Original Article

Evaluating the Diagnostic Accuracy of CANS, Anthropometric, and Proportionality Indices for Fetal Malnutrition in Pakistan

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Abstract

Background: Fetal Malnutrition (FM), a serious neonatal condition, is characterized by inadequate accumulation of subcutaneous fat and muscle, independent of birth weight for gestational age. This study aims to assess and compare the diagnostic accuracy of various nutritional assessment methods, including the Clinical Assessment of Nutritional Status (CANS) score, anthropometric measurements, and proportionality indices in identifying FM.

Methodology: This cross-sectional study included 320 live singleton newborns at Sheikh Khalifa Bin Zayed Al Nahyan Hospital, Rawalakot, Azad Kashmir, Pakistan, from December 2022 to July 2023. The neonatal participants were comprehensively assessed in terms of the CANS score, anthropometric measurements (weight, length, and Body Mass Index_(BMI)), and proportionality indices such as the Ponderal Index (PI) and the Mid-Upper Arm Circumference to Head Circumference ratio (MUAC/HC). Diagnostic accuracy metrics (sensitivity, specificity, Positive Predictive Value [PPV], and Negative Predictive Value [NPV]) were calculated according to established FM diagnostic criteria.

Results: Among the 320 neonates considered in this study, 61.3% were male, and 25.6% were preterm. The mean birth weight was 2.61 ± 0.73 kg, with a mean CANS score of 25.06 ± 8.21. A significant association was observed between gestational age and nutritional status. Preterm neonates exhibited higher rates of FM, as measured by MUAC/HC, PI, and BMI ($p < 0.001$). Diagnostic accuracy assessments indicated that when the CANS score is considered a gold standard, it demonstrated perfect sensitivity and specificity for detecting FM, while BMI and PI showed lower but significant sensitivity and specificity. The combination of BMI and PI (among metrics excluding the CANS score) yielded the highest accuracy in FM detection, reducing diagnostic errors significantly.

Conclusions: FM prevalence was substantial in the studied population sample, particularly among preterm neonates. The CANS score remains a robust tool for FM detection and its incorporation with BMI and PI further enhances diagnostic accuracy. These findings highlight the importance of precise FM assessment and early optimization of neonatal nutritional intake to mitigate the detrimental sequalae of malnutrition.

Keywords: Fetal Malnutrition, Neonatal Nutrition, CANS Score, Maternal Nutrition, Low Birth Weight, Gestational Age.

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Introduction

Fetal Malnutrition (FM), first defined by Scott and Usher in 1966, describes a clinical condition characterized by inadequate accumulation of subcutaneous fat and muscle in the fetus during pregnancy, irrespective of birth weight for gestational age. Importantly, being Small for Gestational Age (SGA) does not equate to FM. Instead, FM reflects the actual nutritional status of the fetus, which has greater clinical relevance to perinatal complications than SGA or Appropriate for Gestational Age (AGA) classifications. Infants with FM face higher risks of adverse outcomes compared to those who are merely SGA without malnutrition.[1]

The assessment of FM can be conducted using various methods, each with its strengths and limitations. While birth weight is often considered a key indicator of nutritional status, FM can occur across a spectrum of

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birth weights, which underscores the inadequacy of the reliance solely on SGA status for diagnosis.[2] Measurements like Head Circumference (HC), body weight, and length provide additional insights but vary in their sensitivity to detect FM. Other proportionality indices, including BMI, PI, and MUAC/HC ratio, complement traditional anthropometric measures.[3,4]

Different assessment methods capture distinct aspects of neonatal health, and their combined use improves the likelihood of FM identification. The CANS score, in particular, emphasizes observable physical changes in newborns, which makes it a promising tool for FM detection.[5.] Designed to address limitations of traditional measurements, the CANS score evaluates nine physical signs of subcutaneous and muscle tissue loss, scoring each from 1 (severe malnutrition) to 4 (normal), and hence achieving a total value from 9 to 36. Scores below 25 indicate malnutrition, while those of 25 or higher suggest an absence of FM. Unlike other indices, the CANS score focuses on the observation of visible nutritional deficiencies that develop during pregnancy, an observation that requires no advanced technology.

Early identification of FM is crucial worldwide, particularly in countries like Pakistan, which faces a high neonatal mortality rate of 42 deaths per 1,000 live births.[6-8] Low birth weight (LBW), a contributor to over 70% of neonatal deaths, is often linked to inadequate maternal nutrition and insufficient antenatal care.[9] Maternal nutrition is a key determinant of neonatal outcomes, and poor dietary intake during pregnancy leads to long-term consequences for both mother and child.[10]

Comprehensive maternal healthcare and nutritional interventions are urgently needed in Pakistan to improve birth outcomes. Although the CANS score is not yet widely adopted in the country, its incorporation it into routine neonatal assessments could enhance early detection of FM and reduce the potentially associated neonatal morbidity and mortality. Furthermore, its use could facilitate targeted follow-up and anticipatory care for high-risk infants.[11]

This study aims to evaluate the diagnostic accuracy of various neonatal nutritional assessment methods—including BMI, PI, MUAC/HC ratio, and the CANS score—in detecting FM, focusing on their sensitivity, specificity, and predictive values.

Methodology

This study utilized a single-center, cross-sectional descriptive design to assess neonatal nutritional status and clinical outcomes.

The research was conducted at Sheikh Khalifa Bin Zayed Al Nahyan Hospital/AK CMH Rawalakot from December 2022 to July 2023. Ethical approval for the study was granted by the Research Committee of Sheikh Khalifa Bin Zayed Al Nahyan Hospital/AK CMH Rawalakot Ref no. 535/SKBZ/CMH. Informed consent was obtained from the legal guardians of all neonates prior to enrollment.

The study included all male and female live-born singleton neonates with gestational ages ranging from 28 to 42 weeks. The sample encompassed neonates with various birth weights, including macrosomic infants born to diabetic mothers. Neonates with congenital abnormalities, disproportionate growth patterns, or those whose mothers had uncontrolled diabetes during pregnancy were excluded from the study sample.

A total of 320 neonates were enrolled in the study. We determined the sample size on the basis of prior studies on neonatal nutrition and clinical outcomes such as to ensure sufficient statistical power to detect significant associations. Among the participants, some neonates were admitted to the Neonatal Intensive Care Unit (NICU) due to one or more medical concerns.

The primary variables in this study included demographic data, neonatal anthropometric measurements, the CANS score, and indicators of neonatal morbidity. Neonatal variables comprised gestational age (in weeks), birth weight (grams), as well as additional measurements such as length, HC, and MUAC. The CANS score was utilized to assess physical characteristics, including skin, hair, and buccal fat, with a total score below 25 indicating the presence of FM. During structured interviews, maternal variables were also collected, including maternal age, parity, medical history (such as diabetes and other complications), and dietary habits.

Information for the study was gathered from three main sources: maternal interviews, direct neonatal observation, and neonatal health records. A trained medical researcher performed neonatal physical examinations within the first 48 hours of life to ensure validity. All infection control measures, including personal hygiene, equipment handling, and cleaning protocols, were strictly adhered to during the data collection process.

Neonates were assessed for anthropometric measures, including weight, length, HC, and MUAC. The CANS score was calculated based on physical appearance parameters to determine the presence of FM. Neonatal morbidity was monitored during the 1st week, tracking conditions such as hypoglycemia, respiratory distress syndrome (RDS), polycythemia, sepsis, elevated bilirubin, and feeding intolerance.

Statistical analyses were performed with the aid of SPSS version 25.0. Descriptive statistics, including means, standard deviations, and proportions were calculated for demographic and clinical variables. The chi-squared (χ^2) test was used to assess associations between categorical variables. For variables with expected cell counts less than five, Fisher's exact test was applied. A p-value of less than 0.05 was considered statistically significant. Sensitivity, specificity, PPV, and NPV were calculated for the CANS score, BMI, PI, and MUAC/HC measures utilized in the detection of FM. Analyses were conducted for each method as a reference test to simulate a gold standard, facilitating comparisons across different approaches.

Results

A total of 320 neonates were studied, with a male-to-female ratio of 1.6:1. Most (74.4%) were full-term, and 77.5% required NICU admission. The majority of mothers were aged 20–39 years, and delivery mode was nearly equally split between NVD and C-section. PROM > 12 hours was observed in 17.5% of cases, while common maternal conditions included preeclampsia, eclampsia, gestational diabetes, and anemia. Mean neonatal anthropometric measurements, PI, BMI, and CANS scores are summarized in Table I.

Table I: Descriptive Statistics of Neonatal and Maternal Data.

Variables		**N(%)**
Gender	Males	196 (61.3%)
	Females	124 (38.8%)
Gestational Age	Preterm (<37 weeks)	82 (25.6%)
	Full-term (≥37 weeks)	238 (74.4%)
NICU Admission	Preterm Neonates (n=82)	66 (80%)
	Full-term Neonates (n=238)	182 (76.5%)
Advanced Resuscitation Needs	Endotracheal Tube	4 (1.3%)
	Cardiopulmonary Resuscitation	54 (16.9%)
	Drugs	21 (6.6%)
NICU Admission	Yes	248 (77.5%)
	No	72 (22.5%)
Neonatal Morbidities in NICU Admitted Neonates (n=248)	Hypoglycemia	19 (7.7%)
	Polycythemia	5 (2%)
	Respiratory Distress Syndrome	72 (29%)
	Neonatal Sepsis	166 (53%)
	Hyperbilirubinemia	84 (34%)
	Feeding Intolerance	24 (10%)
Maternal Age	≤ 19 years	1 (0.3%)
	20-39 years	307 (95.9%)
	≥ 40 years	12 (3.8%)
Mode of Delivery	NVD	163 (50.9%)
	C-Section	157 (49.1%)
Premature Rupture of Membranes (>12h)	Yes	56 (17.5%)
	No	264 (82.5%)
Antibiotic Intake (n=56)	Yes	41(73.2)
	No	15(26.8)
Maternal Weight	Pre-pregnancy (kg)	60.86 ± 7.63
	Gestational Weight Gain (kg)	12.04 ± 4.59
Maternal Illnesses	Preeclampsia	60 (18.8%)
	Eclampsia	14 (4.4%)
	Gestational Diabetes Mellitus	25 (7.8%)
	Antiphospholipid Syndrome	1 (0.3%)
	Anemia	133 (41.6%)
Neonatal Anthropometric Measurements	Weight (kg)	2.61 ± 0.738
	Length (cm)	48.05 ± 4.21
	HC (cm)	33.07 ± 2.40
	MUAC (cm)	9.11 ± 1.48
	MUAC/HC	0.274 ± 0.0372
	PI (g/cm³)	2.31 ± 0.497
	BMI (kg/m²)	11.14 ± 2.349
	CANS score	25.06 ± 8.21

Among the 248 neonates admitted to the NICU, the most common morbidities were neonatal sepsis (53%), hyperbilirubinemia (34%), and respiratory distress syndrome (29%). Less common conditions included hypoglycemia (7.7%), feeding intolerance (10%), and polycythemia (2%). Advanced resuscitation interventions were required for 16.9% of the neonates, including cardiopulmonary resuscitation. Additionally, 1.3% of the neonates required endotracheal intubation, and 6.6% were given medication during neonatal resuscitation.

Our key numerical findings are presented in Tables 1–5. The association between gestational age and nutritional status revealed significant differences. Preterm neonates were more likely to exhibit FM compared to full-term neonates, as indicated by MUAC/HC, PI, and BMI scores ($p < 0.001$). Specifically, 54 preterm and 73 full-term neonates had MUAC/HC ratios below 0.27, which indicates FM. The PI measure indicated FM in 52 preterm and 69 full-term neonates, while BMI suggested FM in 63 preterm and 95 full-term cases.

The diagnostic accuracy of FM detection was evaluated using the CANS score, BMI, PI, and MUAC/HC ratio. When the CANS score was assumed to be the gold standard, it demonstrated perfect diagnostic performance with 100% sensitivity, specificity, PPV, and NPV. In comparison, BMI had a sensitivity of 66.5%, PI had a sensitivity of 70.9%, and MUAC/HC had a sensitivity of 57.3%. In the next few paragraphs, we continue to assume that the CANS score is the gold standard.

Table II: Association of FM with Maternal and Perinatal Risk Factors.

Variables		CANS score < 25 (malnourished)	CANS score ≥ 25 (well-nourished)	p-value
Maternal Age	≤ 19	1	-	0.332
	20-39	108	199	
	≥ 40	4	8	
Mode of Delivery	NVD	50	113	0.076
	CS	63	94	
PROM > 12 hr.	Yes	25	31	0.107
	No	88	176	
Antibiotics Intake (in PROM cases)	Yes	22	26	0.098
	No	91	181	
Antenatal Corticosteroid Treatment (GA ≤ 35 weeks)	Yes	30	8	0.409
	No	16	7	
Preeclampsia	Yes	33	27	< 0.001
	No	80	180	
GDM	Yes	4	21	0.353
	No	109	86	
APS	Yes	-	1	0.459
	No	113	206	

Table III: Association of CANS Score with Indirect FM Assessment Measures.

Variables		CANS score < 25 (malnourished)	CANS score ≥ 25 (well-nourished)	p-value
MUAC/HC	Normal ≥ 0.27	38	151	< 0.001
	FM < 0.27	75	56	
PI (g/cm³)	Normal ≥ 2.2	20	169	< 0.001
	FM < 2.2	93	38	
BMI (kg/m²)	Normal ≥ 11.2	8	154	< 0.001
	FM < 11.2	105	53	

Our analysis suggests that combining BMI and PI (among metrics excluding the CANS score) results in the highest diagnostic accuracy for FM detection, with a significantly lower error rate compared to the reliance on MUAC/HC alone. The combined approach using BMI and PI detects FM if either metric indicates its presence, while FM is considered absent only if both BMI and PI indicate its absence.

Using this combination of BMI and PI resulted in fewer diagnostic errors, particularly when integrated with voting algorithms. Specifically, Boolean analysis showed that combining BMI and PI reduced Type I and Type II errors by 15%, leading to a higher overall accuracy in FM detection compared to MUAC/HC alone.

The total diagnostic error for BMI and PI was reduced to 9%, compared to 29.37% for MUAC/HC. The use of majority voting further minimized diagnostic errors by combining multiple anthropometric measures, thus enhancing the overall performance of FM detection.

Karnaugh map analysis further corroborated these findings, demonstrating that the combination of BMI and PI streamlined the diagnostic process, reducing redundancy and enhancing both sensitivity and specificity in FM detection.

Discussion

The inadequate accumulation of subcutaneous fat and muscle mass during intrauterine growth serves as an early marker of FM. In this study, we evaluated 320 live-born singleton neonates with gestational ages between 28 and 42 weeks. We aimed to determine the prevalence of FM and the potential FM association with early neonatal morbidities among those admitted to the NICU. Consistent with prior research[3,4,12-14], our findings reinforce that FM remains a significant global health concern, especially in underdeveloped and developing countries.

The prevalence of FM in our study varied depending on the assessment method, it was 35.3% when we used the CANS score, 49.4% with the BMI, 40.9% with the PI, and 40.9% with the MUAC/HC ratio. These findings differ from those reported by Almarzoki and Jasim[15], who observed prevalence rates of 31%, 48.90%, 21.20%, and 28.10% for the same methods, respectively. Variations in FM prevalence across studies may stem from differences in ethnic backgrounds, geographical locations, genetic factors, sample sizes, gestational ages, maternal health conditions, access to adequate nutrition during pregnancy, and methodological approaches. Furthermore, some studies exclusively assessed term neonates, whereas others included preterm neonates, which further contributed to variability.

Table IV: Sensitivity, Specificity, PPV, and NPV for CANS score, BMI, PI, and MUAC/HC with Respect to each of them taken as a Reference Measure

Parameters	Sensitivity	Specificity	PPV	NPV
CANS score	1.000	1.000	1.000	1.000
BMI	0.929204	0.743961	0.664557	0.950617
PI	0.823009	0.816425	0.709924	0.894178
MUAC/HC	0.663717	0.729469	0.572519	0.798942
BMI	1.000	1.000	1.000	1.000
CANS score	0.664557	0.950617	0.929204	0.743961
PI	0.803797	0.975309	0.969466	0.835979
MUAC/HC	0.556962	0.734568	0.671756	0.629630
PI	1.000	1.000	1.000	1.000
CANS score	0.709924	0.894180	0.823009	0.816425
BMI	0.969464	0.835979	0.803797	0.975309
MUAC/HC	0.503817	0.656085	0.503817	0.656085
MUAC/HC	1.000	1.000	1.000	1.000
CANS score	0.572519	0.798942	0.663717	0.729469
BMI	0.671756	0.629630	0.556962	0.734568
PI	0.503817	0.656085	0.503817	0.656085

Table V: Numerous direct and reverse assessments of the CANS score (C) in relation to various metrics (including C itself)

Measure	Sensitivity	Specificity	PPV	NPV	Error of the First Kind	Error of the Second Kind	Total Error
CANS score (C)	1.00	1.00	1.00	1.00	0	0	0
BMI (B)	.664557	0.950617	.9292	.7439	0.16562	0.024	0.1906
PI (P)	0.7099	0.8941	0.8230	0.8164	0.1187	0.0625	0.1812
MUAC/HC (M)	0.5725	0.7989	0.6637	0.7294	0.175	0.1187	0.2937

Our study presents a unified assessment table (Table 4) comparing various FM diagnostic methods, with each method treated as a reference test in the absence of a universally accepted gold standard. This approach enables direct comparisons across methods and promotes consistency in future research. To ensure clarity, the table includes a row where each method's sensitivity, specificity, PPV, and NPV are set each at 100% when the method is evaluated against itself. This design addresses potential inaccuracies noted in prior studies and enhances the reliability of the comparisons.

Comparing our findings with similar studies provides valuable context. For instance, Amarendra and Yoganand[16] reported sensitivity and specificity values of 69.5% and 55.6%, respectively, for the PI, using the CANS score as the gold standard. In comparison, our study demonstrated moderately higher sensitivity of 82.30% and specificity of 81.64% for the PI under the same conditions. These differences may reflect variations in study populations, methodologies, or sample characteristics, underscoring the importance of context when interpreting diagnostic accuracy metrics.

Ezenwa and Ezeaka[5], in their study using BMI as the gold standard, reported sensitivity, specificity, PPV, and NPV for the PI as 69.8%, 73.2%, 54%, and 85%, respectively. Comparatively, our results (Table 4) demonstrated stronger performance, with sensitivity of 80.37%, specificity of 97.5%, PPV of 96.9%, and NPV of 83.5%. When evaluating the CANS score against BMI as the gold standard, Ezenwa and Ezeaka study found sensitivity of 39.6%, specificity of 59.8%, PPV of 33.9%, and NPV of 59.8%. By contrast, our findings (Table 4) showed markedly higher values, with sensitivity of 66.4%, specificity of 95.06%, PPV of 92.9%, and NPV of 74.39%. These differences highlight the improved diagnostic accuracy achieved in our study, potentially reflecting methodological or population-based variations.

Almarzoki and Jasim[15], using the CANS score as the gold standard, reported sensitivity, specificity, PPV, and NPV for the MUAC/HC ratio as 34.9%, 75%, 38.6%, and 71.9%, respectively. In comparison, our study demonstrated higher values: sensitivity of 66.37%, specificity of 72.94%, PPV of 57.25%, and NPV of 79.82%. For the PI, their reported values (31.7% for sensitivity, 83.6% for specificity, 46.5% for PPV, and 73.1% for NPV) were also lower than ours, which showed sensitivity of 82.30%, specificity of 81.64%, PPV of 70.99%, and NPV of 89.41%. Similarly, our BMI

assessment yielded higher sensitivity (92.92%), specificity (74.39%), PPV (66.45%), and NPV (95.06%) than those reported in Almarzoki and Jasim study. [15]

Rushdi[17] is believed to be the first author to construct a table similar to our Table 4, in which each of the four prominent FM diagnostic tests alternates as the gold standard. When a test acts as the gold standard, its sensitivity, specificity, PPV, and NPV are all set to 1.0. Rushdi[17] also noted that sensitivity and PPV are reciprocal measures, as are specificity and NPV. This means the sensitivity of one test relative to another equals the PPV of the latter test relative to the former, and vice versa. Similarly, the specificity of one test relative to another equals the NPV of the latter relative to the former, and vice versa.

Our Table IV illustrates these relationships. In each quarter of the table, the top row represents the test designated as the gold standard, with all its entries set at 1.0. Subsequent rows show the values of the remaining three tests in relation to the chosen gold standard, all of which are strictly less than 1.0. For example, the second row in the first quarter of Table 4 shows the performance metrics of BMI relative to the CANS score, while the second row in the second quarter shows the metrics of the CANS score relative to BMI. These rows contain identical values, reorganized in accordance with the aforementioned reciprocity property.

Additionally, Table 4 contains inherent redundancies. Contrary to widespread belief, the four diagnostic measures—sensitivity, specificity, PPV, and NPV—are not independent; each can be derived from the other three.[18] In clinical diagnostics, sensitivity and specificity measure test accuracy, while PPV and NPV assist in interpreting outcomes.

Our findings show BMI to be the most consistent metric across methods, despite the continued reliance on the CANS score as a reference standard.[4, 15] While the CANS score remains a valuable diagnostic tool, BMI may provide greater consistency in FM assessment. These findings emphasize the need for a multifaceted approach to FM diagnosis, as each method may capture different dimensions of this clinical condition.

Limitations: This study has several limitations that may have influenced the findings. First, the cross-sectional design restricts the ability to infer causal relationships between neonatal malnutrition and associated risk factors. In future work, a theory of causal explanation is warranted.[19,20] Second, while the sample included a diverse group of neonates, the study was conducted in a single healthcare facility, which may limit the generalizability of the results to the broader population of Pakistan. Additionally, reliance on maternal self-reported dietary habits introduces the possibility of recall bias[21,22], potentially impacting the accuracy of nutritional assessments. Ultimately, these limitations highlight the need for future research employing longitudinal designs and more representative, multi-center sampling to confirm and expand upon these findings.

Conclusion

We identified a high prevalence of FM in a sample of 320 neonates, particularly in preterm neonates. We also highlighted the strong association between gestational age and neonatal nutritional status. With the CANS score assumed to be a gold standard, it naturally demonstrated perfect sensitivity and specificity in diagnosing FM, followed by the BMI and the PI, while the MUAC/HC ratio showed a comparatively lower diagnostic accuracy. The findings suggest that combining multiple assessment tools could enhance the early identification of malnourished neonates, enabling timely interventions. Appropriate consideration of maternal risk factors such as anemia, gestational diabetes, and preeclampsia remains crucial for the improvement of neonatal health outcomes. The implementation of comprehensive, multi-pronged nutritional screening and management strategies can help reduce the burden of fetal malnutrition, especially in high-risk populations.

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