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Capillary Glucose Concentration during Oral Glucose Tolerance Test for the Diagnosis of Gestational Diabetes in Dakar (Senegal)

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Abstract

Objectives: Due to financial constraints, adherence to the gestational diabetes mellitus (GDM) screening guidelines in sub-Saharan Africa poses significant challenges. This study aims to evaluate the efficacy of more cost-effective glycaemic tests utilized in clinical practice, such as capillary blood glucose measurements. **Methods:** We conducted a prospective study in the Pikine National Hospital (Dakar, Senegal) from January 1, 2019, to June 31, 2023. Simultaneous measurements of venous and capillary blood glucose (VBG and CBG) were performed during a 75 g oral glucose tolerance test (OGTT). The International Association of Diabetes and Pregnancy Study Groups (IADPSG) criteria were employed for the diagnosis of GDM. **Results**: The study comprised 335 pregnant women, with a mean age of 30 years. The prevalence of GDM was 55% based on CBG measurements, compared to 30% for VBG. A significant association was observed between capillary and venous measurements. CBG tests overestimated blood glucose levels relative to VBG by +0.13 g/L (H0 and H1) and +0.06 g/L (H2). The bias was significant, with 95% of deviations falling outside acceptable margins at all stages of the OGTT. The sensitivity and specificity of CBG for diagnosing GDM were 78.2% and 54.7%, respectively. The negative predictive value was 85%, and the negative likelihood ratio (LR) was 0.39. CBG exhibited limited utility in diagnosing GDM (AUC = 0.66), with moderate contributions at H1 and H2 (AUC = 0.77 and 0.79). **Conclusion:** Given its favourable negative predictive value and low LR, CBG may serve as a useful initial screening tool, particularly when normal conditions VBG testing are not met.

Keywords

Gestational Diabetes, Capillary Blood Glucose, OGTT

1. Introduction

Gestational diabetes mellitus (GDM) represents a significant public health issue globally, characterized by an increasing prevalence [1]. High prevalence of GDM between 15% and 33% has been noted in sub-Saharan Africa since the adoption of the International Association of Diabetes and Pregnancy Study Groups (IADPSG) criteria [2]. Screening for GDM is essential to mitigate fetal-maternal morbidity and reduce the risk of developing type 2 diabetes and obesity in both mothers and children [2].

Preferably, screening employs oral glucose tolerance testing (OGTT) with venous blood glucose (VBG) measurements conducted before and after glucose administration. It is critical that venous blood samples are collected in tubes containing glycolysis inhibitors, transported quickly to the laboratory, and processed within 30 minutes in accordance with international standards [3].

In sub-Saharan Africa, screening for GDM remains constrained, particularly by logistical and financial challenges [4]. Thus, it is imperative to evaluate the effectiveness of simplified glycaemic tests tailored to the local socio-economic context. Capillary blood glucose (GBG), with its numerous advantages—including rapid results, minimal sample volume, accessibility, and low cost—represents a viable option for our sub-Saharan setting. To this end, we conducted a study to evaluate the accuracy of CBG in comparison to venous blood glucose (VBG) during OGTT for GDM screening in our context. The objective was to determine the concordance between CBG and VBG measurements at different times of the OGTT and to evaluate the reliability of CBG as a screening method for GDM using VBG as a reference.

2. Methods

The present work was conducted as a prospective, descriptive, analytical study at the Endocrinology, Department at the Pikine National Hospital Center (Dakar, Senegal), from January 1, 2019, to June 31, 2023. Participants included pregnant women aged 18 years or older who were screened in our department during the study period. Pregnant women with fasting blood glucose levels ≥ 1.26 g/L in the first trimester were excluded from the study. An OGTT using solution containing 75 g of anhydrous glucose in accordance with WHO recommendations was administered to all included participants between the 24th and 28th weeks of gestation. Blood glucose levels were measured at different times during the OGTT: prior to ingesting the glucose solution (H0) as well as one hour (H1) and 2 hours (H2) post-ingestion. Both venous blood glucose (VBG) and capillary blood glucose (CBG) measurements were performed at each time point. Capillary blood

samples were collected immediately after venous samples (with in all cases a maximum of 2 minutes between the 2 samples). All VBG measurements were conducted in the hospital laboratory using the glucose oxidase method. CBG measurements were collected at the fingertips using the Roche Accu-Chek Active Meter®, which conforms to the DIN EN ISO 15197:2003 accuracy standards [5]. The device was calibrated according to the manufacturer's specifications, and hands were systematically washed with soap and water prior to sampling. The diagnosis of GDM was based on the criteria established by the International Association of Diabetes and Pregnancy Study Groups (IADPSG) in 2010 [6]. Participants were categorized into two groups: GDM positive and GDM negative. Data analyses were performed using SPSS software for Windows (v.23.0; IBM Corp.).

Several statistical tests were conducted to assess the reliability and validity of CBG compared to VBG, employing the Bland-Altman method to determine the concordance between VBG and CBG at different stages of the OGTT (H0, H1, and H2). The standard deviation between VBG and CBG was observed to be ≤ 0.15 g/L, with 95% of deviations falling within the range of −0.5 to +0.5 g/L. These limits were set based on the 5% maximum error range recommended by the American Diabetes Association (ADA) [7]. The Pearson correlation coefficient (r) between VBG and CBG was calculated at each OGTT time point. The diagnostic performance of CBG was evaluated in terms of its sensitivity and specificity, as well as the Positive Predictive Value (PPV), Negative Predictive Value (NPV), Likelihood Ratios (LR+; LR−), and the calculation of the area under the curve (AUC) for sensitivity and specificity. The minimum sample size required for the validity and reliability studies of CBG was determined to be 212 patients, using the formula: $N_{total} = N_{patients}$/Expected Prevalence. As the Expected Prevalence of GDM, we employed 34.3%, a value that had been reported previously for Dakar hospitals [8].

3. Results

A total of 335 patients were included in the study, with a mean age of 30 ± 5.93 years, ranging from 18 to 46 years. The average number of pregnancies was three, with a maximum of 11 pregnancies. Multipara status was found in 45% of participants.

The OGTT was performed at and average gestational age of 24 ± 3.4 weeks. GDM prevalence was determined to be 30%, according to the IADPSG 2010 guidelines. During the OGTT, the average CBG was significantly higher than the corresponding VBG (**Table 1**).

Linear regression analysis revealed a statistically significant positive correlation (p = 0.000) between VBG and CBG at all OGTT stages. This correlation was moderate at H0 (r = 0.2) and strong at H1 and H2 (r = 0.61 and r = 0.69, respectively). The scatter plot (**Figure 1**) shows a tighter clustering of points and a closer proximity to the lines at H1 (**Figure 1(B)**) and H2 (**Figure 1(C)**), while for H0 (**Figure 1(A)**) the data points are more widely scattered. The Bland-Altman plots for the 3 OGTT stages show a positive deviation between CBG and VBG measurements

of +0.13 g/L at times H0 and H1 and of +0.06 g/L at time H2 (Figure 2). While these biases are statistically significant (Table 2), they are below the maximum acceptable threshold of 0.15 g/L. The limits of agreement are also indicated in Table 2. Approximately 95% of the measurement deviations between CBG and VBG fell outside the maximum acceptable range of ±0.5 g/L.

Table 1. Average of venous and capillary blood glucose during 3 OGTT stages.

Venous and capillary blood glucose during OGTT		Average (g/L)	p
H0	VBG H0	0.78 ± 0.17	0.00
	CBG H0	0.91 ± 0.18	
H1	VBG H1	1.39 ± 0.35	
	CBG H1	1.52 ± 0.39	
H2	VBG H2	1.28 ± 0.37	
	CBG H2	1.34 ± 0.38	

*VBG: venous blood glucose; CBG: capillary blood glucose; OGTT: oral glucose tolerance test; Values are presented as mean ± standard deviation (SD).

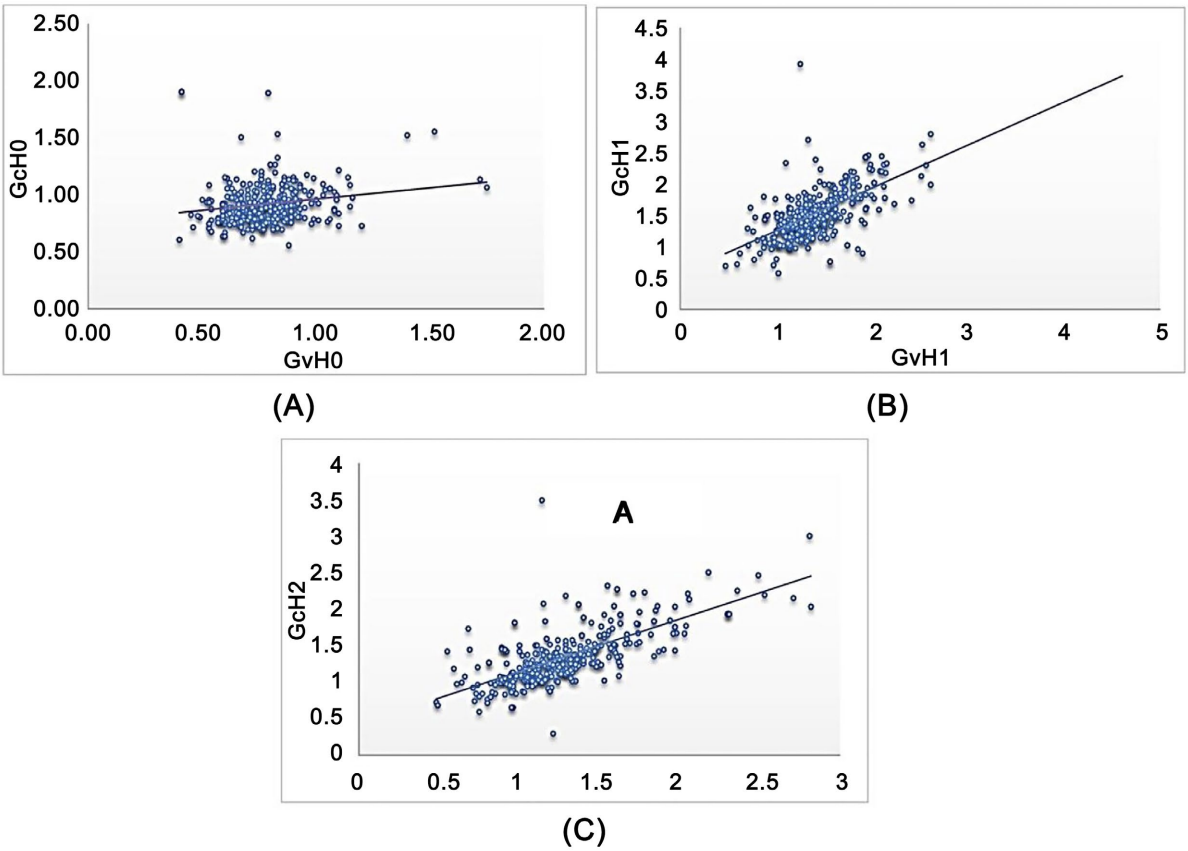

Figure 1. Variation of capillary glucose as a function of venous blood glucose. *scatter plot representing the variation of capillary blood glucose as a function of venous blood glucose at different stages of the OGTT. It thus shows a sparse distribution of points at HO (A) while the points are closer to each other and to the right bisector at H1 (B) and H2 (C).

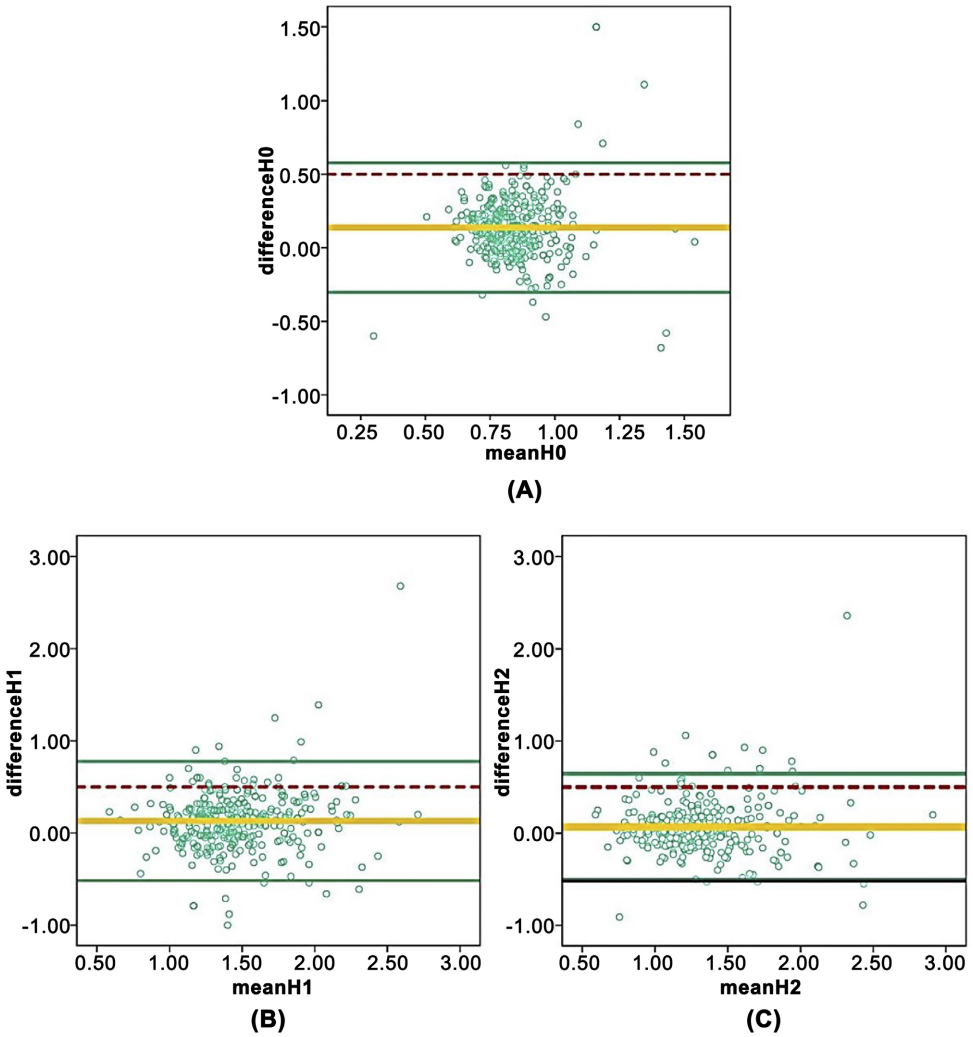

Figure 2. Bland-Altman diagram for the study of the agreement between capillary glucose and venous blood glucose. *Bland-Altman plot analyzing the agreement between venous blood glucose and capillary blood glucose levels at H0 (A), H1 (B), H2 (C). Although the mean difference between capillary and venous measurements was below the maximum acceptable difference set at 0.15 g/l at all OGTT time points, 95% of the measurement deviations between CBG and VBG fell outside the maximum acceptable agreement limits (±0.5 g/L).

Table 2. Biases and limits of agreement between venous and capillary blood glucose at the 3 OGTT stages.

	Deviation between CBG and VBG measurements (g/L)	Agreement area 95%	
		Limits <	Limits >
H0	**+0.137** [0.11; 0.16]	−0.30	+0.57
H1	**+0.131** [0.09; 0.16]	−0.51	+0.77
H2	**+0.066** [0.03; 0.09]	−0.51	+0.64

*VBG: venous blood glucose; CBG: capillary blood glucose.

In our study, GDM prevalence based on CGB was 55%, compared to 30% as determined by VBG. Using VBG as a reference, the sensitivity of CBG to detect

positive GDM cases was 78.2% (Table 3). Both the sensitivity and specificity of CBG were higher at H1 and H2 compared to H0.

The PPV of a pathological CBG for diagnosing GDM was less than 50%, while the NPV was 85% (Table 3).

Table 3. Performance of capillary blood glucose for GDM diagnostic.

	Sensitivity	Specificity	PPV	NPV
H0	64	58.9	21	90
H1	70	87	47	94
H2	**74**	**90**	67	**92**
GDM diagnostic	**78.2**	54.7	42.7	**85.3**

*PPV: Positive Predictive Value; NPV: Negative Predictive Value; Values are presented as percentages (%).

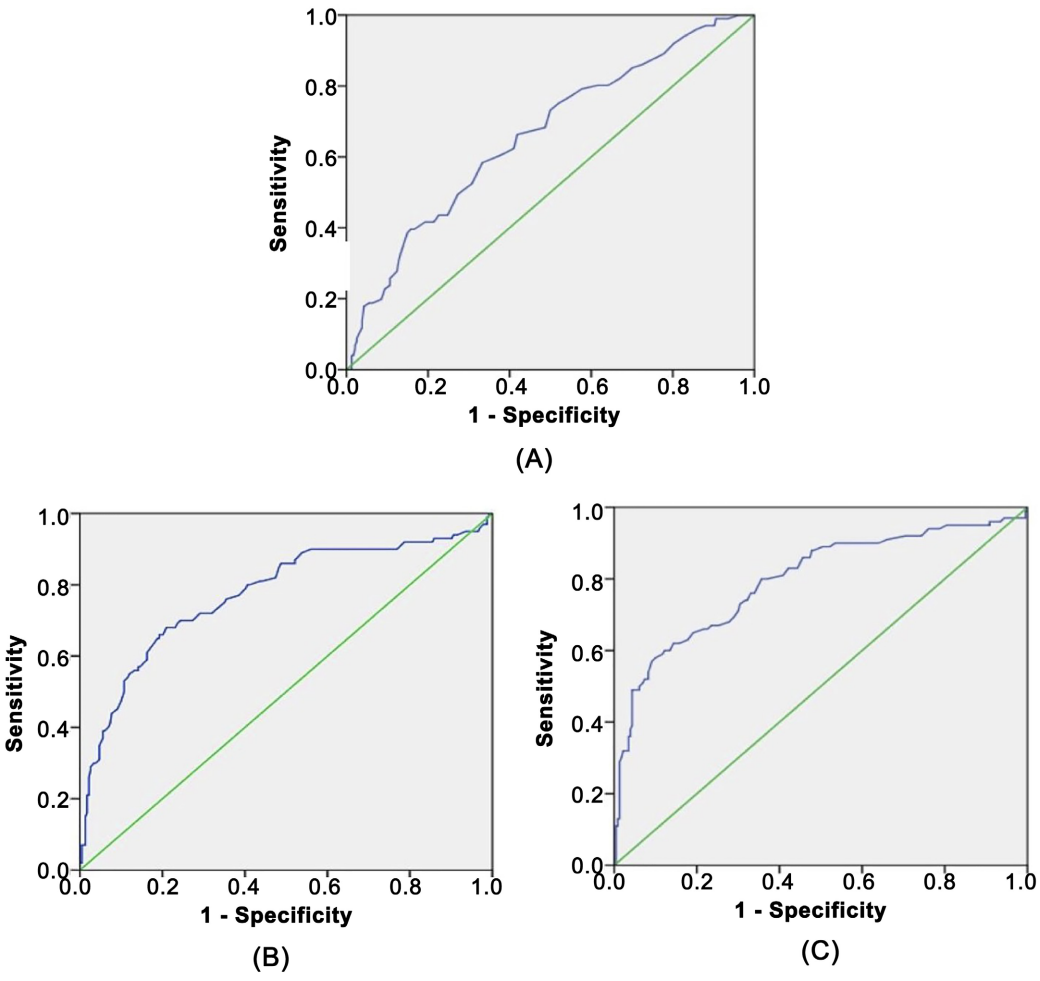

Figure 3. Sensivity/specificity (ROC) curve of capillary glucose during OGTT. *Sensitivity/specificity curve (Courbe Receiver Operating Characteristic-ROC) of capillary blood glucose at different OGTT time points, compared to venous blood glucose. At H0 (A), H1 (B) and H2 (C), the curve was distant from the upper left corner, which represent the optimal diagnostic value.

The NPV of CBG for diagnosing GDM was ≥90% at all OGTT time points. GDM-positive patients (as identified by VBG) were 1.7 times more likely to exhibit pathological CBG levels than GDM-negative pregnant women (LR+ = 0.72). Conversely, the likelihood of a normal CBG among GD-positive patients was less than 1 (LR– = 0.39). **Figure 3** shows the sensitivity and specificity curves of CBG at H0, H1, and H2. At H0 (**Figure 3(A)**), H1 (**Figure 3(B)**), and H2 (**Figure 3(C)**), the curve is notably distant from the upper left corner, which corresponds to optimal diagnostic values. According to the AUC values, CBG contributed poorly to the diagnosis of GDM at H0 and moderately at H1 and H2.

4. Discussion

GDM represents a significant global public health challenge [1]. It is associated with elevated maternal-foetal morbidity and an increased risk of subsequent development of type 2 diabetes [2]. Consequently, the implementation of effective screening and monitoring strategies for GDM is imperative. However, ideal and validated screening conditions are often absent in many healthcare settings, particularly in low-income countries where suitable facilities are frequently lacking [4]. This prospective study aimed to evaluate the utility of CBG at different stages of the OGTT as an alternative to VBG for the screening of GDM. We conducted simultaneous venous and capillary blood glucose tests on a statistically significant sample of over 300 pregnant women. The study population was comprised of young women (mean age 30 years), with nearly 50% being multiparous. The prevalence of GDM in this cohort was 30%, which is consistent with findings from a previous study conducted in a Dakar hospital setting [8]. An OGTT was administered at an average gestational age of 24 weeks, in line with current recommendations [6]. International pre-analytical and analytical standards were adhered to at all stages of the OGTT for VBG measurements [3]. CBG levels were obtained immediately after venous sampling, followed by handwashing to mitigate confounding factors. The readings were taken using the Roche Accu-Chek Active® glucometer, which complies with established analytical and clinical quality standards [5]. The cost difference between the measures is significant in our context: 3.43 $ for BG and 0.43 $ for CBG. Initially, a reliability test was conducted, revealing a statistically significant positive correlation between capillary and venous measurements, exhibiting a moderate correlation at H0 and a strong correlation at H1 and H2. However, the CBG tests overestimated blood glucose levels by up to +0.13 g/L compared to VBG measurements. The literature documents a similar trend of overestimation of blood glucose by capillary tests during pregnancy [9]-[11]. Nonetheless, this level of discrepancy is generally considered "acceptable" in most clinical contexts [10] [11]. Overall, the agreement between capillary and venous measurements was deemed unsatisfactory in our study, as 95% of deviations fell outside the acceptable margins of error. Comparable studies have yielded contradictory results despite employing similar methodologies [9] [12]. These discrepancies may be attributable to variations in glucometer characteristics (meas-

urement variability), differing acceptable margins of error across institutions, and/or population-specific factors, as observed globally in GDM research. Furthermore, the diagnostic performance of CBG was poor in our study, with sensitivity and specificity determined as 78.2% and 54.7%, respectively, compared with VBG. Additionally, CBG overestimated the prevalence of GDM (55% compared to 30% for VBG). These findings are corroborated by existing literature [9] [13] [14]. In sub-Saharan Africa, a high prevalence of GDM has been observed since the implementation of the IADPSG criteria [4] [15]. The reliance on glycaemic tests that overestimate this prevalence could impose a significant burden on local healthcare systems without clear evidence of a favourable benefit-risk ratio. Identifying an optimal diagnostic threshold (glycaemic cutoff) that correlates with adverse pregnancy outcomes remains a compelling avenue for enhancing the sensitivity of CBG in diagnosing GDM [14]. However, when assessed independently, the CBG level at 2 hours post-glucose load demonstrated greater sensitivity, specificity, and utility (AUC = 0.79) for the diagnosis of GDM in comparison to other stages of the OGTT. A related study reported an AUC for CBG at H2 as 0.9 [10]. Therefore, the use of CBG in isolation may represent a valuable diagnostic tool in settings where optimal conditions for performing VBG assessments are not achievable. For instance, Daly *et al.* [11] indicated that CBG tests exhibited superior sensitivity and specificity for diagnosing GDM relative to VBG measurements conducted under suboptimal conditions. Furthermore, within our study population, the likelihood of obtaining normal CBG values in patients diagnosed with GDM was minimal, as evidenced by NPV exceeding 90% and a weak LR. As a result, the implementation of CBG testing can be regarded as an initial screening measure for GDM in low-income countries. Women presenting with pathological CBG results at this preliminary stage may subsequently be referred to accredited facilities for more comprehensive testing, utilizing adequate VBG measurements.

5. Conclusion

CBG represents a promising instrument for the diagnosis of GDM in low-income countries. Nonetheless, due to its inadequate concordance with VBG measurements and moderate diagnostic performance, its application in practice for this purpose should be limited to specific circumstances. The use of CBG as an initial screening tool for GDM is warranted given its favourable NPV and weak LR. Moreover, CBG, particularly at 2 hours post-glucose load, may be recommended for the diagnosis of GDM in healthcare centres lacking access to adequate VBG measurement capabilities.

Disclosure

Authors have no conflict of interests and the work was not supported or funded by any drug company.

AI tools are not utilized in the writing of the article, creation of images, collection and analysis of data.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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