Original Article

Ann Rehabil Med 2024;48(1):65-74
eISSN: 2234-0653
https://doi.org/10.5535/arm.230012

Annals of Rehabilitation Medicine

Predicting Age of Independent Walking in Preterm Infants: A Longitudinal Study Using Neonatal Characteristics and Motor Development Variables

Noppharath Sangkarit, PhD[1,2], Weerasak Tapanya, PhD[1,2], Arunrat Srithawong, MSc[1,2], Patchareeya Amput, PhD[1,2], Boonsita Suwannakul, PhD[1]

[1]*Department of Physical Therapy, School of Allied Health Sciences, University of Phayao, Phayao, Thailand*
[2]*Unit of Excellence of Human Performance and Rehabilitations, University of Phayao, Phayao, Thailand*

Objective: To formulate an equation estimating months to independent walking in moderate to late preterm infants based on neonatal characteristics and gross motor development from 7 months to independent walking.
Methods: Sixty infants born between 32 to 36 weeks were assessed using Alberta Infant Motor Scale (AIMS) for gross motor development. Neonatal characteristics were recorded at 7 months, and caregiver-reported independent walking onset. Pearson correlation analyzed age, AIMS scores, and neonatal factors. Multiple regression developed the prediction equation.
Results: The equation for independent walking onset, which included gestational age (GA) at birth, total AIMS score at 10 months of age (10th AIMS), and birth head circumference (BHC), exhibited a strong correlation (r=0.707) and had a predictive power of 50.0%. The equation is as follows: age onset of independent walking (months)=33.157, -0.296 (GA), -0.132 (10th AIMS), -0.196 (BHC), with an estimation error of 0.631 months.
Conclusion: Neonatal characteristics, such as GA, 10th AIMS, and BHC, are key determinants in estimating the onset of independent walking in moderate to late preterm infants.

Keywords: Preterm infants, Walking, Gestational age, Alberta, Prognosis

Received: October 28, 2023
Revised: December 15, 2023
Accepted: January 18, 2024

Correspondence:
Weerasak Tapanya
Department of Physical Therapy, School of Allied Health Sciences, University of Phayao, 19/2 Maeka Subdistrict, Muang District, Phayao 56000, Thailand.
Tel: +66-869236141
Fax: +66-5446-6697
E-mail: weerasak.ta@up.ac.th

INTRODUCTION

The attainment of independent walking stands as a crucial milestone in the motor development of infants, holding considerable sway over their fine motor skills and linguistic capabilities [1]. Typically, infants acquire the ability to walk independently between the ages of 8.2 and 17.6 months, as indicated by a multinational study conducted by the World Health Organization [2]. However, preterm infants often face challenges, including delayed and incomplete standing capabilities, primarily attributed to delays in their vertical developmental trajectory and antigravity movements [3].

Although some preterm infants may attain developmental milestones similar to their full-term peers in prone and supine positions by eight months, disparities emerge when it comes to sitting and standing positions, which necessitate robust muscular engagement against the force of gravity. This developmental gap persists even when observed up to 12 months of age, with preterm infants frequently achieving lower scores on gross motor assessments [4]. These disparities may arise from variations in the rate and sequence of neurological development, which unfold along a continuous continuum, commencing with the formation of tissues in both the central and peripheral nervous systems and culminating in the initiation of coordinated motor movements [5].

Preterm infants often experience walking delays, as indicated by a systematic review of 24 studies using the Alberta Infant Motor Scale (AIMS). At 3 months, moderate preterm infants exhibited a 12% abnormal motor development rate, signaling delays in standing at 4 and 6 months [6]. Subsequent research with 403 preterm and 1,038 full-term infants further emphasized distinctions, especially in the standing sub-scale, at 1.5 and 18.5 months [7,8]. The significance of independent walking, vital for preterm infants' motor milestones and language skills, is influenced by complex factors [1]. Understanding neonatal characteristics, including congenital diseases, birth weight (BW), birth head circumference (BHC), and gestational age (GA) at birth, is crucial for identifying developmental risks. A study revealed a positive correlation between GA and gross motor development in the first year [9]. Low BW, frequently associated with prematurity, increases the risk of delayed gross motor development [10]. BHC influences gross motor and cognitive domains, while a low Apgar score at birth signals clinical complications and an increased risk of poor gross motor development [11].

Evaluating motor development as a predictor for cerebral palsy (CP) is crucial, particularly in high-risk children, as emphasized in insights from CP. A systematic review and meta-analysis in 2018 highlighted the importance of achieving independent sitting by age two for potential ambulation in children with CP, revealing a strong association (relative risks, 4.82; 95% confidence interval [95% CI], 3.20–7.24) [12]. This consistent finding underscores the essential role of early assessments in guiding clinical decisions, where the AIMS stands out for its simplicity and minimal equipment requirements.

Monitoring and promoting gross motor development in healthy preterm infants is crucial to reduce developmental delays. The Thai version of AIMS is a reliable tool for assessing gross motor development, starting as early as 15 days and continuing up to 18 months [13]. Only a previous cross-sectional study examined the impact of biological and environmental factors on the acquisition of gross motor skills in Thai. This study identified the key factors as internal systems, the environment, task complexity, and movement experiences. Caution is advised regarding the use of baby walkers in typically developing infants during their first year of life due to potential negative impacts [14]. Therefore, predicting the age of independent walking in preterm infants remains a challenging and understudied area, likely due to the complex influence of neonatal characteristics and individual variations in motor proficiency.

Limited research exists on the long-term assessment of how neonatal characteristics contribute to the essential gross motor development required to achieve walking milestones in moderate to late preterm infants raised at home. The aim of this study was to yield a significant contribution to the current academic literature by demonstrating that AIMS scores serve as a feasible predictor of independent walking in moderate to late preterm infants. In clinical and research aspects, the formulated predictive model utilizing AIMS and neonatal characteristics can serve as a straightforward and practical tool for assessing gross motor development in moderate to late preterm infants. Through establishing an association among independent walking, gross motor development, and neonatal characteristics, this academic investigation holds promise for fostering a new methodological approach. Should this research yield theoretical outcomes, it could potentially enable healthcare professionals to assess both independent walking and gross motor development. This pivotal outcome could facilitate targeted rehabilitation programs, spanning from 7 months to independent walking for moderate to late preterm infants. It would enable meticulous monitoring and the strategic design of interventions for addressing gross motor assessment in this population.

METHODS

Participants

This research employed a prospective longitudinal assessment with a correlational study design to develop a prediction equation. A cohort of 60 moderate to late preterm infants were selectively recruited through outreach efforts involving district health-promoting hospitals and community healthcare volunteers. The selection of parents or guardians with infant dyads was made based on every second order from the provided name list. After applying inclusion/exclusion criteria, 88 preterm infants initially met the specified criteria, with 28 subjects subsequently excluded for various reasons. Among those excluded, 17 declined participation, 7 experienced acute illness within the last 7 days before assessment, and 4 families moving their houses. Therefore, the study involved the participation of 60 preterm infants, with a mean admission age of 6.74±0.38 months, residing in Muang District, Phayao Province, Thailand, out of the initial 60 subjects available for analysis.

For calculating the required sample size, we employed the Correlation: bivariate normal model G*Power analysis program, with a low correlation (r) value of 0.30, alpha=0.05, and power=0.95. Participants who met the inclusion criteria, which included being healthy preterm males and females with controllable symptoms, such as glucose-6-phosphate dehydrogenase deficiency, and able to walk independently with an average age of 12.0±0.9 months were included in the study and are listed in Table 1. Infants were excluded if they had a documented history of seizures, visual or hearing impairments, congenital abnormalities, significant brain damage, periventricular leukomalacia beyond grade I [15], intraventricular hemorrhage exceeding grade II [16], or a neonatal intensive care unit stay lasting more than 17 days. Approval for this study was obtained from the Human Research Ethics Committee at the University of Phayao (No1.3/056/64 and 1.3/013/66).

Research protocol

The parents or guardians of the infants in this study were provided with comprehensive information regarding the research's purpose and the data collection procedures. Before participating in the study, they were required to complete a consent form. Data related to parents or guardians and infants were collected from parents or guardians. Neonatal characteristics and vaccination data of preterm infants were recorded from the personal health booklet. Infant demographic information was documented in the structured questionnaire.

Subsequently, scheduled sessions were organized to evaluate the progress of gross motor development. On the appointed date, a direct observation was conducted for each infant to assess their gross motor development. This assessment took place in a quiet area of the infant's home, a place they were familiar with, with a parent or guardian in close proximity. Infants were unclothed except for wearing a diaper, allowing clear observation of their gross motor movements. They were given the freedom to move without restraint and received minimal physical contact during the evaluation, although the option to use a toy to encourage their movements was available. The infants remained awake and alert throughout the assessment. In cases where some infants were unprepared for the evaluation, their gross motor development was reevaluated within five days following the initial assessment.

The assessments were consistently conducted each month, within a window of plus or minus 5 days, starting from the corrected age of 7 months until the infants accomplished independent walking. Parents or guardians were requested to document the date of independent walking attainment in the logbook recording (parents/guardians note) and promptly inform the researcher. To confirm independent walking, as per the operational definition described below, the researcher assessed the infant's independent walking within 5 days of receiving notification from the parents or guardians. The assessment procedure and approach followed the description below:

The AIMS test of gross motor movement

The AIMS is a standardized assessment tool designed for the

Table 1. Neonatal characteristic of all infants (n= 60)

Demographics data	Mean±SD	Range
Birth weight (g)	2,306.2±383.8	1,610–2,955
Birth length (cm)	47.5±2.1	43–52
Birth head circumference (cm)	30.4±1.5	29–33
The Apgar score at 5 min (point)	9.4±0.5	8–10
Gestational age (wk)	34.5±1.3	32–36
The age at walking independent (months of corrected age)	12.0±0.9	10.3–13.3
Thai version of total AIMS score (months of corrected age)		
At 7	27.6±1.8	24–33
At 8	29.9±1.8	26–36
At 9	31.2±2.0	27–36
At 10	37.7±1.8	35–42

SD, standard deviation; AIMS, Alberta Infant Motor Scale.

evaluation of gross motor development in infants aged 0 to 18 months [17]. It comprises 21 items for assessing prone position, 9 for supine, 12 for sitting, and 16 for standing, with the option to incorporate toys for stimulation. The assessment process emphasizes minimal physical contact to observe infants' spontaneous movements, with the assessor offering assistance for transitions into sitting or standing positions as necessary. Each item is categorized as either "observed" or "not observed."

The range of motor development is determined by identifying the lowest and highest observed items within each position, known as a "window." Items preceding this window are referred to as "previous items." Subscale scores are computed based on observed items within the window and the previous items, ultimately contributing to the calculation of total scores, which entail summing all subscale scores (Fig. 1) The typical duration of the assessment for each infant is approximately 15 minutes. In this specific study, the AIMS Thai version was utilized. This version has demonstrated robust inter-rater reliability (intraclass correlation coefficient [ICC], 0.988; 95% CI, 0.976–0.994) and intra-rater reliability (ICC, 0.995; 95% CI, 0.989–0.998) [13].

The age of independent walking (months)

The operational definition of independent walking in the current study is defined as the ability of infants to walk without any external support while maintaining a stable trunk in a vertical position with a straight back [18]. To determine when independent walking begins, parents or guardians were asked to notify us when their infant could take five consecutive steps without any assistance or falling. This date was recorded in a logbook and reported to the researcher by phone. To confirm that the infant's capacity for independent walking aligned with the operational definition, a test was conducted within five days of receiving the notification from parents or guardians.

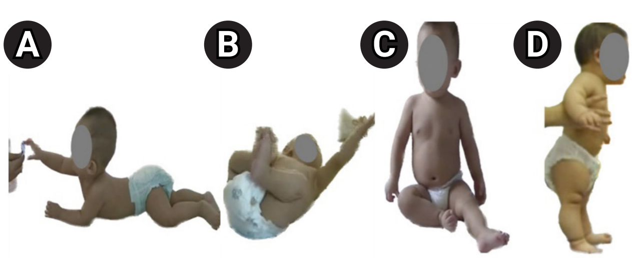

Fig. 1. The components of the Alberta Infant Motor Scale, including (A) prone, (B) supine, (C) sitting, and (D) standing positions. This figure is approved and allowed to be legally published by the guardian of the infant.

The structured questionnaire

Parents or guardians participated in face-to-face interviews during which they completed a structured questionnaire regarding neonatal characteristics, including BW, birth length (BL), BHC, Apgar score at 5 minutes, gestational age (GA), age at admission, sex, and health status in the 7 days prior to the assessment.

Statistical analyses

The Kolmogorov–Smirnov test was used to evaluate the data distribution, indicating a normal distribution among the variables. Descriptive statistics were employed to provide a characterization of the subjects, while the Pearson product moment correlation coefficient was utilized to establish the correlation coefficient between the age onset of independent walking (months), neonatal characteristics, and the total AIMS score from corrected age at 7 to 10 months. The study employed the Stepwise Multiple Linear Regression Analysis technique to create a prediction equation for the age onset of independent walking (months) through a multiple regression analysis. The equation incorporated several variables, including the age of independent walking onset (measured in months), neonatal characteristics, and the total AIMS score. The selection was made based on identifying the most optimal model, determined by the highest adjusted r^2 value and the lowest degree of variance inflation. To identify the most significant independent variable coefficients for each prediction model, an in-depth analysis was conducted to ascertain their significance. All statistical analyses were performed using IBM SPSS Statistics 21 (IBM Corp.), adhering to a consistent significance level of 0.05 for all statistical tests.

RESULTS

The study enrolled a sample of 60 preterm infants, consisting of 37 males and 23 females, with an average age 6.74±0.38 months corrected age. The infants' average BW was 2,306.2±383.8 g, average BL was 47.5±2.1 cm, average BHC was 30.4±1.5 cm, average Apgar score at 5 minutes was 9.4±0.5, and average GA was 34.4±1.3 weeks. The age onset of independent walking was found to be 12.0±0.9 months corrected age, while the average total AIMS score was 37.7±1.8 as shown in Table 1.

The study investigated the association between neonatal characteristics, such as BW, BL, BHC, Apgar score, GA, total AIMS score from the corrected age of 7 to 10 months and their age onset of independent walking. The results revealed negative moderate levels of correlation ranging from r=-0.568 to -0.311, all statistically significant at p<0.01. The age onset of independent walking exhibits a modest negative association with BHC (r=-0.439, p<0.001). Furthermore, the study identified a low negative correlation (r=-0.354, -0.311, -0.328, respectively, p<0.005) between age onset of independent walking and the Total AIMS score at 7, 8, 9 months. While a moderate negative correlation (r=-0.501, p<0.001) was observed between age onset of independent walking and total AIMS score at 10 months of age (10th AIMS). Table 2 presents the detailed correlation results.

Based on the results of a multiple regression analysis of the age onset of independent walking, all 3 models of factors were identified and are presented in Table 3. Model 1 showed that only the GA factor had a significant effect on the age onset of independent walking. Meanwhile, models 2, and 3 included GA factor and 10th AIMS, respectively. Among all 3 models, model 3 was significant strongly correlation (r=0.707, p<0.01) and had the highest coefficient of determination (r^2=0.500), indicating that the combined effect of the GA, 10th AIMS, and BHC accounted for 50.0% of the variance in the age onset of independent walking. The standard error of estimation was approximately 0.631 month.

As a result, the equation for the age onset (month) of independent walking's predictive accuracy was 33.157, -0.296 (GA), -0.132 (10th AIMS), -0.196 (BHC) ±0.631, where GA (month), BHC (cm), and 10th AIMS variable.

DISCUSSION

The aims of the current study were to: (1) investigated the relationship between the age of walking independent correlation gross motor development of moderate to late preterm Thai infants via AIMS score from 7 to 10 months corrected age and variables obtained from neonatal characteristics and (2) to examine an equation to calculate the age of walking independent. Additionally, the study focused at other neonatal characteristic factors that may affect the ability to walking independent, such as GA, BW, BL, BHC, and the Apgar score at 5 minutes. The study revealed that a prediction equation could be developed to calculate the age of walking independent of moderate to late preterm infant based on the gross motor development measured via the Thai version of total AIMS score and variables obtained from neonatal characteristics. It is a well-established relationship between GA, 10th AIMS, and BHC.

Table 2. Correlation between age onset of independent walking and demographic information of the participant, and total AIMS score at 7, 8, 9, and 10 months

Dependent variable	The age onset of independent walking (p-value)
Birth weight (g)	-0.346* (0.007)
Birth length (cm)	-0.122 (0.353)
Birth head circumference (cm)	-0.439** (<0.001)
Apgar score (point)	0.168 (0.199)
Gestational aged (wk)	-0.568** (<0.001)
Total AIMS score (point)	
At 7 mo	-0.354* (0.006)
At 8 mo	-0.311* (0.016)
At 9 mo	-0.328* (0.010)
At 10 mo	-0.501** (<0.001)

AIMS, Alberta Infant Motor Scale.
*Correlation is significant at p<0.05.
**Correlation is significant at p<0.001.

Table 3. Model of regression analysis for walking independent age with different predictive variables

Model	Included variable	β	p-value	r	Adjusted r^2	SEE
1	Constant	24.931	<0.001**	0.568	0.323	0.722
	GA	-0.376	<0.001**			
2	Constant	29.307	<0.001**	0.669	0.447	0.658
	GA	-0.306	<0.001**			
	10th AIMS	-0.180	0.001*			
3	Constant	33.157	<0.001**	0.707	0.500	0.631
	GA	-0.296	<0.001**			
	10th AIMS	-0.132	0.014**			
	BHC	-0.196	0.018*			

SEE, standard error of estimation; GA, gestational aged (mo); 10th AIMS, total Alberta Infant Motor Scale score at 10 months of age; BHC, birth head circumference (cm).
*Correlation is significant at p<0.01.
**Correlation is significant at p<0.001.

Certainly, while the independent walking age for moderate to late preterm infants may align closely with that of full-term children utilizing the AIMS remains valuable. The strength of the calculation formula found in this study lies in its multifaceted nature [19], considering variables such as GA, 10th AIMS, and BHC. If any of these variables show less typical progression than expected [20,21], employing AIMS together with these factors allows for heightened sensitivity to detect deviations more promptly. Even if the overall walking age aligns with norms [22], AIMS offers a comprehensive evaluation beyond just predicting walking age. It provides a detailed assessment of diverse motor domains, enabling the detection of potential developmental delays or disparities in specific motor skills. This sensitivity allows for early intervention strategies tailored to an infant's unique motor development profile, facilitating timely support despite the general alignment of walking ages between preterm and full-term infants. Therefore, utilizing AIMS enhances our understanding by offering a more nuanced assessment of motor development beyond the mere prediction.

Strong interactions among GA, 10th AIMS, and BHC play a crucial role in predicting challenges during walking. Specifically, it was found that for every 1 unit decrease in the GA (week), and 10th AIMS (point), and BHC (cm) there was an associated later at the age onset of independent walking (month) by 0.296, 0.132, and 0.196 month, respectively.

Additionally, it was found that lower gross motor scores coincident with small BHC (cm) had a significant impact on later walking independent. This aligns with previous research, indicating that preterm infants born between 32 and 36 weeks, though typically free from life-threatening complications at birth, show increased fragility and susceptibility to medical issues in childhood. Infants born between 34 and 36 weeks exhibit lower gross motor abilities, particularly in standing and walking independently [23], during their first year, compared to full-term infants [24].

In previous studies [18,25] were noted that infants, aged from 6 months to their first year, acquire new skills related to upright postures, including crawling, sitting up, pulling to stand, cruising, and eventually walking independently. During this stage, infants learn to coordinate lower body and pelvis movements, which improve their upper trunk and chest motor skills, especially when they're on prone position [26]. Approximately 9 to 10 months, infants typically transition to an upright posture, preparing them for standing and walking [2]. In our recent study, even though participants were born prematurely, they demonstrated the ability to achieve independent walking within this age range. We found a moderate correlation between 10th AIMS and walking milestones, indicating that, while preterm infants had not achieved independent walking, their overall low gross motor development in prone, supine, sitting, and standing positions, as demonstrated by 10th AIMS, was interconnected. This suggests the potential for developing an equation to predict future walking ability based on 10th AIMS.

These findings are consistent with a previous study, where they continuously monitored infants of various ages to track the development of gross motor skills using different positions. The assessment of supine position at 6 months provided valuable insights. As infants progressed to 8, 12, and 18 months, evaluating motor skills in a vertical position offered consistent surveillance benefits [27]. Specifically, assessing the total AIMS score with sitting and standing subscales importance to the ongoing monitoring of gross motor development, especially in comparing extremely preterm infants to those born full-term [3]. The study also emphasized the importance of observing developmental aspects related to balance against gravity in the vertical position, reinforcing the value of continuous surveillance [3,27].

The importance of low GA in monitoring preterm infants' walking skills is evident. Our study found a moderate negative correlation (-0.568, $p<0.001$) between GA and the age of independent walking, underlining the relevance of considering GA when evaluating later standing proficiency during independent walking assessments. Previous study investigates the impact of intrauterine environments on children's motor development at 3 and 6 months. It included 346 mother/newborn pairs from public hospitals, grouped by maternal conditions: diabetes, newborns with intrauterine growth restriction (IUGR), maternal smoking during pregnancy, and a control group. IUGR infants showed lower 6 month gross motor scores, with anthropometrics and sociodemographic negatively affecting motor development. This highlights the significance of monitoring preterm infants' walking skills, especially those with low GA [28].

Additional support for this observation is provided by a study in 2011, where it was reported that moderate to late preterm infants exhibited lower gross motor skills in the standing subscale at 4 months when compared to full-term infants ($p=0.014$) [7]. At 6 months, these preterm infants also scored notably lower in standing proficiency than their full-term counterparts, suggesting potential challenges in muscle tone regulation for upright support and balance [29]. Furthermore, a study conducted in 2017 illustrated consistent lower developmental scores in premature infants, encompassing extremely, very, moderate, and late preterm cases, from 1 to 12 months of age when compared to their full-term counterparts. These differences were statistically significant across all age groups, with extremely premature infants exhibiting the lowest standing abilities, significantly lower than infants with higher GA at all assessment periods (p<0.0001) [23].

In the context of preterm infants, the upright position's importance cannot be overstated, it impacts coordination, language skills, fine motor abilities, and cognitive functions [1]. This association between lower GA at birth and an increased risk of delayed gross motor development is particularly significant for infants born after 32 weeks, including those with low-risk preterm births [30]. Our study has revealed a noteworthy positive linear relationship between GA and both gross motor developmental scores. Prior research has identified key factors contributing to sitting development delays in moderate to late preterm infants aged 4 to 9 months, specifically those born between 33 to 36 weeks of gestation. These delays primarily result from deficits in flexor and extensor muscle activation, impacting trunk postural muscles. Consequently, low GA at birth may lead to balance instability, elevating the risk of delayed gross motor development in preterm infants' upright position [31].

The evaluation of gross motor development in infants involves analyzing the variability of percentile values via the AIMS. The AIMS is the gold standard for precision, considering tool like weight-bearing, posture, and antigravity compositions in four subscale positions. The commonly used method assesses long-term developmental percentile variations, using cutoff values to gauge the risk of developmental delays at different ages. In Thailand, though, there are no specific cutoff values; instead, they rely on continuous long-term developmental monitoring to detect variations, indicating typical development. When infants experience delayed gross motor development, their percentiles tend to remain consistently low throughout the monitoring period. These methods help identify developmental delays or consistent changes in raw scores. However, each approach has its advantages and limitations. Therefore, it's essential to consider the pros and cons of each testing method when evaluating development. Our study provides valuable insights for predicting independent walking development in preterm infants. We utilize raw scores from standardized tools, such as 10th AIMS, in associate with neonatal characteristic factors. Low cost and time consuming with basic neonatal characteristic data were applied in the current study.

Trunk postural control is a vital developmental milestone for infants, enabling them to achieve an upright posture and perform various tasks [32,33]. However, extremely and very preterm infants typically attain independent walking at around 14 months, later than full-term infants who achieve this milestone at around 12 months [6,8]. In very high risk infants, walking independence may be further delayed, occurring at approximately 16 months [8]. Our study highlights that moderate to late preterm infants exhibit a lower rate of independent walking ability, with only 42 out of 60 infants achieving independent walking by 12 months corrected age. This discrepancy is likely attributed to inadequate trunk control in premature infants, impacting their capacity to perform complex gross motor skills, particularly walking.

BHC serves as a valuable predictor of independent walking age in preterm infants, as evidenced by a significant negative association in our study (Table 2). Regression analysis identified GA, 10th AIMS, and BHC as predictive factors for the age of independent walking. These findings align with previous studies, indicating that head circumference is linked to extending beyond the average age for walking attainment and persists into the infant's first year. Several studies have emphasized the association between smaller head circumference and delayed gross motor development. Recent research has established a positive connection between having a larger head circumference at one month of age and the enhanced gross motor development of preterm infants, as evaluated by the AIMS motor scale [34].

Conversely, infants with smaller BHC, regardless of intrauterine factors, exhibit a higher risk of early motor development delays within their first 6 months of life [6,35]. The assessment of BHC is a standardized, non-invasive medical procedure that measures the circumference over the occiput and just above the eyebrows [2], with the standard measurement for Thai infants set at an average of 31.6 centimeters at 34 weeks GA [21]. Our study found that infants had head circumferences below the average for 34 weeks GA. We relied on birth history data recorded in the personal health booklet (Pink Book) as secondary data. Notably, a one-unit change in BHC could lead to an alteration in the age at which independent walking occurs, with an approximate difference of 36 days. Hence, when caring for preterm infants, healthcare providers and families should take into account the infant's BHC and evaluate their motor development, specifically their capacity for independent walking, to address their developmental requirements.

This study aimed to establish a prediction equation that proves valuable in estimating the age at which preterm infants will achieve independent walking. This equation leverages gross motor development scores obtained from the Thai version of AIMS, considered a gold standard in developmental assessments, and neonatal characteristics for forecasting the age onset of independent walking. The equation of age onset of independent walking (months)=33.157, -0.296 (GA), -0.132 (10th AIMS), -0.196 (BHC) ±0.631, where GA is denoted in weeks, 10th AIMS for AIMS total score at 10 months, BHC. The prediction equation was found to have moderate predictive ability, yielding a prediction accuracy of roughly 50.0%, with a corresponding measurement error of approximately 0.631 month. The utilization of a prediction equation in this research study resulted in the significant method holds practical applicability in clinical settings and is easily implemented. The benefit of using the prediction equation lies in early precision and efficiency in diagnosing and stimulating gross motor development at the 10-month, especially in preterm infants with lower GA and smaller BHC. Timely interventions can prevent delays in achieving independent walking by addressing gross motor development stimulations.

One potential clinical implication is the utilization of estimated age of independent walking as an objective measure to gross motor abilities in preterm infants with four main postures: supine, prone, sitting, and standing. By incorporating this estimation into clinical assessments, healthcare professionals can gain valuable insights into infants gross motor development and overall neonatal characteristics. This information can guide early intervention planning, goal setting, and monitoring of progress over time. Furthermore, the study's results can inform the development or modification of strategies aimed at stimulating walking and gross motor developments during early development. Using the estimated age of walking ability as a baseline measure, healthcare providers can customize rehabilitation or stimulation programs to address specific delays in gross motor ability or challenges in maintaining an upright balance in infants. This customization allows for the implementation of various postures or exploration of alternative stimulation techniques to enhance walking development. While this study has presented a predictive equation for estimating the age of independent walking onset, future research should prioritize its validation. By comparing predicted age values for independent walking from the equation with observed values in independent samples, researchers can assess its performance and reliability. These insights may lead to refinements that enhance its predictive accuracy in assessing infant motor development.

Although this study provides valuable insights, it has limitations, notably regarding the assessment of gross motor development in preterm infants using the Thai version of the AIMS. Although this assessment is considered a gold standard and can provide percentile values for long-term variability comparisons, it is important to note that Thai infants have not yet established cutoff values indicating developmental risk across various age points from birth to 18 months.

Consequently, for the sake of efficiency, raw scores were employed for the analysis, as converting the scores to percentiles would necessitate a substantial amount of time and extended longitudinal data collection. This approach, unlike the Canadian version, which uses percentile values at specific cutoff points, may lack the level of detail provided by percentile comparisons [34]. Nonetheless, raw AIMS scores remain widely utilized for assessing developmental values and exploring relationships with factors influencing motor development [28] and upright posture in premature infants [31], ensuring an accurate assessment of various contributing factors.

Furthermore, the research exclusively involved participants from a specific geographic region, which raises questions about the applicability of the findings to diverse populations or other geographic areas. This study did not stratify the population by GA, resulting in uneven subject distribution. Additionally, data on the history of using devices that affect movement and upright positioning in daily activities were not collected. It is imperative to acknowledge this limitation when interpreting and extrapolating the results to broader contexts, as it holds significant importance and warrants attention. One limitation in this study is the assumption that moderately to late preterm infants are prone to milder developmental delays without congenital diseases or medical complications. However, it is crucial to recognize that these assessments rely solely on parental reports of independent walking ability, potentially leading to issues like misclassification or underreporting.

Building upon the Thai version of AIMS, this study analyzed motor development and its impact on neonatal characteristics in healthy preterm infants with the goal of early detection of walking development delays and timely intervention. However, limitations, such as excluding preterm infants with medical conditions, should be acknowledged. Future research should enhance these aspects for a more comprehensive exploration of motor development in preterm infants. To address these limitations, future research should investigate the relationship between postural efficiency during standing and the onset of independent walking in preterm infants. Considering these factors, it is vital to account for these limitations when interpreting factor analysis results. Environmental elements, such as the infant's engagement in other activities, use of assistive tools, and safety measures limiting movement exploration, can affect gross motor development and independent walking attainment. Additionally, there might be additional variables influencing independent walking in premature infants that were not included in our study. Future investigations could indeed benefit from considering a broader spectrum of factors to provide a more comprehensive understanding of this developmental milestone. Factors like nutritional status and medical conditions require careful consideration. This investigation should consider serious medical conditions, environmental factors, and caregiving practices that influence gross motor development assessed by the Thai version of AIMS. These limitations may impact the generalizability and external validity of the findings to a broader population, constraining their applicability. Future research should consider these factors to enhance our comprehension of this field, offering valuable insights and a deeper understanding of the determinants of independent walking ability in healthy preterm infants.

In conclusion, the present study identified several factors that have a significant impact on the walking independently, including GA, 10th AIMS, and BHC. Based on our findings, we were able to develop a predictive equation to estimate the age of walking independently which provides a useful tool for clinicians and researchers to estimate the gross motor development as well as to assess the effectiveness of interventions aimed at improving this important aspect of gross motor development.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

FUNDING INFORMATION

This research project was supported by School of Allied Health Sciences, University of Phayao (No. AHS-RD-66002), Thailand Science Research and Innovation funds and the University of Phayao (Grant No. FF66-RIM074 and FF66-UoE009).

AUTHOR CONTRIBUTION

Conceptualization: Sangkarit N, Tapanya W. Methodology: Sangkarit N, Tapanya W. Formal analysis: Sangkarit N, Tapanya W. Funding acquisition: Sangkarit N, Amput P. Project administration: Sangkarit N. Visualization: Tapanya W. Writing – original draft: Sangkarit N, Tapanya W, Srithawong A. Writing – review and editing: Sangkarit N, Tapanya W, Amput P, Suwannakul B. Approval of final manuscript: all authors.

ACKNOWLEDGMENTS

We would like to thank all participants who volunteered to participate in this study.

ORCID

Noppharath Sangkarit, https://orcid.org/0000-0003-4622-5638
Weerasak Tapanya, https://orcid.org/0000-0002-7080-5213
Arunrat Srithawong, https://orcid.org/0000-0002-7647-5657
Patchareeya Amput, https://orcid.org/0000-0002-2484-2996
Boonsita Suwannakul, https://orcid.org/0000-0003-4716-657X

REFERENCES

1. Prommin S, Siritaratiwat W, Bennett S, Mato L, Keeratisiroj O, Kamruecha W. Effects of play in an upright position on intra-individual variability of gross motor and language development in institutionalized infants. Int J Environ Res Public Health 2022;19:11804.
2. WHO Multicentre Growth Reference Study Group. WHO Motor Development Study: windows of achievement for six gross motor development milestones. Acta Paediatr Suppl 2006;450:86-95.
3. Pin TW, Butler PB, Cheung HM, Shum SL. Longitudinal development of segmental trunk control in full term and preterm infants- a pilot study: part I. Dev Neurorehabil 2020;23:185-92.
4. Kayenne Martins Roberto Formiga C, Linhares MB. Motor development curve from 0 to 12 months in infants born preterm. Acta Paediatr 2011;100:379-84.
5. Hadders-Algra M. Early human motor development: from variation to the ability to vary and adapt. Neurosci Biobehav Rev 2018;90:411-27.
6. Fuentefria RDN, Silveira RC, Procianoy RS. Motor development of preterm infants assessed by the Alberta Infant Motor Scale: systematic review article. J Pediatr (Rio J) 2017;93:328-42.
7. Maia PC, Silva LP, Oliveira MMC, Cardoso MVLML. Motor development of preterm and term infants: using the Alberta Infant Motor Scale. Acta Paul Enferm 2011;24:670-5.
8. Syrengelas D, Kalampoki V, Kleisiouni P, Manta V, Mellos S, Pons

R, et al. Alberta Infant Motor Scale (AIMS) performance of greek preterm infants: comparisons with full-term infants of the same nationality and impact of prematurity-related morbidity factors. Phys Ther 2016;96:1102-8.
9. Saccani R, Valentini NC, Pereira KR, Müller AB, Gabbard C. Associations of biological factors and affordances in the home with infant motor development. Pediatr Int 2013;55:197-203.
10. Halpern R, Giugliani ER, Victora CG, Barros FC, Horta BL. [Risk factors for suspicion of developmental delays at 12 months of age]. J Pediatr (Rio J) 2000;76:421-8. Portuguese.
11. Casey BM, McIntire DD, Leveno KJ. The continuing value of the Apgar score for the assessment of newborn infants. N Engl J Med 2001;344:467-71.
12. Keeratisiroj O, Thawinchai N, Siritaratiwat W, Buntragulpoontawee M, Pratoomsoot C. Prognostic predictors for ambulation in children with cerebral palsy: a systematic review and meta-analysis of observational studies. Disabil Rehabil 2018;40:135-43.
13. Aimsamrarn P, Janyachareon T, Rattanathanthong K, Emasithi A, Siritaratiwat W. Cultural translation and adaptation of the Alberta Infant Motor Scale Thai version. Early Hum Dev 2019;130:65-70.
14. Tupsila R, Siritaratiwat W, Bennett S, Mato L, Keeratisiroj O. Intra-individual variability in gross motor development in healthy full-term infants aged 0-13 months and associated factors during child rearing. Children (Basel) 2022;9:801.
15. de Vries LS, Eken P, Dubowitz LM. The spectrum of leukomalacia using cranial ultrasound. Behav Brain Res 1992;49:1-6.
16. Papile LA, Burstein J, Burstein R, Koffler H. Incidence and evolution of subependymal and intraventricular hemorrhage: a study of infants with birth weights less than 1,500 gm. J Pediatr 1978;92:529-34.
17. Piper MC, Darrah J. Motor assessment of the developing infant. Saunders; 1994. p.1-210.
18. Wijnhoven TM, de Onis M, Onyango AW, Wang T, Bjoerneboe GE, Bhandari N, et al. Assessment of gross motor development in the WHO Multicentre Growth Reference Study. Food Nutr Bull 2004;25(1 Suppl):S37-45.
19. Thelen E. Dynamic systems theory and the complexity of change. Psychoanal Dialog 2005;15:255-83.
20. Kurtoğlu S, Hatipoğlu N, Mazıcıoğlu MM, Akın MA, Çoban D, Gökoğlu S, et al. Body weight, length and head cir cumference at birth in a cohort of Turkish newborns. J Clin Res Pediatr Endocrinol 2012;4:132-9.
21. Jenjarat K, Chamnanvanakij S. New reference for neonatal growth: 10-year data of Phramongkutklao Hospital. J Med Assoc Thai 2020;103:1284-91.
22. Tupsila R, Bennett S, Mato L, Keeratisiroj O, Siritaratiwat W. Gross motor development of Thai healthy full-term infants aged from birth to 14 months using the Alberta Infant Motor Scale: inter individual variability. Early Hum Dev 2020;151:105169.
23. Yaari M, Mankuta D, Harel-Gadassi A, Friedlander E, Bar-Oz B, Eventov-Friedman S, et al. Early developmental trajectories of preterm infants. Res Dev Disabil 2018;81:12-23.
24. McGowan JE, Alderdice FA, Holmes VA, Johnston L. Early childhood development of late-preterm infants: a systematic review. Pediatrics 2011;127:1111-24.
25. Adolph K, Karasik L, Tamis-LeMonda CS. Moving between cultures: cross-cultural research on motor development. In: Bornstein M, editor. Handbook of cross-cultural developmental science. Taylor and Francis; 2010.
26. Bartlett D, Piper MC. Neuromotor development of preterm infants through the first year of life. Phys Occup Ther Pediatr 1993;12:37-55.
27. Wang TN, Howe TH, Hinojosa J, Hsu YW. Postural control of preterm infants at 6 and 12 months corrected age. Early Hum Dev 2010;86:433-7.
28. Costa Wiltgen A, Valentini NC, Beltram Marcelino T, Santos Pinto Guimarães L, Homrich Da Silva C, Rombaldi Bernardi J, et al. Different intrauterine environments and children motor development in the first 6 months of life: a prospective longitudinal cohort. Sci Rep 2023;13:10325.
29. Gaetan EM, Moura-Ribeiro MV. Developmental study of early posture control in preterm and fullterm infants. Arq Neuropsiquiatr 2002;60:954-8.
30. Shapiro-Mendoza CK. Infants born late preterm: epidemiology, trends, and morbidity risk. NeoReviews 2009;10:e287-94.
31. Sangkarit N, Keeratisiroj O, Yonglitthipagon P, Bennett S, Siritaratiwat W. Segmental assessment of trunk control in moderate-to-late preterm infants related to sitting development. Children (Basel) 2021;8:722.
32. Saavedra SL, van Donkelaar P, Woollacott MH. Learning about gravity: segmental assessment of upright control as infants develop independent sitting. J Neurophysiol 2012;108:2215-29.
33. Pin TW, Butler PB, Cheung HM, Shum SL. Segmental Assessment of Trunk Control in infants from 4 to 9 months of age- a psychometric study. BMC Pediatr 2018;18:182.
34. Zhou L, Zhong W, Liu L. Investigation and influence analysis of motor development in preterm infants. Am J Transl Res 2023;15:273-80.
35. Duncan K, Goodworth A, Da Costa CSN, Wininger M, Saavedra S. Parent handling of typical infants varies segmentally across development of postural control. Exp Brain Res 2018;236:645-54.