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COMPARATIVE EVALUATION OF POINT-OF-CARE TESTING METHODS AND LABORATORY-BASED SPECTROPHOTOMETRIC ANALYSIS FOR BLOOD GLUCOSE ESTIMATION: A NARRATIVE REVIEW

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Abstract

Diabetes Mellitus (Food & Drug) has emerged as one of most critical health challenges, evolving into the most alarming disease in the 21st century. According to the International Diabetes Federation, 11th edition (2024), approximately 589 million adults aged 20-79 were living with diabetes which is equal to 11.1% of the global population. Based on the current dynamics, future projections are even more alarming indicating that there will be sharp rise among diabetic patients, by 45% reaching the 853 million by 2050 driven by unhealthy dieting patterns, aging populations.

Exact blood sugar level estimation is fundamental to the diagnose, monitor and manage the alarming situation of diabetes mellitus either type 1 or type 2 and other metabolic disorders. Currently, various rational approaches are employed in clinical settings most importantly point-of-care testing (POCT) techniques and laboratory-based spectrophotometric methods. Each mode of glucose estimations possesses certain advantages and limitations that affects its clinical pertinence across different healthcare settings.

This review offers an inclusive comparative estimation of various POCT glucose testing methods and laboratory-based spectrophotometric methods of blood glucose evaluation. The review debates about the potential error of analytical approaches underlying commonly used testing methods and the effect of pre-analytical, analytical and post-analytical variables on accuracy of interpretations. Optical sensor devices, glucometers that runs electrochemically and continuous glucose monitoring systems (CGMs) are examined together with enzymatic laboratory methods including oxidase-peroxidase and hexokinase methods.

Comparative evaluation accentuates that POCT methods delivers fast turnaround time and workflow productivity making them crucial for intensive care units, emergency and outpatient settings. Though, POCT methods for estimation of glucose are markedly affected by physiological extremes, operator skills and analytical interventions. On the other hand, laboratory based spectrophotometric methods shows higher analytical accuracy, standardization

and precision backup their roles as gold standard methods for diagnosis, monitoring, validation and quality assurance.
following review further reports about quality management or enhancement, current challenges or research gaps, clinical applications across vast number of patient populations and future perspective in glucose monitoring. Overall evidence supports a balanced, integrated testing strategy that combines the rapid availability of POCT with the analytical robustness of laboratory methods to optimize patient safety and clinical outcomes.

1. Introduction

Diabetes mellitus is a rapidly growing universal health problem that imposes considerable morbidity, mortality and economic burden all over the world. Authentic and accurate blood sugar level monitoring is crucial to diagnose early diabetes and preventing other complications such as hypoglycemic and hyperglycemic state. Because of this both Point-of-Care testing devices (also known as bedside monitoring devices) and spectrophotometric analysis of blood glucose methods coexist in clinical practice. Although each approach has unique analytical characteristics that attribute their effective use in different clinical settings (Hauss et al., 2024).

Point of care glucose meters and rapid glucose monitoring systems have modified diabetes management by providing rapid and precise glucose information outside of clinical setting. POCT devices are beneficial due to their portability, easy to use by a common person, supporting immediate clinical decisions on outpatients, hospitalized patients and also due to the short turnaround time (Pleus et al., 2020). However, POCT devices are more liable to pre-analytical and analytical level because their performance may be affected by various factors such as hypotension, extremes of blood hematocrit level and the presence of certain interfering substances in addition to medications such as acetaminophen and ascorbic acid etc. (Dunseath et al., 2019) These limitations have been repeatedly demonstrated in both controlled evaluations and real world clinical studies (Pleus et al., 2020).

Laboratory based spectrophotometric assays especially enzymatic hexokinase and glucose oxidase-peroxidase (GOD-POD) methods remain the gold standards for many confirmatory glucose measurements due to their analytical specificity, accuracy and traceability when performed on automated chemistry analyzers (Shaker, 2023; Sonagra, 2024). The hexokinase method, which measures the formation of Nicotinamide Adenine Dinucleotide Phosphate (NADPH) spectrophotometrically is observed as a high quality laboratory method and is recurrently used in comparison with other methods of glucose monitoring for validation studies (St Clair et al., 2024). However unified laboratory testing requires venous blood sample, a trained personal and an appropriate instrumentation that increases its turnaround time and restricts its availability in emergency cases which is serious concern for emergency patients (Paloma Oliver et al., 2021).

Technical standards, guiding documents and regulatory frameworks aim to poise availability and patient safety across glucose testing devices. International standards such as ISO 22870 for POCT and ISO 15197 for glucose monitoring systems along with the supervisory guidance issued by US Food and Drug Administration (FDA) defines quality control procedures, analytical procedures and performances, labeling standards, and evaluation requirements of glucose monitoring devices (Hauss et al., 2024). Despite these agendas, post-market investigation and comparison studies continue to validate clinically substantial variability among different blood glucose monitoring devices strengthening the need for strong and effective quality management (Paloma Oliver et al., 2021)

From a treatment perspective, even minute analytical errors in glucose monitoring can cause improper dosage of insulin or false interpretation of hypoglycemia and hyperglycemia. To tackle

with this issue, certain clinical impact assessment tools such as Clarke error grid, insulin dose error grid and Parkes error grid have been developed to assess potential clinical risks and to evaluated analytical deviations (Lyon & Kovatchev, 2019; Sengupta, 2021). Comparative studies increasingly assess and report both analytical metrices such as bias and mean absolute relative difference and also clinical risk evaluations to provide more comprehensive assessments of device fitness (Klonoff & Prahalad, 2018)

Evidence published since 2015 focuses several reliable themes that are relevant to comparative evaluations. Firstly, while many POCT devices provide fast and rapid results meeting regulatory analytical thresholds, their performance is more variable and questioning for vulnerable patient populations including critically ill patients and neonates (St Clair et al., 2024). Secondly, laboratory spectrophotometric methods remain crucial for external quality assurance programs despite their longer turnaround time and higher cost (Sonagra, 2024). Thirdly device suitability is highly situation specific just like systems suitable for outpatients self-assessment may be unsuitable for patients for intensive care units without quality safeguards and additional validation (Dunseath et al., 2019).

Continuous glucose monitoring (CGM) has added a new layer to glucose estimation by providing trend-based data recurrent estimation that allow early detection of glycemic condition. Benefits provided by CGM techniques is improving glycemic control and reducing hypoglycemia in outpatients while recent studies are emphasizing in improving the accuracy and traceability of them in hospitalized and intensive care unit patients (Zelada & Braithwaite, 2023). However, there are certain challenges that limit the CGM technologies including reduced accuracies under physiological extremes, calibration discrepancies and sensor lag demonstrating that they should be held as complement rather than replace blood glucose measurements (O'Connor et al., 2024)

The choice between POCT and laboratory-based glucose testing further depends upon operational and economic factors. Operator competency, turnaround time connectivity with electronic medical record, device and consumable costs and the administrative burden of quality assurance are essential parameters of real-world performances and sustainability. (Paloma Oliver et al., 2021) Standardized protocols, strong laboratory oversight and routine comparison with gold standard laboratory methods are crucial for ensuring the reliability and safety of POCT devices and programs (Mok et al., 2017).

At last important research gaps remain including assessments of hematocrit compensation technologies under clinical environment, the need of situation specific comparative studies in neonates and critically ill adults, investigation of CGM laboratory based conflict in inpatient care and cost effectiveness analyses that take part clinical outcomes with economic burden (St Clair et al., 2024; Zelada & Braithwaite, 2023) addressing these gaps will support evidence based implementation of glucose testing strategies adapted to specific clinical environments as well as patient populations.

This review seeks to provide laboratory professionals with evidence-based framework for optimizing glucose testing practices and enhancing patient safety.

2. Overview of Blood Glucose Measurement Principles:

2.1 Physiological Basis of Blood Glucose Regulation

Blood glucose is firmly regulated to ensure a suitable supply of energy to ti[i]ssues, predominantly the brain and red blood cells(erythrocytes) while preventing the harmful effects of hyperglycemia. In healthy individuals, glucose regulation is maintained through a complex relationship of hepatic, renal, hormonal and peripheral tissue mechanisms. Insulin, secreted by beta cells of pancreas, is the main source hormone capable of lowering blood glucose by promoting cellular glucose uptake and inhibiting hepatic gluconeogenesis, whereas other hormone responsible of counter regulation such as glucagon, growth hormone, cortisol and

catecholamines raise blood glucose levels during fasting or stress states (Rizza, 2016)

Physiologically, blood sugar level exists in dynamic equilibrium between dietary intake, endogenous production and tissue utilization. Postprandial blood sugar levels reflects insulin mediated peripheral uptake and intestinal absorption, whereas fasting blood sugar levels are largely determined by hepatic output of glucose through mechanisms of glycogenolysis and gluconeogenesis (Cryer, 2016). Renal handling of glucose also plays a role in spite of liver, as glucose is freely filtered by the glomerulus and reabsorbed by the proximal convoluted tubules; changes in renal threshold like diabetes and pregnancy can influence measured glucose values (DeFronzo et al., 2017)

Significantly, glucose concentrations differ in accordance with sample types. Capillary blood samples typically show higher glucose levels than venous blood in postprandial state due to active tissue uptake, however differences are minimal when dealing with fasting conditions. Plasma glucose values are approximately 10 to 15% raised than whole blood values because glucose is distributed in aqueous phase which is comparatively greater in plasma (Sacks et al., 2018). These physiological distinctions have direct implications for glucose monitoring and interpretation across different testing platforms.

2.2 Pre-Analytical, Analytical and Post-Analytical Variables Affecting Glucose Estimation

Accurate blood glucose monitoring depends not only on analytical study but also on strategic control of pre-analytical and post-analytical factors. Pre-analytical variables are major source of error including sample type, patient preparation, sample handling and collection techniques. Delayed separation of plasma from sample allows glycolysis by erythrocytes and leukocytes , resulting in low blood glucose levels (false negative) typically decreasing by 5 to 7% per hour at 25^0C if untreated (Chan et al., 2017). Use of effective glycolysis inhibitors such as sodium fluoride combined with citrate buffer is therefore crucial for laboratory setting (Fischer et al., 2021)

Source of sample substantially influences glucose results. Capillary samples may be affected by poor perfusion, contamination with interstitial fluid or improper squeezing of the finger while venous samples may reflect systemic rather than localized glucose changes (Tang et al., 2017). Variations in Hematocrit level alter the plasma to cell ratio and can significantly bias whole blood glucose measurements particularly in POCT devices that rely on certain electrochemical reaction for glucose detection (Dimeski et al., 2019)

Analytical parameters relate to the measurement principle and instrumentation. Enzymatic methods differ in specificity and susceptibility to interference. For example, oxygen tension is the major factor that affects glucose oxidase method whereas for hexokinase-based method the major interfering factor is not maintaining the reagent and calibration control (Burnett et al., 2019). Appropriate temperature, stability of reagent, calibration of instrument and accuracy of wavelength are the essential factors for spectrophotometric assay performances (Tietz & Rifai, 2018)

Factors that can compromise post analytical accuracy are incorrect conversion of units (mg/dl vs mmol/L) while reporting, improper data processing and clinical interpretation and other transcriptional errors (Plebani, 2017). In POCT environment, there is a lack of result integration with laboratory information system that may lead to increasing the risk of systematic error (O'Kane et al., 2020) Below is the table summarizing variables affecting blood glucose measurement across pre-analytical, analytical and post-analytical phases.

Table 1. Variables Affecting Blood Glucose Measurement Across Testing Phases

Phase	Variable	Effect on glucose measurement	Clinical impact	Key Reference
Pre-analytical Phase	Delay in plasma separation	Falsely low level of glucose (due to glycolysis)	Misdiagnosis of hypoglycemia	(Chan et al., 2017; del Pino et al., 2016)
	Type of Sample (venous or capillary)	Postprandial type (glucose higher)	Incorrect decisions related to treatment	(Sacks et al., 2018; Tang et al., 2017)
	Hematocrit extremes	Error in entire POCT interpretations	Insulin dosing related errors	(Dimeski et al., 2019)
Analytical Phase	Method principle (GOD-POD vs Hexokinase)	Variable interference and specificity	Method dependent variability	(Tietz & Rifai, 2018)
	Instrument calibration	Systematic error	Poor result comparability	(Burnett et al., 2019; Plebani, 2017)
Post-analytical Phase	Unit conversion errors	Misinterpretation (mg/dl vs mmol/L)	Clinical risk	(Plebani, 2017)
	Transcription of data	Errors in reporting	Patient safety issues	(O'Kane et al., 2020)

3. Point-of-Care Testing (POCT) Methods for Blood Glucose Estimation:

3.1 Definition and Clinical Applications of POCT:

The actual goal of POCT is to provide rapid and fast results that enables immediate making of decisions with or without the need of healthcare provider at or near the site of patient care. That is why POCT has become a vital component in the situation of glucose monitoring, critical care medicine, management of diabetes, emergency care and perioperative monitoring. In such cases when there might be a delay in result from central laboratory, POCT glucose testing enables reliable therapeutic outcomes that may avoid any sort of compromise with patient safety (Nichols et al., 2020).

Clinical implementation of POCT glucose testing span various healthcare setting including emergency care, intensive care units, outpatient settings, hospital wards and self-monitoring in home. Rapid detection of glucose is essential for diagnosing emergencies related to hypoglycemia and hyperglycemia (Rebel et al., 2012). In home and outpatient healthcare setups POCT actively participates in patient safety and trustworthiness (Greenwood & Grady, 2021).

3.2 Types of POCT Glucose Devices:

3.2.1 Electrochemical Glucometers:

The most extensively used POCT devices for glucose monitoring nowadays are electrochemical glucometers. These systems depend upon the electrochemical detection of electrons generated during the process of glucose oxidation by the action of glucose oxidase or glucose dehydrogenase enzymes. The current produced as a result is directly proportional to the amount to glucose present in sample (Kim et al., 2025).

However, to deal with the challenges like hematocrit interferences and temperature variations, modern electrochemical glucometers are available that ran over advanced level algorithms. Despite these improvisations there are factors that disturb the analytical accuracy such as volume of sample, strip availability environmental conditions and presence of interfering substances like maltose and galactose in certain enzyme systems (Karon et al., 2015; Lv et al., 2013).

3.2.2 Optical and Reflectance Based Devices

Optical and reflectance-based glucose devices represent an alternate POCT approach and are based on photometric measurement of changes in color produced on reagent strips by enzymatic reactions. Light absorbance or reflectance is measured and correlated with glucose concentrations using various calibration curves (Jing et al., 2022).

Although these devices offer uncomplicatedness and low cost, their analytical capability is generally lesser to electrochemical systems, particularly when dealing with extreme glucose concentrations. Optical devices are more vulnerable to light, operator handling errors and strip discoloration which limits their widespread adoption and overall quality (Pullano et al., 2022).

3.2.3 Continuous Glucose Monitoring Systems (CGMS):

Continuous glucose monitoring systems (CGMS) characterize a significant technological advancement in POCT by giving near continuous glucose measurements via subcutaneous sensors. CGMS monitors interstitial glucose concentrations at frequent intervals and generate data that support glycemic management proactively (Battelino et al., 2019).

There are some important benefits of CGMS in diabetes care of outpatients including detection of nocturnal hypoglycemia and variability in glycemic index but in certain inpatient settings, CGMS technique also face challenges including sensor calibration requirements, rapid fluctuations in blood glucose and its physiological lag with interstitial glucose. (Galindo et al., 2020).

All types of glucose devices are summarized along with measurement principle, required sample type, key features and common limitations in Table 2.

Table 2: Different types of POCT devices along with their clinical features

POCT Device Type	Measurement Principle	Sample Type	Key Features	Common Limitations
Electrochemical glucometers	Enzyme based reaction and electrochemical detection	Capillary whole blood	Widely used, Portable, Rapid results	Strip variability, hematocrit interference
Optical/ Reflectance based devices	Colorimetric reaction with photometric detection	Capillary whole blood	Low cost, Simple design	Low accuracy, affected by light
Continuous glucose monitoring systems (CGMS)	Measuring interstitial glucose by subcutaneous sensor	Interstitial fluid	Hypoglycemic detection, Trend analysis	Calibration needs, Sensor lag

3.3 Analytical Performance of POCT Methods

The analytical outcome of POCT glucose devices is typically estimated using parameters such as precision, accuracy, bias and mean absolute relative difference (MARD). International standards and clinical studies highlight that POCT devices must meet predefined performance criteria to validate patient safety (Weiss et al., 1994)

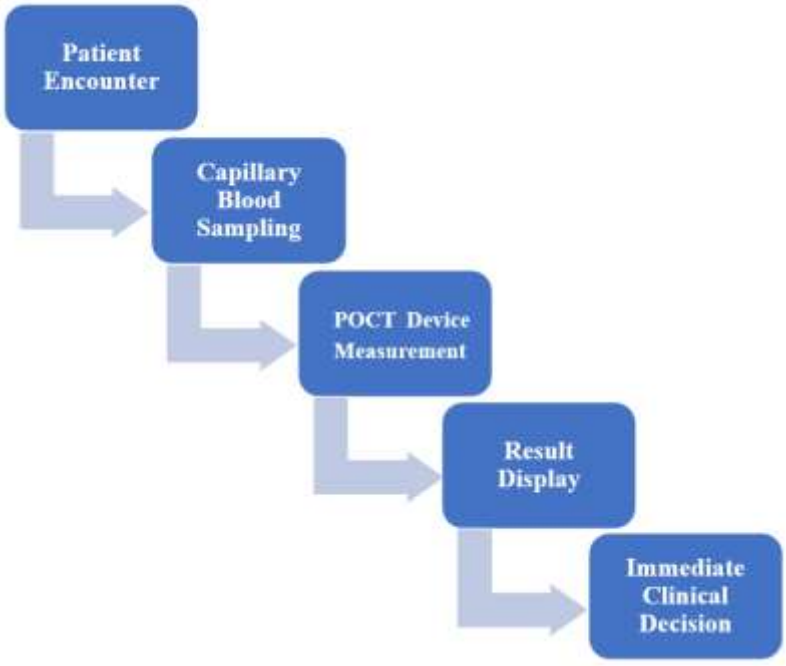
Comparative and comprehensive studies have shown that while many POCT devices achieve acceptable analytical performance, accuracy compromises in critically ill patients due to factors such as anemia, edema and hypotension (Hoedemaekers et al., 2008; Karon et al., 2015). These findings suggest the importance of context specific validation and ongoing quality assurance.

Overall description of certain clinically important parameters along with their clinical relevance is described in Table 3

Table 3. Parameters involved to monitor POCT reliability.

Parameter	Description	Clinical Relevance
Precision	Repeatability of measurements	Affects consistency of monitoring
Accuracy	Closeness of results to reference method	Determines reliability of glucose value
Bias	Systematic deviation from true value	Can cause over or under treatment
MARD (%)	Mean absolute relative difference	Common parameter for device comparison
Error grid analysis	Clinical risk assessment	Evaluates patient safety impact

3.4 Pros and Cons of POCT in Clinical Practice:
The primary significance of POCT glucose monitoring include reduction from sample handling, fast and turnaround time, improved patient engagement and enhanced clinical workflow. POCT also helps in reduction of hospital stay and overall expenditures related to healthcare when implemented properly (St John & Price, 2019).
Despite these pros, POCT also presents substantial cons that can be neglected over time. These include operator dependent skills, variability in the performance of device due to change in strip, challenges in quality control and difficulty while integrating POCT interpretations into laboratory information system (Agus et al.) (Agus et al.). Unknown errors and inadequate training may increase the chance of compromising patient safety (Patel & Suh-Lailam, 2019). So, POCT implementation is crucial under strong laboratory frameworks to ensure reliability and clinical traceability.



Flow Sheet Diagram 1. POCT Blood Glucose Testing Workflow

4. Laboratory-Based Spectrophotometric Methods for Blood Glucose Estimation:

4.1 Role of Central Laboratories in Glucose Monitoring:

There is a central role of clinical laboratories in blood sugar monitoring by giving standardized information and traceable results that encompass the basis of long term of diabetes mellitus. In contrast to POCT glucose devices, laboratory-based glucose estimation runs under strict quality management system including internal and external quality assessment and satisfactory calibration. These calibration and control procedures provide assurance about analytical traceability (Karkalousos & Evangelopoulos, 2011).

Laboratory-based glucose estimation is primarily important for making crucial diagnostic decisions like as confirmation whether the POCT findings are normal or abnormal, establishing diabetes related concerns after fasting glucose level thresholds and oral glucose tolerance testing. For calibrating quality assurance programs in outpatient settings and validating POCT devices, central laboratories serve as a reference points (Rodbard, 2013). That is why these methods remain in a center despite longer turnaroud times.

4.2 Enzymatic based Spectrophotometric Methods:

Almost all the spectrophotometric glucose monitoring relies on certain enzyme-based reactions that are detectable at specific wavelength when co-enzymatic products or chromogenic substances are produced. Automated chemistry analyzers work on this principle and considered as most valuable for their sensitivity, specificity and precision in laboratories (Rifai, 2019).

4.2.1 Glucose Oxidase-Peroxidase (GOD-POD) Method (Spectrophotometrically):

For glucose estimation, the oxidase-peroxidase (GOD-POD) method is on the most commonly applied spectrophotometric method. In this method, glucose oxidase enzyme act on glucose and convert it into gluconic acid and hydrogen peroxide. The hydrogen peroxide then reacts with the chromogenic substance yielding a colored compound in the presence of peroxidase enzyme that is measured by the automated chemistry analyzer spectrophotometrically, usually at 500 to 550nm (Wu, 1997).

The advantages of this method are cost effectiveness, simplicity and suitability for routine clinical purpose. There are certain limitations also such as peroxide reaction is affected by the interference of certain substances for example uric acid, ascorbic acid and bilirubin etc. in spite of these challenges, adequate sample handling and formulation of reagent can alleviate many analytical error (McPherson & Pincus, 2021).

4.2.2 Hexokinase Method (Spectrophotometrically):

The method that is considered as gold standard or reference is hexokinase method for laboratory glucose monitoring. In this method hexokinase enzyme phosphorylates glucose and converts it into glucose-6-phosphate. The glucose-6-phosphate dehydrogenase enzyme acts on resultant glucose-6-phosphate and produces NADPH. The increase in absorbance at 340nm is directly proportional to concentration of glucose (Rifai, 2017).

This method offers high level of specificity and minute or no interference compared to above mentioned GOD-POD method making it most valuable method in comparison with other methods or external quality assessments. As a result this method is used as a reference for evaluating POCT devices (Freckmann et al., 2015).

4.3 Analytical Precision, Accuracy and Reference Standards:

One of the most critical parameters to check clinical reliability of glucose monitoring are precision and accuracy. Accuracy reflects actual closeness of measured value to the true concentrations on the other hand precision reflects repeatability under identical conditions. However if we look for comparison with POCT systems and controlled analytical environment

then laboratory spectrophotometric techniques provide greater performances in both cases (No & Committee, 2020).

Standardized reference methods further strengthen laboratory testing. International reference measurement procedures make sure of that laboratory-based glucose determination methods must be aligned with recognized standards facilitating reliable diagnostic initiatives across foundations

(Özcürümez et al., 2019). By contributing in external quality assessment programs empower laboratories to detect systematic error and monitor long term analytical performance (Peter, 2023).

4.4 Strengths and Limitations of Spectrophotometric Glucose Estimation:

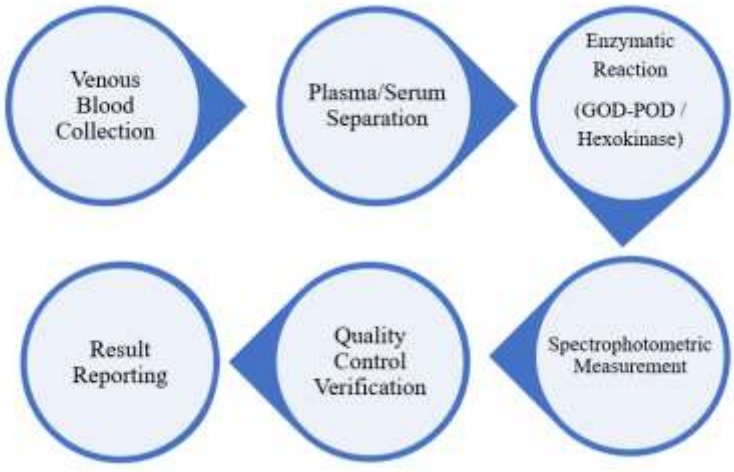
Excellent precision, operator skills, reduced susceptibility and high level of accuracy are the primary fortes of spectrophotometric glucose estimation. These qualities make laboratory methods vital for diagnosis, confirmation and quality comparison with POCT devices (Rodbard, 2013).

Though laboratory-based testing also face some challanges. Need of venous sampling, higher infrastructure costs, longer turnaround time and dependance on centralized facilities limit immediate clinical pertinence in emergency cases or in bedside scenarios. In addition to, preanalytical errors such as improper sample handling and delayed processing can still affect interpretations if not properly controlled (Cornes et al., 2019). As a result, laboratory spectrophotometric methods are best as complementary to POCT rather than competing technologies.

Table 4. Comparison of Major Spectrophotometric Methods for Blood Glucose Estimation

Parameter	GOD-POD Method	Hexokinase Method
Analytical Principle	Peroxidase-based colorimetric reaction	NADPH formation at 340nm wavelength
Interference Risk	Higher (ascorbic acid, bilirubin)	Minimal
specificity	Moderate	High
Cost	Lower	Higher
Automation compatibility	High	High
Reference suitability	Routine testing	Reference/ comparator method

Sources: (Özcürümez et al., 2019) (McPherson & Pincus, 2021) (Rodbard, 2013)



Flow-Sheet Diagram 2. Laboratory Spectrophotometric Glucose Testing Workflow

5. Comparative Evaluation of POCT and Laboratory-Based Methods

5.1 Accuracy and Precision Comparison:

Accuracy and precision are the most crucial determinants when comparing POCT devices and laboratory-based glucose estimation techniques. We have already discussed that accuracy reflects the closeness of measured values to the true glucose concentrations whereas precision reflects reproducibility under repeated measurements. Frequent comparative studies reveal that laboratory based spectrophotometric methods, especially hexokinase method consistently outperform POCT devices in analytical accuracy and precision due to standardized calibration and reduced vulnerability to operator error (Heinemann et al., 2018)

POCT devices, although improved in recent generations, show greater inconsistency, especially at hyperglycemic and hypoglycemic extremes where clinical risk is highest. Multicenter evaluations have shown that POCT accuracy and specificity may decline substantially in critically ill patients due to anemia, biochemical interferences and altered perfusions (Mifsud et al., 2018) of POCT may also affected by environmental conditions and strip lot variation, in contrast laboratory methods maintain tighter coefficients of variation (Ji et al., 2016).

5.2 Turnaround Time and Workflow Efficiency

Turnaround time (TAT) represents a major benefit of POCT over laboratory-based testing. This fast and rapid accessibility of results improves workflow efficiency, shorten hospital length of stay and reduces clinical delays (Larsson et al., 2015).

On the other side, laboratory-based glucose testing involves multiple workflow steps including batch analysis, centrifugation and result verification resulting in longer TAT. However central laboratories offer higher throughput, data integration and automation making them more reliable and efficient for routine testing (Gupta et al., 2018). Thus, POCT excels in time critical scenarios whereas laboratory testing is preferred for systematic monitoring and diagnosis.

5.3 Cost- Effectiveness and Resource Utilization:

Although POCT devices have lower equipment costs, the cumulative expenses associated with consumables, staff training, quality control and connectivity can exceed those of centralized laboratory testing over time (Lingervelder et al., 2021). Studies have shown that POCT glucose testing may cost 2-5 times more per test than laboratory glucose methods when full operational costs are taken into account (Goldstein et al., 2019).

Laboratory-based testing benefits from automation and centralized expertise and resulting in lower cost per test in high volume settings. However, indirect costs related to delayed decision making must also be considered. Cost-effectiveness hence depends on patient acuity, test frequency and clinical context (Pease et al., 2022).

5.4 User Dependency and Operator Variability:

User dependency is a major challenge for POCT glucose testing devices. POCT is occasionally performed by common person or non-laboratory personnel with or without proper training leading to increased level of analytical errors such as improper sampling technique, failure to perform quality control and inadequate strip storage (Lazaro-Pacheco et al., 2025).

Laboratory-based glucose testing minimizes user dependency through standardized procedures, automated procedure and oversight by trained laboratory personnels. Automated analyzers lowers the manual handling and transcription errors enhancing reliability and traceability (Plebani, 2015). As a result, operator-related variability is considerably lower in laboratory based spectrophotometric analysis compared to POCT environments.

5.5 Interfering Substances and Analytical Bias

Analytical error arising from interfering substances is a crucial challenge in glucose measurements. POCT devices are predominantly vulnerable to interference from hematocrit variation, medications, oxygen tension and endogenous substances such as bilirubin and uric acid (Erbach et al., 2016) intrusions may lead to

clinically significant over or underestimation of glucose levels.

Laboratory-based spectrophotometric methods address higher analytical validity, especially hexokinase method which usually do not affect by interfering substances. However, if spectrophotometric measurements if not properly maintained then factors like extreme lipemic sample and hemolysis can still affect these measurements (Thakur et al., 2023).

5.6 Clinical Decision-Making Impact

The conclusive parameters for comparing laboratory-based methods with POCT devices are their influence on decision making at clinical level and outcomes on patients. In acute care settings, fast and rapid POCT interpretations simplify timely administration of insulin and hypoglycemia management preventing adverse events (Campos-Náñez et al., 2017). However, inaccurate POCT results may lead to inappropriate insulin dosing raising the risk of iatrogenic hypoglycemia.

Laboratory-based glucose testing supports definitive diagnosis, calibration of POCT programs and longitudinal monitoring. Studies using clinical grid analysis demonstrate that laboratory methods steadily place results in low-risk zones whereas POCT results may occasionally fall into zones associated with moderate to severe clinical risk (Bachache et al., 2022). Optimal clinical practice therefore relies on a complimentary approach integrating POCT for rapid decision-making with confirmation of laboratory for diagnostic accuracy.



Flow Diagram 3. Impact of Glucose Testing Modality on Clinical Decisions

Table 5. Comparative Evaluation of POCT and Laboratory-Based Glucose Estimation

Parameter	POCT Methods	Laboratory-Based Methods
Precision	Variable	Excellent
Accuracy	Moderate-High	High (reference standard)
Cost per test	Higher (overall)	Lower (high-volume)
Turnaround time	Minutes	30-120 minutes
Interference risk	Higher	Lower
Operator dependency	High	Minimal
Best clinical use	Emergency and bedside decisions	Diagnosis and confirmation

6. Errors due to Quality Assurance and Standardization

In both mentioned approaches for Blood glucose determination, it is essential to maintain the reliability with the process of Quality Assurance and standardization. As clinical therapy is devised on the basis of clinical diagnosis, any error in the glucose determination will directly affect treatment plan i.e. Dose of insulin, and in return can be harmful to the patient. So, it is clear that glucose analysis in any healthcare setup needs predefined standards and Quality Assurance protocols (van Rossum, 2022).

Central laboratories follow the international standards established in the ISO 15189 to determine Blood glucose levels which includes Internal and external Quality assurance, traceable instrument calibration with a reference and constant monitoring of performance of the instrument. These frameworks are helpful in securing the reliability, standardization and lasting analytical consistency of spectrophotometer used for glucose determination (Stavelin & Sandberg, 2017). Diagnostic accuracy is well supported by application of certified reference protocols and material in the laboratories and public diagnostic services (Prestedge et al., 2025).

Various clinical situations, variety of performing hands and underrated significance of test has created an unimaginable challenge for Quality management in Rapid POCT testing. As POCT is a bedside analytic procedure which requires minimum operating skills, the instances of variation in protocols and errors of documentation arises more frequently. The international organization of standardization specifically mentions the importance of hand on practice training, calibration and validation of POCT instruments and evaluation of comparability and competency, under the section of ISO 22870. It also signifies the importance of supervision of a managing central body. (P. Oliver et al., 2021). Reliable POCT models ensures the oversight of Clinical laboratories in diagnostic systems (Prestedge et al., 2025).

Verification of test strips and chemical reagents along with ensured calibrations are vital components to maintain the quality of test results. The lot change of the reagents has a significant impact on the predisposition of analysis in electrochemical glucometers. To pin out the systemic errors and to ensure a deliverable performance, Consistent verification methods are suggested (Loh et al., 2023). Any negligence in these processes may raise hidden errors that can put the patients at a risk.

Along with the standardization of measuring process, reporting, specific SI units for measurement and subtle interpretations are also essential part of the benchmark for glucose measurement protocols. International criteria for laboratory diagnosis establish the reliable units (mg/dL or mmol/L) for reporting the blood glucose levels. In interlinked health care institutes, dysregulation of standardized units in reporting may result in false interpretations (Plebani, 2016).

As in view of the importance of 12 quality essentials, Documentation, record keeping and data management, enables result storage, traceability and rapid monitoring of quality if laboratory information systems (Agus et al.). or hospital information systems (Vashist) are integrated in POCT devices. According to various researches, in comparison to non-unified POCT systems, this interlinking mechanism has a significant impact and is greatly helpful to maintain the quality by decreasing the risk of transcriptional errors generated due to manual typing (Fung, 2020).

Educating the Clinical staff and assessing their skills is important to support the Glucose testing systems. To maintain the personnel capability and establish the standards, regular clinical training, proficiency testing, and relevant feedback systems are essential. According to studies in 2020, it is suggested that well defined training systems have meaningful effect on minimizing the errors related to POCT (Yenice, 2021).

In other words, both Spectrophotometric and rapid POCT glucose assessment requires strong implementation of Quality protocols and standards. POCT methods lacks structured lab expertise, Quality assurance and oversight in comparison to a well-established Central

laboratory. Current efforts to integrate the advanced technology and educating the personnels is the key to advance the ongoing sustainability, reliability and accuracy of glucose evaluation in healthcare services.

7.Clinical Applications and setting based Performance:

7.1 Hospital and Emergency Settings

Bedside Blood glucose determination is helpful on for the estimation of glucose level in patients of mental wards, hypoglycemia, ketoacidosis as a result of diabetes, or hyperosmolarity due to hyperglycemic conditions. The Use of POCT devices is preferred in these setups because they provide the clinicians with rapid results for immediate clinical treatment and decision making, which is an important factor for prompt treatment (Alter, 2021). According to a a study conducted, POCT devices have significantly reduced the reporting time of results as compared to laboratory-based analysis which improves the efficiency and workflow for patients in emergency and Intensive care Units.

But the accuracy of results by POCT device is determined by various factors including dehydration, shock, anemia and Vasoconstriction. Thus, critical results are verified using the more stable spectrophotometric measurement, methods to ensure accuracy (McIntosh et al., 2018).

7.2 Intensive Care Unit (ICU)

In critical patient care, both extremes of glucose level; hyperglycemia and hypoglycemia are considered critical as they are associated with more risk of morbidity and mortality. It effects the rate of Glucose evaluation with POCT more compatible choice due to its prompt results and bedside testing (Bohé et al., 2021). However, conditions like edema, hypotension, change in Pack Cell volume of Red blood cells and administration of vasoactive medications in ICU patients, negatively effects the reliability of POCT. Recent studies have showed that spectrophotometric analysis has comparative superiority of accuracy in ICU patients. As a result, to minimize the risk clinically in Critical patients, blood glucose should be measured by POCT for real-time monitoring and by laboratory reference methods for confirmation as well (van Rossum, 2022).

7.3 Outpatient and Home-Based Monitoring

In home-based patients, self-monitoring of blood glucose level with POCT plays a central role in long term management of diabetes and in outpatient clinics and home-based settings, glucose monitoring plays a central role in long-term diabetes management to plan their diet, physical activities, and medication., contributing to improved control of glycemic conditions by reducing complication rates (Chen & Chang Yeh, 2015). Continuous glucose monitoring systems (CGMS) have improved outpatient care by using trend data and real-time signals for hypoglycemia and hyperglycemia.

Although POCT has advantages, the effectiveness of home-based monitoring relies on patient education, device precision, and implementation of testing protocols. Inaccurate technique or misinterpretation of results may obstruct the clinical benefit, down regulate the importance of periodic clinical assessment and regular laboratory-based review (Charleer et al., 2018).

7.4 Special Populations (Neonates, Pregnant women and Critically Ill Patients)

Special populations present exclusive challenges for glucose measurement due to various physiological and analytical features In neonates, certain factors like high level of hematocrit, hypovolemia and narrow glycemic ranges marks the risk of error in measurement, making laboratory confirmation vital for important decisions. Accurate glucose estimation is also vital to manage and confirm the condition of gestational diabetes mellitus especially in case of pregnancy where laboratory-based plasma glucose testing retains its position as diagnostic standard (Charleer et al., 2018).

8. Challenges, Limitations, and Current research Gap:

A lot of development has been made since the birth of glucose determination, still there are various areas of progress which are being faced as challenges and restriction in both POCT and Laboratory based methods. These limitations are in the areas of analysis, operation, clinical and methodological areas forcing the researchers to make a work up plan.

Irregularity in the real-world experiment cases is the most forsaken challenge in POCT glucose testing. Even if at the time of manufacturing, the devices are regulated to meet the performance standards, but still the studies have shown a lag in accuracy in patient sample with conditions like anemia, edema and change in Vaso permeability (Mahmoodpoor et al., 2016). These discripancies are usually occurs in critically ill patients. It poses a great concern towards the reliability and aaccuracy of POCT devices in ICU cases. To add on HCT compensation system varies device to device and their performance in clinical samples is not considered a major limitation . (Hattemer & Wardat, 2018).

The absence of standards for glucose assessment is another restriction. Various standards including calibration, reporting units and reference materials gives vague comparisons between POCT and Laboratory results, leading to a potential false interpretation during patient transfer to other clinics or further follow ups latter in time.

(Fonseca et al., 2016). This issue is being resolved at international level with documented, synchronized standards across the manufacturers and healthcare systems.

Systems called Continuous Glucose monitoring system (CGMS) have emerged with new opportunities but it has also imposed new challenges. The defect of sensor which leads to lag between interstitial fluid and blood glucose, low accuracy in rapid glucose testing and sensor failures have put a limit on the use of POCT devices as a separate diagnostic tool, especially in large patient settings.(Ajjan et al., 2018). Furthermore, limited evidence exists about the scientific impact of CGM–laboratory discordance on insulin dosing choices in hospitalized patients, posing a key research gap.

Laboratory-based spectrophotometric methods, although medically firmer, but are not perfect. Pre-analytical errors such as overdue sample processing, inappropriate anticoagulant use, and sample contamination remain the source of error, affecting result accuracy (Lippi et al., 2015). Furthermore, laboratory turnaround time may be not suitable for time-limited decisions, highlighting the necessity for improved integration between laboratory and POCT systems.

As a research standpoint, many comparative studies contain methodological limitations, comprising on limited sample quantity, single-center layout, and deficiency of standardized result measurements. Only a few studies completely evaluate the clinical effect of glucose determination error by using patient-centered results for example hypoglycemia rates, insulin dosing errors, or lengthy duration of hospital stay (Agus et al., 2017). Monetary evaluations are also limited, with inadequate integration of downstream clinical significances and quality-adjusted life years.

Lastly, personnel-related challenges persist to be underexplored. The effect of operator training, skill deterioration, and workload on POCT performance is poorly calculated, principally in low- and middle-income healthcare setups. Future research should prioritize multicenter, setting-specific researches that includes analytical performance, diagnostic results, economic analysis, and application of science to guide evidence-based glucose monitoring strategies.

9. Future Perspectives in blood Glucose Monitoring:

Rapid technological innovations are reshaping the future of blood glucose assessment and monitoring by integrating digital methods, and making it more patient centered approach. Developments int the technology of biosensors, connectivity, and data analysis are anticipated to make the performance gap narrower between point-of-care testing (POCT) and laboratory-based methods and enhancing clinical consumption and safety as well.

Another principal area of improvement is the continuous refining of continuous glucose monitoring systems CGMS. Enhanced accuracy, longer life span and low requirements for calibration are the characteristics of Next Generation CGM sensors. Current research studies are focused on reducing the physiologic lag existing between interstitial and blood glucose and enhancing the performance during rapid fluctuations of glycemic conditions which will improve the continuous glucose monitoring systems in hospitalized patients and critical care setups (Battelino et al., 2023). The integration of CGM and Hospital information system will help to maintain digital records with less use of paper documentation and will help in rapid decision making.

The use of digital technologies, Machine learning, algorithms integrated with artificial intelligence and data analytic applications can transform the glucose determination. Analysis of large numbers of glucose results can help to predict hypoglycemic events to recognize mechanistic errors or other noise in results as well as to determine the dosage of Insulin (Dankwa-Mullan et al., 2019). These futuristic approaches in POCT and Laboratory determination system may increase the accuracy and number of cases.

Future developments mark the novel coordination between different testing procedures in laboratory. Efforts are being made to synchronize the calibration protocols, reference standards and reporting methods in required areas of manufacturing and care givers to maintain the reliability of glucose assessments.(Plebani, 2016). Advanced interconnection between LIS and POCT will improve quality and reduce post-analytical errors.

Optical, spectroscopic and transdermal methodologies are noninvasive or minimally invasive technologies to reduce the discomfort and improve the patient satisfaction decreasing the risk accidental pathogen introduction into body system. Although ongoing studies need further validations before clinical adoption (Lin et al., 2017).

In summary, the integration of accurate sensors, digital analysis and reliable frameworks is the future of blood glucose analysis. A hybrid model of rapid POCT and CGM is supported by laboratory based standard methods~~ are expected to deliver more accurate, reliable, and optimal results clinically.

10. Conclusion:

For effective diagnosis and monitoring of diabetes, more accurate or reliable determination methods for glucose are essential. This review article highlights that both, laboratory based spectrophotometric assays and POCT assays play complimentary role in glucose assessment. POCT is rapid bedside method that are critical in emergency situations and out-patient settings, but the performance is affected by the person using this procedure, analytical inferences and physiological variables.

Conversely, Lab based methods; hexokinase method has superiority over POCT in terms of analytical accuracy, precision and quality assurance making them the only gold standard.

The most effective strategy is to integrate both assessment methods to make a hybrid model. It will ensure enhanced patient safety and Clinical significance. AI technologies, improved device connectivity and evidence-based implementation of technologies and machine learning is the highlighted areas of advancement in glucose measurement.

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