group compared with the mixed-feeding group, with difficulty scores decreasing by 0.06 points (95% CI, –0.13 to 0.01) in the adjusted model.

Supplementary Figures S2–S7 provide graphical visualizations corresponding to the statistical results presented in Tables 2–7.

Discussion

Circadian rhythms play an essential role in early-life physiology, influencing immune responses, metabolic regulation, sleep–wake organization, and neurodevelopment^{14,15}. Multiple external factors—

particularly light exposure, sleep–wake schedules, and the timing of food intake—serve as key zeitgebers that shape the developing circadian system, and disruptions in these cues can alter sleep patterns in early life¹⁶. Newborns are born with an immature circadian clock that is highly dependent on these external rhythmic signals, including light–dark exposure and the time-of-day information conveyed through breast milk¹⁵. Early-life circadian cues—such as nocturnal melatonin and diurnal cortisol in human milk—have been hypothesized to be related to the maturation of sleep–wake rhythms. Therefore, differences in feeding patterns may be associated with variations in early circadian organization^{8,9,17,18}. The present study addresses this issue by specifically examining the relationship between breastfeeding patterns and sleep outcomes in newborns.

In our study, infants in the formula-feeding group slept longer during the day than those who were exclusively breastfed, while formula-fed infants exhibited shorter nighttime sleep compared with those receiving mixed feeding. These patterns may suggest a potential association between breastfeeding and the early organization of day–night sleep distribution. Human breast milk is a dynamic, bioactive fluid that provides optimal nutritional and developmental support for infants and has a profound impact on their lifelong health¹⁹. Infants who were exclusively or partially breastfed appeared to demonstrate more mature sleep–wake organization, consistent with prior research showing that formula-fed infants tend to exhibit longer daytime sleep durations than breastfed infants as circadian regulation gradually emerges over early infancy^{11,20}.

One plausible explanation lies in the distinct circadian signatures of breast milk. Unlike formula, breast milk contains rhythmic variations in hormones and bioactive components—including higher daytime cortisol and higher nighttime concentrations of melatonin, tryptophan, and immune factors—which have been hypothesized to be associated with day–night differentiation and nocturnal sleep patterns¹⁸. These time-of-day–specific fluctuations have been proposed as chronobiological cues potentially related to the development of circadian organization and sleep patterns⁷. Supporting this concept, a previous cross-sectional study reported that mistimed expressed breast milk feeding was associated with delayed sleep onset in infants, suggesting a potential link between feeding timing and early sleep regulation²¹.

In the present study, formula-fed infants experienced more frequent nighttime awakenings than exclusively breastfed infants, whereas they woke less often at night compared with infants in the mixed-feeding group. This pattern differs from findings reported in some previous studies. Cross-sectional studies found that infants who were directly breastfed experienced more frequent nighttime awakenings.^{11,21} This is commonly explained by the faster digestion of breast milk compared to formula, resulting in shorter satiety duration and, consequently, a need for more frequent nighttime feedings²².

This discrepancy may be partly explained by differences in the study population and developmental stage. The present study focused on neonates, whereas many prior studies examined older infants. During the early neonatal period, nighttime awakenings may be more strongly influenced by parent–infant interaction and caregiving behaviors than by satiety or digestive factors alone. In this context, the

physiological attachment and emotional soothing associated with breastfeeding may play a particularly important role in shaping nighttime awakening patterns²³.

Importantly, nighttime awakenings should not be interpreted simply as “fewer is better,” but rather as indicators of sleep organization and circadian health. The regularity of awakenings, ease of resettling, and overall sleep structure are likely more informative than awakening frequency alone. In line with this perspective, although no statistically significant differences were observed in the difficulty of soothing infants to sleep, a consistent trend was noted whereby caregivers in the breastfeeding group perceived their infants as easier to soothe.

Supporting this interpretation, previous studies have shown that breastfeeding mothers are more likely to engage in close physical contact with their infants and to adopt bed-sharing or proximity-based sleep practices²⁴. Infants’ sleep patterns, duration of crying, and total sleep time have all been shown to exhibit dose-dependent responses to mother-infant skin-to-skin contact²⁵. Furthermore, a randomized controlled trial demonstrated that regular daily skin-to-skin contact significantly reduced neonatal crying time and may increase total sleep duration, with particularly pronounced effects in younger infants²⁶. The intimate interactions associated with breastfeeding, together with the circadian variation of its nutritional components, may contribute to differences in nighttime awakening patterns and sleep in neonates. For example, tryptophan concentrations in breast milk peak during the early morning hours, around 4:00 a.m., facilitating endogenous melatonin synthesis and serving as a nocturnal melatonin signal for the infant^{9,17,27}.

Taken together, the intimate physical interactions and soothing mechanisms inherent in breastfeeding, combined with the circadian variation of bioactive components in human milk may be related to a more stable sleep structure in breastfed neonates. This framework offers a possible explanation for the observed finding that formula-fed infants woke less often at night compared with infants in the mixed-feeding group. Mixed feeding may provide less consistent temporal cues through direct breastfeeding while also being associated with greater variability in feeding regularity and mother–infant physical contact, which may in turn relate to differences in circadian signaling and overall sleep coherence.

Moreover, the composition of human milk is highly complex, and beyond the circadian-related hormones examined in this study, its impact on infant sleep may involve additional biological mechanisms. In recent years, research on the gut microbiota and the gut–brain axis has offered new perspectives on the regulation of infant sleep–wake rhythms. Sleep and the gut microbiota exhibit a close bidirectional relationship: on the one hand, circadian disruption and sleep disturbances can induce gut microbial dysbiosis; on the other hand, alterations in the gut microbiome may further exacerbate sleep disturbances^{28–30}. Multiple factors shape the development of the infant gut microbiota, including mode of delivery, medication exposure, environmental factors, and feeding practices³¹. Accumulating evidence indicates that breastfeeding plays a pivotal role in the establishment and maturation of the infant gut microbiome and may represent the optimal pathway for early microbial colonization. A cohort study based on fecal samples from preterm infants demonstrated that hospitalized preterm infants receiving

human milk feeding were more likely to develop a gut microbiota composition resembling that of healthy term infants³².

Consistent with this notion, studies have shown that infants receiving prebiotics exhibit faster consolidation of daytime wakefulness³³. Furthermore, within one week of supplementation with active *Bifidobacterium* infants, infants demonstrated marked improvements in sleep quality³⁴, suggesting that the gut microbiota may influence circadian synchronization through gut–brain signaling pathways. Notably, breastfed infants typically exhibit a higher abundance of *Lactobacillus* and *Bifidobacterium* species, as well as greater overall microbial diversity, compared with formula-fed infants³⁵. Together, these findings are consistent with the hypothesis that circadian components in human milk may be related to infant sleep–wake patterns through a potential “chrononutrition” pathway.

These findings suggest that responsive breastfeeding during hospitalization may be a practice worthy of consideration. A recent randomized controlled trial evaluated a chronobiological feeding model in preterm infants and reported improved weight gain, higher discharge percentiles, and shorter hospitalization duration compared with standard feeding³⁶. For mothers who are unable to exclusively breastfeed directly, the concept of “circadian-aligned feeding” may warrant consideration. Labeling expressed breast milk by time of expression and administering it accordingly may help maintain natural diurnal variation in milk components. Previous studies have demonstrated that melatonin in frozen breast milk remains stable for at least 4 hours after thawing and, in some cases, up to 24 hours, providing empirical support for this practice³⁷. Taken together, our findings suggest the relevance of a circadian-informed perspective in early neonatal feeding and sleep guidance. Clinical practice should emphasize feeding patterns and caregiving strategies that support the maturation of circadian rhythms and the development of healthy sleep structure in early life.

Limitations

This study has several limitations. First, given that newborns have not yet established stable circadian rhythms, differences in sleep-related outcomes may be subtle and difficult to detect, even under standardized data collection and quality control procedures. Although overlap weighting was applied to achieve balance in baseline covariates across feeding groups, residual variability related to the immaturity of neonatal circadian regulation may still attenuate observable group differences. This reflects the highly dynamic nature of neonatal sleep and circadian development, which evolves rapidly across early life stages and is influenced by multiple biological and environmental factors. Moreover, the cross-sectional design of the present study limits our ability to capture developmental trajectories or infer causal relationships between feeding patterns and sleep regulation. Future studies employing longitudinal designs, continuous monitoring from birth, or including older infants may provide more robust and developmentally informative insights into circadian rhythm maturation.

Conclusion

In this multicenter cross-sectional study of neonates, feeding patterns were associated with differences in both sleep duration and sleep-related behaviors. With respect to sleep duration, formula-fed infants exhibited longer daytime sleep than exclusively breastfed infants, while demonstrating shorter nighttime sleep compared with infants receiving mixed feeding. Regarding sleep behaviors, formula-fed infants experienced more frequent nighttime awakenings than exclusively breastfed infants but fewer awakenings than those in the mixed-feeding group. These findings suggest that breastfeeding and circadian-aligned feeding practices may be related to early sleep–wake organization during the neonatal period. Future longitudinal studies with extended follow-up are warranted to further elucidate the developmental trajectories and underlying mechanisms linking early feeding patterns with circadian-related sleep outcomes.

Declarations

Clinical trial registration

Not applicable.

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Author contributions

Qiuyue Zhai: Methodology, Validation, Formal analysis, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization. **Haoyang Chen:** Methodology, Formal analysis. **Xinxin Mao:** Investigation. **Wei Sha:** Investigation. **Minmin Sun:** Investigation. **Jianhua Jin:** Investigation. **Cai Hua:** Investigation. **Ting Bai:** Investigation. **Fan Fan:** Investigation. **BiYu Shen:** Conceptualization, Validation, Supervision, Project administration, Funding acquisition.

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Ethics statement

This study was approved by the Institutional Review Board of Shanghai Children's Medical Centre, affiliated with Shanghai Jiao Tong University School of Medicine (Approval No. SCMCIRB-K2022156-1), on November 18, 2022. Written informed consent was obtained from all participants or their legal guardians prior to enrolment.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process.

During the preparation of this manuscript, the author(s) used ChatGPT (OpenAI) solely for language editing and polishing, including improving grammar, clarity, and readability. The AI tool was not used to generate scientific content, interpret data, or draw conclusions. After using this tool, the author(s) carefully reviewed and edited the manuscript and take full responsibility for the accuracy, originality, and integrity of the content of the published article.

Data availability

The de-identified datasets that support the findings of this study are not publicly available due to participant privacy and institutional restrictions. The data are available from the corresponding author, Dr. Biyu Shen, upon reasonable request for the purpose of academic, non-commercial research. Requests should be sent to [shenbiyu@126.com] and will be considered in accordance with institutional ethics requirements. A response will normally be provided within 10 working days.

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Tables

Tables 1 to 7 are available in the supplementary files section

Figures

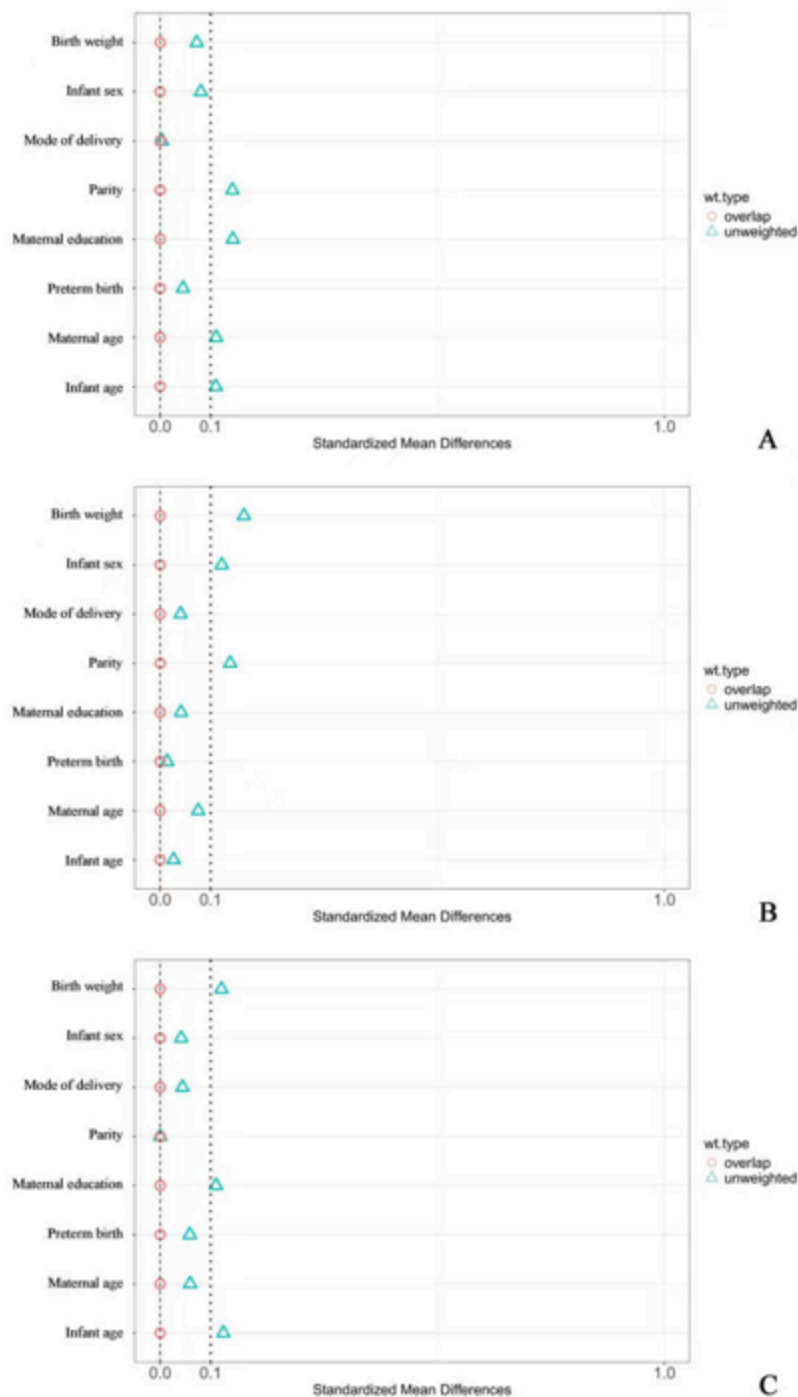


Figure 1

Covariate balance across feeding groups before and after propensity score overlap weighting.

Supplementary Files

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