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KEY WORDS: Gestational age, foot length measurement, preterm neonates, New Ballard Score, neonatal care.

# STUDY OF FOOT LENGTH MEASUREMENT AS A TOOL TO IDENTIFY GESTATIONAL AGE OF PRETERM, LATE PRETERM AND TERM NEONATE

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**ABSTRACT**

**BACKGROUND:** Accurate assessment of gestational age is critical for neonatal care, influencing clinical decisions and outcome. Traditional GA estimation methods such as the last menstrual period [LMP], early pregnancy ultrasound and the New Ballard Score have limitations especially in resource constrained settings. This study evaluates foot length measurement as a simple, non-invasive and reliable tool for estimating GA in preterm, late preterm and term neonates. **OBJECTIVES:** To assess the correlation between foot length and GA To compare its accuracy with New Ballard Score **METHODS:** A prospective study was conducted at P.D.U. Medical College and Hospital, Rajkot, involving 1000 neonates. Foot length was measured within 24 hours of birth and GA was assessed using LMP, NBS and foot length. Statistical analysis including Pearson correlation, Bland-Altman plots and interclass correlation coefficients [ICC] were used to evaluate the relationship and agreement between methods. **RESULTS:** Foot length showed a strong correlation with GA as determined by LMP [r=0.83] and NBS [r=0.989]. Bland-Altman plots indicated good agreement between foot length and NBS. The ICC for single measures was 0.791 and for average measures, it was 0.883, indicating excellent reliability. Foot length demonstrated sensitivity [80.6%], specificity [78.3%] and a high negative predictive value [90%] in identifying preterm and term neonates comparable to the NBS.**CONCLUSION:** Foot length measurement is a reliable, cost-effective and easy to use method for GA estimation with accuracy comparable to the NBS. It is particularly valuable in low resource settings, aiding in early identification of preterm neonates and improving neonatal outcomes.

## INTRODUCTION

### Background

Accurate assessment of gestational age is critical for managing neonatal care, as it influences clinical decisions, prognosis, and outcomes. Traditional methods of estimating GA include the last menstrual period, early pregnancy ultrasound, and postnatal assessments using physical and neurological criteria. However, these methods can be limited by factors such as recall bias, late presentation to antenatal care, and interobserver variability. Therefore, there is a need for reliable and straightforward methods to estimate GA, especially in settings where advanced technology and resources are limited.

One such promising method is the measurement of neonatal foot length. The foot is one of the earliest fetal body parts to be fully developed, and its length has been shown to correlate well with gestational age. The simplicity and non-invasive nature of foot length measurement make it an attractive tool, particularly in low-resource settings where other methods might not be feasible.

Foot length measurement is advantageous because it is a quick, non-invasive, and cost-effective method that does not require specialized equipment or extensive training. It can be easily performed in any setting, including remote or resource-limited areas, making it an invaluable tool for global health initiatives aimed at improving neonatal outcomes.

## AIMS AND OBJECTIVES

### Aim

The primary aim of this study is to evaluate the effectiveness of foot length measurement as a tool for estimating gestational age in preterm, late preterm, and term neonates. This study seeks to determine the accuracy and reliability of foot length measurement compared to the New Ballard Score , a widely used postnatal assessment tool. By validating foot length measurement as a method for GA estimation, the study aims to provide a simple, non-invasive, and cost-effective alternative for neonatal care, particularly in resource-limited settings.

### Objectives

1. To Evaluate Foot Length Measurement for Gestational Age Identification
2. To Compare the Accuracy of Foot Length Measurement with the New Ballard Score

## MATERIAL AND METHODS

### Study Design

A prospective study design was employed to evaluate the effectiveness of foot length measurement as a tool for estimating gestational age in preterm, late preterm, and term neonates. The accuracy of foot length measurement was compared with the New Ballard Score (NBS).

### Study Setting

The study was conducted in the neonatal units of a SNCU, Pediatric Department, PDU Medical College and Hospital, Rajkot, India. The hospital provided a comprehensive range of maternal and neonatal healthcare services, ensuring a diverse sample of neonates for the study.

### Study Population

The study population consisted of neonates admitted to the neonatal units of the hospital.

### Inclusion and Exclusion Criteria

**Inclusion Criteria:**

- Neonates born within the study period.
- Intramural and extramural newborn of age less than 24 hours at PDU Medical College, Rajkot
- Neonates with a confirmed gestational age determined by ultrasound or last menstrual period.
- Neonates whose parents or guardians provided informed consent.

**Exclusion Criteria:**

- Neonates with congenital anomalies affecting foot length or overall growth.
- Neonates whose parents or guardians did not provide informed consent.

Neonates with missing or incomplete medical records regarding gestational age.

### Data Collection Procedures

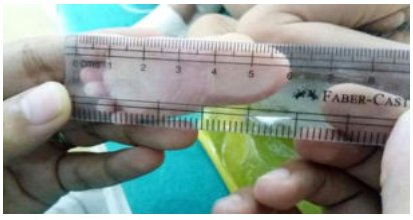
Data collection was carried out within the first 24 hours of life for each neonate. The procedures included foot length measurement and the New Ballard Score assessment.

**Methodology**

The study was conducted in the SNCU, Pediatric Department, PDU Medical College, Rajkot. After obtaining informed written consent from the parents or guardians, newborns were enrolled in the study. All newborns admitted within less than 24 hours of birth were included. General information was recorded in a proforma, and congenital malformations were ruled out before measuring foot length.

Foot length was measured in the right foot of all neonates for uniformity, with the newborns placed in a supine position. The measurement was taken from the posterior most prominence of the heel to the tip of the longest toe using a hard, transparent plastic ruler. This task was performed by an on-duty resident doctor of the nursery. The length of the foot was documented in centimeters. The ruler was cleaned with an antiseptic solution before and after each use.

After 24 hours, gestational age was calculated using the New Ballard Score (NBS). The gestational ages obtained from foot length measurements and the NBS were then compared to evaluate the accuracy and reliability of foot length as a tool for estimating gestational age.




Using linear regression analysis gestational age in weeks can be estimated using the formula:
Gestational Age: 4.5 x Foot length + 3.61

**New Ballard Score Assessment**

The New Ballard Score (NBS) assessment was conducted by trained healthcare professionals. The assessment included evaluation of six physical and six neuromuscular criteria. Each criterion was scored according to the NBS guidelines, and a composite score was calculated to estimate gestational age.

Neuromuscular Maturity

| Score | -1 | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|
| Posture | | | | | | | |
| Square window (wrist) | | >90° | 90° | 60° | 45° | 30° | 0° |
| Arm recoil | | | 180° | 140-180° | 110-140° | 90-110° | <90° |
| Popliteal angle | 180° | 160° | 140° | 120° | 100° | 90° | <90° |
| Scarf sign | | | | | | | |
| Heel to ear | | | | | | | |

Physical Maturity

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Skin | Sticky, friable, transparent | Gelatinous, red, translucent | Smooth, pink; visible veins | Superficial peeling and/or rash; few veins | Cracking, pale areas; rare veins | Parchment, deep cracking, no vessels | Leathery, cracked, wrinkled |
| Lanugo | None | Sparse | Abundant | Thinning | Bald areas | Mostly bald | |
| Plantar surface | Heel-toe 40–50 mm: −1<br><40 mm: −2 | >50 mm, no crease | Faint red marks | Anterior transverse crease only | Creases anterior 2/3 | Creases over entire sole | |
| Breast | Imperceptible | Barely perceptible | Flat areola, no bud | Stippled areola, 1–2 mm bud | Raised areola, 3–4 mm bud | Full areola, 5–10 mm bud | |
| Eye/Ear | Lids fused loosely: −1<br>tightly: −2 | Lids open; pinna flat; stays folded | Slightly curved pinna; soft; slow recoil | Well-curved pinna; soft but ready recoil | Formed and firm, instant recoil | Thick cartilage, ear stiff | |
| Genitals (male) | Scrotum flat, smooth | Scrotum empty, faint rugae | Testes in upper canal, rare rugae | Testes descending, few rugae | Testes down, good rugae | Testes pendulous, deep rugae | |
| Genitals (female) | Clitoris prominent, labia flat | Clitoris prominent, small labia minora | Clitoris prominent, enlarging minora | Majora and minora equally prominent | Majora large, minora small | Majora cover clitoris and minora | |

| Maturity Rating | |
|---|---|
| Score | Weeks |
| −10 | 20 |
| −5 | 22 |
| 0 | 24 |
| 5 | 26 |
| 10 | 28 |
| 15 | 30 |
| 20 | 32 |
| 25 | 34 |
| 30 | 36 |
| 35 | 38 |
| 40 | 40 |
| 45 | 42 |
| 50 | 44 |

**Data Management and Statistical Analysis**

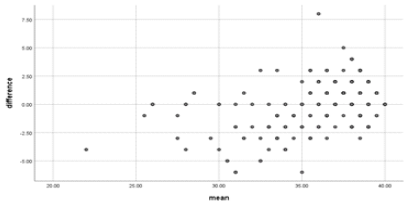
Data management was carried out using a secure, computerized database. Data were checked for completeness and accuracy before analysis.

Statistical analysis was performed using SPSS (Statistical Package for the Social Sciences) software. Descriptive statistics were used to summarize the demographic and clinical characteristics of the study population. Correlation analysis was conducted to assess the relationship between foot length and gestational age. Bland-Altman plots were generated to evaluate the agreement between foot length measurement and the New Ballard Score. Intraclass correlation coefficients (ICC) were calculated to determine the reliability of foot length measurement relative to the NBS. Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated to evaluate the effectiveness of foot length measurement in identifying preterm, late preterm, and term neonates.

**RESULT:**

Evaluate the agreement between foot length measurement and the New Ballard Score.

For estimating gestational age, Bland-Altman plots are used for evaluating if foot length and New Ballard Score are in agreement. Bland-Altman plots visualize the differences between the mean values of the two measurement methods.




Bland-Altman plots comparing foot length measurement with the New Ballard Score indicate good agreement. Based on the mean difference between the two methods, it appears that there is no systematic bias. The majority of differences fall within the limits of agreement, approximately -5 to +5 weeks, demonstrating reliable consistency between the methods. The distribution of points around the mean difference shows no apparent systematic pattern, indicating that agreement does not vary significantly across different gestational ages. Although occasional larger discrepancies are present, the majority of the data points suggest that foot length measurement and the New Ballard Score are largely consistent and reliable for estimating gestational age.

**Assess the relationship between foot length and gestational age**

| | Gestational Age according to LMP | Gestational age according to foot length | Gestational age according to new Ballard score |
|---|---|---|---|
| Gestational Age according to LMP | 1 | 0.83 | 0.817 |
| Gestational age according to foot length | 0.83 | 1 | 0.989 |
| Gestational age according to new ballard score | 0.817 | 0.989 | 1 |

The analysis of the relationship between foot length and gestational age shows strong positive correlations among the three variables: Gestational Age according to LMP, Gestational Age according to Foot Length, and Gestational Age according to New Ballard Score. The Pearson correlation coefficient between Gestational Age according to LMP and Gestational Age according to Foot Length is 0.83, indicating a robust correlation. Similarly, the correlation between Gestational Age according to LMP and Gestational Age according to New Ballard Score is 0.817, also demonstrating a

strong relationship. The highest correlation is observed between Gestational Age according to Foot Length and Gestational Age according to New Ballard Score, with a coefficient of 0.989, suggesting an almost perfect correlation. These findings indicate that foot length is a reliable and valid measure for estimating gestational age, closely aligning with traditional methods such as the LMP and the New Ballard Score.

**Assess if there are significant differences in foot length among different gestational age groups**

| Measurement Method | Group | N | Mean | Std. Deviation | F | Sig. |
|---|---|---|---|---|---|---|
| Gestational Age According to LMP | Preterm (<34 Weeks) | 155 | 30.1344 | 3.21051 | 130.291 | 0.000* |
| | Late Preterm (34-<37 Weeks) | 155 | 34.4032 | 3.21051 | | |
| | Full-term (37-<42 Weeks) | 690 | 38.2947 | 1.02167 | | |
| Gestational Age According to Foot Length | Preterm (<34 Weeks) | 155 | 31.26 | 3.272 | 63.408 | 0.000* |
| | Late Preterm (34-<37 Weeks) | 155 | 35.78 | 3.272 | | |
| | Full-term (37-<42 Weeks) | 690 | 37.41 | 1.475 | | |
| Gestational Age According to New Ballard Score | Preterm (<34 Weeks) | 155 | 31.96 | 3.055 | 51.196 | 0.000* |
| | Late Preterm (34-<37 Weeks) | 155 | 35.88 | 3.055 | | |
| | Full-term (37-<42 Weeks) | 690 | 37.52 | 1.4 | | |

* Statistically significant ** statistically non-significant

The analysis of gestational ages using three different measurement methods—LMP (Last Menstrual Period), foot length, and the New Ballard Score—demonstrates statistically significant differences between three groups: Early Preterm (<34 weeks), Late Preterm (34-<37 weeks), and Full-term (37-<42 weeks). For each method, the mean gestational ages for Preterm and Late Preterm groups were significantly lower than for the Full-term group, as indicated by p-values less than 0.000. Specifically, the mean gestational ages according to LMP were 30.13 weeks for Preterm, 34.40 weeks for Late Preterm, and 38.29 weeks for Full-term. According to foot length, the mean gestational ages were 31.26 weeks for Preterm, 35.78 weeks for Late Preterm, and 37.41 weeks for Full-term. According to the New Ballard Score, the mean gestational ages were 31.96 weeks for Preterm, 35.88 weeks for Late Preterm, and 37.52 weeks for Full-term. The F-statistics for the overall ANOVA tests were significant across all methods, confirming that the differences in gestational age among the groups are highly significant. This indicates that each measurement method consistently distinguishes between the different gestational age groups.

Evaluate the agreement between foot length measurement and the New Ballard Score.

The agreement between foot length measurement and the New Ballard Score was evaluated using the Intraclass Correlation Coefficient (ICC). The ICC assesses the reliability of the measurements by quantifying the degree to which they are consistent.

| Intraclass Correlation Coefficient | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Intraclass Correlationb | 95% Confidence Interval | | F Test with True Value 0 | | | |
| | | Lower Bound | Upper Bound | Value | df1 | df2 | Sig |
| Single Measures | 0.791a | 0.744 | 0.829 | 8.549 | 299 | 299 | 0.000 |
| Average Measures | 0.883c | 0.853 | 0.907 | 8.549 | 299 | 299 | 0.000 |
| Two-way mixed effects model where people effects are random and measures effects are fixed. | | | | | | | |
| a. The estimator is the same, whether the interaction effect is present or not. | | | | | | | |
| b. Type C intraclass correlation coefficients using a consistency definition. The between-measure variance is excluded from the denominator variance. | | | | | | | |
| c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise. | | | | | | | |

The ICC for single measures is 0.791 (95% CI: 0.744 - 0.829), indicating a substantial level of agreement between foot length measurement and the New Ballard Score for estimating gestational age. The F-test value of 8.549 with a p-value of 0.000 suggests that the observed agreement is statistically significant. For average measures, the ICC is higher at 0.883 (95% CI: 0.853 - 0.907), demonstrating excellent agreement. This higher ICC for average measures suggests that combining multiple measurements would result in even greater reliability. These results, derived from a two-way mixed-effects model where people effects are random and measurement effects are fixed, underscore the strong consistency and reliability of foot length measurement when compared to the New Ballard Score.

Evaluate the effectiveness of foot length measurement in identifying preterm, late preterm, and term neonates.

Foot length measurement was evaluated for sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) in identifying preterm, late preterm, and term neonates. We compare the results with those obtained using the New Ballard Score.

| Metric | Gestational Age According to Foot Length | Gestational Age According to New Ballard Score |
|---|---|---|
| Sensitivity | 80.60% | 80.60% |
| Specificity | 78.30% | 80.70% |
| Positive Predictive Value (PPV) | 62.50% | 65.20% |
| Negative Predictive Value (NPV) | 90.00% | 90.30% |

Both foot length measurement and the New Ballard Score are equally sensitive to identifying preterm, late preterm, and term neonates, indicating they are equally effective in identifying preterm neonates. The specificity of foot length measurement is 78.30%, slightly lower than the 80.70% specificity of the New Ballard Score. This suggests that the New Ballard Score is marginally better at identifying term neonates. The PPV for foot length measurement is 62.50%, compared to 65.20% for the New Ballard Score. This indicates that the New Ballard Score has a slightly higher likelihood of accurately detecting preterm neonates among those

expected to be preterm. The (NPV is very high for both methods, at 90.00% for foot length measurement and 90.30% for the New Ballard Score, showing that both methods are highly reliable in identifying term neonates among those expected to be term. Both methods are highly effective in identifying gestational age categories, but the New Ballard Score demonstrates slightly better specificity and PPV, while both methods are equally effective in sensitivity and NPV. This suggests that foot length measurement is a reliable and effective tool for estimating gestational age, with performance comparable to the New Ballard Score.

## CONCLUSION:

- Foot length measurement is a reliable and effective tool for estimating gestational age, showing strong correlations with traditional methods.
- It holds significant potential for improving neonatal outcomes, particularly in resource-limited settings where traditional methods may be less feasible.

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