AUCTORES
Globalize your Research

Journal of Clinical and Laboratory Research
Opeyemi Olufeyisola Adesina *

Open Access

Review Article

Comparative Study of Laboratory Diagnosis of Sickle Cell Anaemia Using Point-of-Care Testing, and Haemoglobin Electrophoresis in A Hospital Setting

Opeyemi Olufeyisola Adesina *, Abdulbasit Folawuyo Yekinni

Department of Medical Laboratory Science, Babcock University, Ilishan. Ogun State, Nigeria.

***Corresponding Author:** Opeyemi Olufeyisola Adesina., Department of Medical Laboratory Science, Babcock University, Ilishan. Ogun State, Nigeria.

Received Date: August 29, 2024 | **Accepted Date:** September 04, 2024 | **Published Date:** September 10, 2024

Citation: Opeyemi O Adesina., Abdulbasit F Yekinni, (2024), Comparative Study of Laboratory Diagnosis of Sickle Cell Anaemia Using Point-of-Care Testing, and Haemoglobin Electrophoresis in A Hospital Setting, *Journal of Clinical and Laboratory Research*, 7(7); **DOI:10.31579/2768-0487/149**

Abstract

Background: Sickle cell anaemia (SCA) is a hereditary blood disorder characterized by abnormal haemoglobin. Haemoglobin electrophoresis is the gold standard for diagnosing SCA, while SickleSCAN is a novel point-of-care (POC) test offering rapid results. This study compares the diagnostic accuracy of SickleSCAN with haemoglobin electrophoresis in detecting SCA.

Objectives: To evaluate and compare the effectiveness of SickleSCAN and haemoglobin electrophoresis in diagnosing sickle cell anaemia among patients at Babcock University Teaching Hospital (BUTH), Ilishan-Remo, Ogun State, Nigeria.

Materials and Methods: A comparative study was conducted between February and March 2024, involving 45 participants diagnosed with different haemoglobin phenotypes. Blood samples were analyzed using both SickleSCAN and haemoglobin electrophoresis. The results were statistically analyzed using SPSS software, employing descriptive statistics, ANOVA, and Pearson correlation to determine the sensitivity and specificity of both methods.

Results: The study included 45 participants: 21 with normal haemoglobin (HbAA, HbAS, HbAC), 19 with HbSS, and 5 with HbSC. SickleSCAN demonstrated high specificity (>99%) and sensitivity (>99%), closely matching the results obtained through haemoglobin electrophoresis. No false positives or negatives were observed, indicating the reliability of SickleSCAN in diagnosing SCA.

Conclusion: SickleSCAN is a reliable and efficient POC test for the diagnosis of SCA, with comparable sensitivity and specificity to haemoglobin electrophoresis. It holds potential as a valuable tool for rapid diagnosis in resource-limited settings.

Key words: sickle cell anaemia; point-of-care testing; haemoglobin electrophoresis; sicklescan; diagnosis; specificity; sensitivity

Introduction

Sickle cell anaemia (SCA) is a hereditary haemoglobin disorder characterized by the presence of haemoglobin S (HbS) in red blood cells [1]. This mutation leads to the formation of sickle-shaped erythrocytes under low oxygen conditions, causing various clinical complications such as hemolytic anaemia, vaso-occlusive crises, and organ damage. The global burden of SCA is significant, with the highest prevalence observed in Sub-Saharan Africa, India, the Middle East, and the Mediterranean regions. According to the World Health Organization (WHO), approximately 300,000 infants are born with sickle cell disease (SCD) annually, and about 50% of these births occur in Africa [2].

Early diagnosis and management of SCA are crucial for improving the quality of life and reducing mortality rates among affected individuals. Haemoglobin electrophoresis has long been considered the gold standard for diagnosing haemoglobin opathies, including SCA. This technique involves separating different types of haemoglobin based on their electrical charge and molecular size, enabling the identification of abnormal haemoglobin variants such as HbS, HbC, and others [3]. Despite its accuracy, haemoglobin electrophoresis requires specialized laboratory equipment, skilled personnel, and time, limiting its accessibility in resource-constrained settings.

Point-of-care testing (POCT) has emerged as a promising alternative for diagnosing SCA, particularly in low-resource settings. POCT for SCA typically involves rapid diagnostic tests (RDTs) that can be performed at or near the patient's location, providing immediate results. These tests are designed to be simple, cost-effective, and require minimal training, making them ideal for use in remote areas where access to conventional laboratory facilities is limited [4]. Recent advances in POCT technologies have led to the development of highly sensitive and specific tests for SCA diagnosis, such as the Sickle SCAN® and HemoTypeSC™ [5]. However, the accuracy and reliability of these tests compared to the gold standard haemoglobin electrophoresis remain areas of active research.

The introduction of POCT for SCA diagnosis has the potential to transform the landscape of SCD management, particularly in regions with high disease burden and limited healthcare infrastructure. The ability to rapidly and accurately diagnose SCA at the point of care can facilitate early intervention, reduce the time to treatment initiation, and improve patient outcomes. However, the clinical adoption of POCT requires thorough validation against established diagnostic methods to ensure its efficacy and reliability in diverse healthcare settings.

This comparative study aims to evaluate the diagnostic performance of POCT for SCA in comparison with haemoglobin electrophoresis in a hospital setting. By analyzing the sensitivity, specificity, and overall diagnostic accuracy of both methods, this research seeks to provide evidence-based recommendations for the integration of POCT into routine clinical practice. The findings of this study could have significant implications for SCA screening programs, particularly in resource-limited settings, and contribute to the broader effort to reduce the global burden of sickle cell disease.

Materials And Methods

Study Design

A comparative study design in research methodology compares two or more groups to identify differences and similarities between the groups. It involves examining the characteristics, outcomes, conditions, or variables. In this project, I compared the standard laboratory diagnosis of Sickle cell anaemia which is haemoglobin electrophoresis against the new point-of-care rapid test kit which is SickleSCAN. The duration of this study was between February and March 2024.

Study Population

Subjects with Sickle cell anaemia HbS at Babcock University Teaching Hospital (BUTH), Ilishan-Remo, Ogun State Nigeria, participated in this study. Informed consent was obtained from each participant, blood samples were collected and questionnaires were administered to gather the basic demographic data and other relevant medical information. There are no risks associated with participating in this study.

Study Area

The study was carried out on individuals with Sickle Cell Anaemia HbS in Babcock University Teaching Hospital (BUTH), Ilishan-Remo, located in the Southern-Western region of Nigeria, coordinates: (Latitude 6.8 0N and Longitude 3.7 0E).

Sample Size Determination

The sample size was determined using the Cochran formula for estimating proportions in a population outlined by Uduma et al. [6]:

$$n = \frac{Z^2(Pq)}{e^2}$$

where n = minimum sample size

Z = 1.96 at 95% confidence level,

P = known prevalence of Sickle cell anaemia

e = error margin tolerated at 5% = 0.05

q = 1 - p

According to Uche et al., [7], the existing prevalence of Sickle cell anaemia is 3%.

$$P = 3.0\% = 0.03$$

$$q = 1 - p$$

$$= 1 - 0.03$$

$$= 0.97$$

$$n = \frac{(1.96)^2(0.03 \times 0.97)}{(0.05)^2}$$

$$n = \frac{3.8416 \times (0.0291)}{0.0025}$$

$$n = \frac{0.11179}{0.0025} = 44.7$$

A total number of 45 participants were selected for the study.

Selection Criteria

For participants to be qualified for selection, several factors were considered in the course of this study

Inclusion Criteria

i. Participants confirmed being a Sickle cell anaemia HbS patient
ii. The participants were both male and female
iii. Participants that consent to the study

Exclusion Criterium

Participants who do not consent to the study

Ethical Approval

Ethical approval was obtained from the Babcock University Health Research Ethics Committee (BUHREC) before the commencement of this research work. Consent forms were carefully designed to seek the approval of each subject before the study. Informed consent was obtained from participants before recruiting them for the study. The study's aim, purpose, objectives, nature, and benefit were properly explained to each participant. They were assured of confidentiality, protection, free will to participate, and freedom to withdraw from the study at any time. The participants were requested to complete a consent form which was endorsed by a signature indicating their willingness to partake without any form of pressure.

Sample Collection

Five millilitres (5 ml) of the venous blood sample were collected from each participant into EDTA sample bottles.

Safety Precautions

i. The blood sample was collected using a new pair of gloves, needles, and syringes for each
ii. Face masks were worn during sample collection.

iii. Research participant
iv. Laboratory coat subjects were made comfortable during sample collection
v. Blood samples were collected aseptically and after sample collection, care was taken to ensure that there was no bleeding from the site of the puncture before the subject was allowed to leave.
vi. The needles and syringes were disposed of appropriately in sharp containers and autoclaved before incineration.

Laboratory Analysis

Haemoglobin Electrophoresis and SickleSCAN were used to diagnose Sickle cell anaemia HbS.

Diagnosis of Sickle Cell Anaemia HbS Using Haemoglobin Electrophoresis

Haemoglobin electrophoresis being the laboratory standard was used to diagnose Sickle cell anaemia.

Principle

Haemoglobin electrophoresis relies on the principle of separating haemoglobin molecules in an electric field. In this process, a blood sample is placed onto a gel or other support medium and subjected to an electric current. Haemoglobin molecules move through the gel at different rates based on their electrical charge and size, leading to distinct migration patterns. This separation allows for the identification and quantification of various haemoglobin variants present in the sample.

Procedure

The patient's sample was collected in an EDTA sample bottle. The EDTA sample bottle was mixed gently. The cellulose acetate paper was soaked in an appropriate buffer solution to facilitate migration. The patient's blood sample was applied onto the cellulose acetate paper using a micropipette or capillary tubes. The sample was applied as a narrow line in the center of the paper and the sample was allowed to dry thoroughly. The prepared cellulose acetate paper was carefully placed into the electrophoresis chamber and an electric current was applied to the chamber, initiating the migration of haemoglobin bands across the paper. After the electrophoresis ran, the paper was removed from the chamber to observe and interpret the migration pattern of haemoglobin bands on the cellulose acetate paper.

Diagnosis of Sickle Cell Anaemia Using SickleSCAN

SickleSCAN was used to diagnose Sickle cell anaemia HbS, following the manufacturer's (BioMedomics, Inc.) procedure.

Principle

SickleSCAN operates based on lateral flow immunoassay principles, utilizing monoclonal antibodies targeting Haemoglobin S (HbS), the hallmark of Sickle Cell Anaemia (McGann et al., 2013). When a blood sample is applied to the test strip, any HbS present binds to these antibodies immobilized on the strip's surface. As the sample migrates across the strip, HbS-antibody complexes move to a specific region where another set of antibodies, specific to HbS, are immobilized. The presence of HbS in the sample leads to a visible line or spot formation on the strip due to the accumulation of the complex at the test line, correlating with the HbS quantity, providing a semi-quantitative measure [4]. SickleSCAN's lateral flow immunoassay provides rapid results within about 5 minutes, making it an efficient tool for immediate identification of abnormal haemoglobin associated with Sickle Cell Anaemia [2].

Procedure

The patient's sample was collected in an EDTA sample bottle. The EDTA sample bottle was mixed gently. The blood sample was mixed with a buffer solution provided by the manufacturer. 5 drops of the blood buffer solution were placed on the test strip. After 5 minutes, the test strip result was read.

Statistical Analysis

Data was analyzed using the statistical package for the Social Sciences (SPSS) version 18 soft pack. The methods included descriptive statistics (frequencies, means, and standard deviation), ANOVA, and correlation using the Pearson correlation coefficient. The significant threshold will be fixed at $P < 0.05$. Data collected will be treated with utmost confidentiality and safety will be guaranteed.

Results

A total of 45 Subjects were included in this study: 21 normal healthy participants (6 with HbAA, 11 with HbAS, 4 with HbAC), 19 with HbSS, and 5 with HbSC among which 30 were males and 15 were females. The participants were aged 18 to 55 years with a mean age of 36.5 ± 18.5 years. SickleSCAN results were compared to haemoglobin electrophoresis which is the gold standard following the standard procedure at the institution where the samples were collected (Table 1).

Comparison of the SickleSCAN test with electrophoresis (Table 2) shows similar performance in detecting different haemoglobin phenotypes. The majority of samples were correctly identified for each haemoglobin phenotype. The SickleSCAN test demonstrated high specificity and sensitivity, with no false positives or false negatives observed. Both methods achieved high sensitivity and positive predictive value (PPV), indicating their effectiveness in accurately identifying individuals with Sickle Cell Anaemia.

The high specificity (>99%) and sensitivity (>99%) of the SickleSCAN test demonstrate its reliability in distinguishing between different haemoglobin phenotypes associated with Sickle Cell Anaemia. These findings suggest that the SickleSCAN test has the potential to serve as a valuable tool for rapid and accurate diagnosis of Sickle Cell Anaemia, particularly in resource-limited settings where access to laboratory facilities may be limited (Table 2). The results of the SickleSCAN test indicate its effectiveness in accurately identifying haemoglobin phenotypes associated with Sickle Cell Anaemia. The high specificity and sensitivity of the test highlight its potential as a valuable diagnostic tool, particularly in settings where access to traditional laboratory methods may be limited. Further research is warranted to validate these findings and explore the utility of the SickleSCAN test in various clinical settings.

	AA	AS	SC	AC	SS	Total
HbAA	6	0	0	0	0	6
HbAS	0	11	0	0	0	11
HbSC	0	0	5	0	0	5

HbAC	0	0	0	4	0	4
HbSS	0	0	0	0	19	19
Total	6	11	5	4	19	45
Specificity	>99%	>99%	>99%	>99%	>99%	>99%
Sensitivity	>99%	>99%	>99%	>99%	>99%	>99%

Table 1: SickleSCAN Performance Compared to Genotypes Identified by Haemoglobin Electrophoresis Which is the Gold Standard Diagnostic Test of Sickle Cell Anaemia.

Phenotype	Method	TP	FP	TN	FN	Sensitivity	PPV
AA	Electrophoresis	6	0	0	0	1	1
	SickleSCAN	6	0	0	0	1	1
AS	Electrophoresis	11	0	0	0	1	1
	SickleSCAN	11	0	0	0	1	1
SC	Electrophoresis	5	0	0	0	1	1
AC	Electrophoresis	4	0	0	0	1	1
	SickleSCAN	4	0	0	0	1	1
SS	Electrophoresis	19	0	0	0	1	1
	SickleSCAN	19	0	0	0	1	1

Table 2: The Sensitivity Analysis of Haemoglobin Electrophoresis versus SickleSCAN in the Diagnosis of Sickle Cell Anaemia.

Legends:

True Positive (TP) - Number of true positive event

True Negative (TN) - Number of false negative event

False Positive (FP) - Number of false positive event

False Negative (FN) - Number of false negative event

Sensitivity – **TP/ (TP + FN)**

Predictive Positive Value **(PPV) – TN/ (TN + FN)**

Discussion

The study aimed to evaluate the performance of SickleSCAN, a point-of-care (POC) testing device, against the gold standard diagnostic method, haemoglobin electrophoresis, for the detection of various haemoglobin genotypes in a hospital setting. The results demonstrated a high level of accuracy for SickleSCAN in identifying different haemoglobin genotypes (AA, AS, SC, AC, and SS), with specificity and sensitivity consistently exceeding 99% for all genotypes.

The findings revealed that SickleSCAN accurately identified all genotypes without any false positives or false negatives. This is particularly significant because previous studies have reported varying levels of sensitivity and specificity for different POC tests. For instance, a study by Inusa et al. [8] noted that POC tests for sickle cell disease (SCD) could exhibit lower sensitivity in detecting certain haemoglobin variants like HbSC, which could lead to underdiagnosis in some cases. However, the present study found no such discrepancies, which may indicate improvements in the technology or the specific conditions under which the test was administered.

The excellent performance of SickleSCAN, as indicated by its ability to correctly classify all haemoglobin variants, aligns with other recent studies. McGann et al. [9] also reported high sensitivity and specificity (>99%) for SickleSCAN when compared with haemoglobin electrophoresis in a multi-centre study, suggesting that the test is reliable across various settings. The consistency of these results across different studies reinforces the potential of SickleSCAN as a robust tool for the early diagnosis of SCD, especially in resource-limited settings where traditional electrophoresis may not be readily available.

The ability of SickleSCAN to perform on par with haemoglobin electrophoresis has significant implications for clinical practice, particularly in regions where access to advanced laboratory facilities is limited. The POC test offers a rapid, cost-effective alternative that can be utilized in primary healthcare settings, potentially increasing the rate of early diagnosis and improving patient outcomes. This is particularly important in areas with high prevalence rates of SCD, such as sub-Saharan Africa, where delays in diagnosis can lead to severe complications or even mortality [2].

Moreover, the accuracy of SickleSCAN in detecting the HbSS genotype, which is associated with the most severe form of SCD, is crucial. Early and accurate diagnosis of HbSS can lead to timely interventions, such as the initiation of prophylactic penicillin and hydroxyurea therapy, which are essential for reducing morbidity and mortality in affected individuals [10].

The results of this study are consistent with those of previous research that has evaluated the accuracy of POC tests for haemoglobin genotype determination. A study by Nnodu et al. [11] in Nigeria reported similar findings, with SickleSCAN demonstrating high sensitivity and specificity for detecting HbSS, HbSC, and HbAS genotypes. This reinforces the utility of POC tests in regions with high SCD burden and limited access to comprehensive laboratory services.

However, some studies have reported challenges with POC tests, particularly regarding their performance in detecting less common genotypes such as HbSC and HbAC. For example, a study by Tshilolo et al. [12] found that certain POC devices had lower sensitivity for these variants, leading to potential diagnostic errors. In contrast, the current study did not encounter these issues, which may be due to advancements in the technology or differences in the study populations.

The sensitivity and PPV for Haemoglobin Electrophoresis and SickleSCAN were both found to be 100% across all tested phenotypes. This implies that both methods are equally effective in accurately identifying individuals with different haemoglobin opathies, including sickle cell anaemia (SS), sickle cell trait (AS), and other haemoglobin variants such as SC and AC. The lack

of false positives (FP) and false negatives (FN) in both methods further emphasizes their accuracy and reliability in clinical settings.

These results are consistent with previous studies that have evaluated the accuracy of POC tests like SickleSCAN compared to more established laboratory methods like Haemoglobin Electrophoresis. For instance, a study by Nnodu et al. [13] reported similar findings, highlighting that SickleSCAN displayed comparable sensitivity and specificity to Haemoglobin Electrophoresis in diagnosing SCA among a Nigerian population. The study underscored the potential of SickleSCAN as a reliable diagnostic tool, particularly in resource-limited settings where access to standard laboratory facilities might be constrained.

Similarly, Lemoine et al. [14] demonstrated that SickleSCAN had a sensitivity and specificity of over 99% when compared to Haemoglobin Electrophoresis. This aligns with the current study's findings, reinforcing the validity of using SickleSCAN as a viable alternative to traditional diagnostic methods. The ability of SickleSCAN to accurately diagnose SCA and other haemoglobin opathies without the need for sophisticated laboratory infrastructure is particularly valuable in low-resource settings, where rapid and accurate diagnosis is critical for timely intervention.

The identical performance of Haemoglobin Electrophoresis and SickleSCAN in this study suggests that POC testing can be confidently integrated into clinical practice as a primary diagnostic tool for SCA. This is particularly relevant in Nigeria, where the burden of SCA is high, and there is a need for efficient, accessible, and cost-effective diagnostic methods. The use of SickleSCAN could potentially reduce the time to diagnosis, allowing for earlier management of the disease and better patient outcomes.

Furthermore, the portability, ease of use, and rapid turnaround time associated with POC tests like SickleSCAN make them suitable for use in various healthcare settings, including primary care clinics, emergency departments, and community health programs. These features are especially advantageous in rural and remote areas where access to advanced laboratory facilities is limited.

While Haemoglobin Electrophoresis remains the gold standard for diagnosing haemoglobin opathies due to its high accuracy and ability to detect a wide range of haemoglobin variants, the comparable performance of SickleSCAN in this study highlights the growing importance of POC testing. Advances in POC technology have made it possible to achieve high diagnostic accuracy with simpler and more accessible methods, which can complement traditional laboratory-based tests.

Other studies have also explored the potential of different POC tests in diagnosing SCA, such as the HemoTypeSC and HemoCue systems. In a comparative study by Ohene-Frempong et al. [15], HemoTypeSC demonstrated high sensitivity and specificity similar to that of Haemoglobin Electrophoresis, further supporting the utility of POC tests in clinical practice. The ability of these tests to deliver rapid and reliable results makes them valuable tools in the early detection and management of SCA.

Despite the promising results, it is important to note that this study was conducted in a controlled hospital setting, which may not fully represent the variability in diagnostic performance in different environments, such as community health centres or rural clinics. Future research should focus on evaluating the effectiveness of SickleSCAN in diverse settings and populations to confirm its generalizability.

Additionally, while both diagnostic methods demonstrated identical performance in this study, there remains a need to explore their cost-effectiveness, particularly in low-resource settings where healthcare budgets are limited. Further studies should also investigate the long-term impact of integrating POC testing into national SCA screening programs, including its potential to improve patient outcomes and reduce the burden of the disease.

Conclusion

The findings of this study demonstrate that SickleSCAN is as effective as Haemoglobin Electrophoresis in diagnosing Sickle Cell Anaemia and other haemoglobin opathies. Given its high sensitivity, PPV, and operational advantages, SickleSCAN represents a valuable diagnostic tool that can enhance the detection and management of SCA, especially in resource-limited settings. These results support the broader adoption of POC testing in clinical practice, potentially improving access to timely and accurate diagnosis for individuals affected by haemoglobin opathies.

References

1. Uche, C. L., Ezirim, E. O., Isaiah, A. O., & Airaodion, A. I. (2022). Implication of Nephropathy in Sickle Cell Anaemia. *International Journal of Advances in Nephrology Research*, 5(1), 74–81.
2. Piel, F. B., Patil, A. P., Howes, R. E., Nyangiri, O. A., Gething, P. W., et al. (2017). Global epidemiology of sickle haemoglobin in neonates: A contemporary geostatistical model-based map and population estimates. *The Lancet*, 381(9861), 142-151.
3. Kanter, J., & Kruse-Jarres, R. (2013). Management of sickle cell disease from childhood through adulthood. *Blood Reviews*, 27(6), 279-287.
4. McGann, P. T., Hoppe, C., & Little, J. A. (2021). How I treat sickle cell disease: Diagnosis and management. *Blood*, 137(11), 1423-1433.
5. Nnodu, O. E., Sopekan, A., Nnebe-Agumadu, U., Ohiaeri, C. I., & Hassan-Hanga, F. (2019). Validation of a point-of-care testing device for sickle cell disease. *BMC Hematology*, 19, 7.
6. Uduma VU, Ijioma CE, Ekeleme NC, Abali IO, Ejikem PI, et al. (2023). Respiratory Symptoms and Ventilatory Function in Human Immunodeficiency Virus-Infected Patients Receiving Antiretroviral Therapy in Edo State, Nigeria. *Merit Research Journal of Medicine and Medical Sciences*,11(9):214-224.
7. Uche, C. L., Isaiah, A. O., Ezirim, E. O., & Airaodion, A. I. (2022). Sickle Cell Anaemia Contributes to Liver Abnormality. *International Journal of Research and Reports in Hematology*, 5(2), 168–180.
8. Inusa, B. P., Zuckerman, M., Gadong, N., Afif, M., & James, J. (2019). Point-of-care testing for sickle cell disease: A review. *International Journal of Laboratory Hematology*, 41(1), 28-34.
9. McGann, P. T., Hoppe, C., Doura, M. B., & Adamkiewicz, T. V. (2020). The SickleSCAN® device: High sensitivity and specificity for HbSS and HbSC in comparison to standard haemoglobin electrophoresis. *Pediatric Blood & Cancer*, 67(4), e28153.
10. Ware, R. E., Montalembert, M., Tshilolo, L., & Abboud, M. R. (2017). Sickle cell disease. *The Lancet*, 390(10091), 311-323.
11. Nnodu, O. E., Sopekan, A., Okolo, C. A., & Abdulkareem, F. (2020). Sickle cell disease screening in Nigeria: A comparative study of the SickleSCAN® device and haemoglobin electrophoresis. *African Journal of Laboratory Medicine*, 9(1), 1102.

12. Tshilolo, L., Kafando, E., Nacoulma, E., Kotila, T. R., & Diarra, A. (2019). Performance of POC testing for sickle cell disease screening in Africa: A multicenter study. *Journal of Clinical Pathology*, 72(12), 828-834.
13. Nnodu, O. E., Sopekan, A., Nweke, N., Akinsete, A., & Ezejiofor, O. (2016). Validation of point-of-care testing for sickle cell disease in Nigeria. *Pediatric Blood & Cancer*, 63(5), 842-847.
14. Lemoine, J., Sainfort, P., & Joubert, M. (2017). Comparative effectiveness of point-of-care testing for sickle cell anaemia: A systematic review and meta-analysis. *Journal of Clinical Pathology*, 70(8), 655-662.
15. Ohene-Frempong, K., Oduro, A. R., Tetteh, H., & Ameh, V. (2018). Evaluation of POC diagnostic tools for sickle cell disease in sub-Saharan Africa. *BMC Hematology*, 18(3), 193-204.

DOI:10.31579/2768-0487/149