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Agreement among rapid diagnostic tests, urine malaria tests, and microscopy in malaria diagnosis of adult patients in southwestern Nigeria

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Abstract

Objective: We determined the malaria prevalence and ascertained the degree of agreement among rapid diagnostic tests (RDTs), urine malaria tests, and microscopy in malaria diagnosis of adults in Nigeria.

Methods: This was a cross-sectional study among 384 consenting patients recruited at a tertiary health facility in southwestern Nigeria. We used standardized interviewer-administered questionnaires to collect patients' sociodemographic information. Venous blood samples were collected and processed for malaria parasite detection using microscopy, RDTs, and urine malaria tests. The degree of agreement was determined using Cohen's kappa statistic.

Results: The malaria prevalence was 58.3% (95% confidence interval [CI]: 53.0–63.1), 20.6% (95% CI: 16.6–25.0), and 54.2% (95% CI: 49.0–59.2) for microscopy, RDTs, and urine malaria test, respectively. The percent agreement between microscopy and RDTs was 50.8%; the expected agreement was 45.1% and Cohen's kappa was 0.104. The percent agreement between microscopy

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and urine malaria tests was 52.1%; the expected agreement was 50.7% and Cohen's kappa was 0.03.

Conclusion: The malaria prevalence was dependent on the method of diagnosis. This study revealed that RDTs are a promising diagnostic tool for malaria in resource-limited settings. However, urine malaria test kits require further improvement in sensitivity prior to field use in malaria-endemic settings.

Keywords

Malaria, diagnostic, rapid diagnostic test, urine malaria test, microscopy, Nigeria

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Introduction

Malaria infection remains a global public health problem and a leading cause of morbidity worldwide.[1,2] Approximately 3.2 billion people globally, nearly half the world's population, are at risk of contracting malaria.[3] In Nigeria, there are over 100 million individuals at risk of malaria.[4]

The World Health Organization (WHO) has developed guidelines for microscopy detection, identification, and quantification of malaria parasites in research settings using stained thick and thin blood smears.[1,5] Microscopy is regarded as the gold standard in malaria diagnosis and serves as the method of reference for other malaria diagnostic tests.[5] The drawback to blood smear microscopy in the diagnosis of malaria is that it is operator-dependent and requires initial and continuous training to maintain a high quality of testing. Such quality assurance practices are often difficult to implement in resource-poor countries.[5]

Blood-based rapid diagnostic tests (RDTs) have been found to be effective in the diagnosis of malaria. RDTs use immune chromatographic materials impregnated with monoclonal antibodies against *Plasmodium* species to detect malaria parasite antigen in the blood of infected individuals.[6] The most commonly used RDT kits target histidine-rich protein 2 (HRP-2) antigen, which is produced in an infected individual.[6] The sensitivity and specificity of HRP-2-based RDT kits have improved over time.[6] Adesanmi et al. evaluated HRP-2-based RDTs among 380 febrile children aged 6 to 59 months in Enugu, Nigeria and found a sensitivity of 82%, specificity of 91.5%, and a strong positive correlation.[7]

In addition to RDTs, the urine malaria test (UMT) is a recombinant monoclonal antibody-based test that detects *P. falciparum*-specific HRP-2, a poly-histidine protein or fragment present in the urine of febrile patients.[6] A specific urine-based malaria strip, the Fyodor® UMT, is the only available UMT strip test on the Nigerian market. This UMT had sensitivity of 83.7% and specificity of 83.48% in a study conducted in Enugu State, southern Nigeria.[8] Considering the ease of use of RDTs and UMTs and according to the WHO recommendation of T3 (testing, treatment, and tracking of malaria), it is considered important to incorporate both tests in malaria diagnosis.[5]

The degree of agreement between RDTs and UMTs, as well as each in comparison with microscopy, is expressed as the

proportion of the maximum improvement that could occur beyond the agreement expected by chance alone. This was described by Cohen in 1960, who proposed the kappa statistic to calculate the degree of agreement.[9] Landis and Koch suggested that a kappa greater than 0.75 represents excellent agreement beyond chance, a kappa below 0.40 represents poor agreement, and a kappa between 0.40 and 0.75 represents intermediate to good agreement.[9]

Most primary health facilities in Sub-Saharan Africa have a very high patient load and approximately 25% of patients have suspected malaria.[6] Hospital microbiology laboratories in this region are usually overwhelmed by the number of people requiring microscopy malaria testing. The need to efficiently utilize existing and potentially available anti-malarial drugs is critical in Africa owing to the high burden of this disease and poor socioeconomic status of the population. Therefore, the adoption of community-based diagnosis using RDTs and UMTs. in addition to traditional hospital microscopy, has become imperative in malaria management. In this study, we determined the malaria prevalence among adult patients in southwestern Nigeria, using microscopy, RDTs, and UMTs. We also ascertained the degree of agreement among these available diagnostic methods. The findings of this study may serve as a useful basis for health policy formulation in the management of malaria. Our findings could also help promote the implementation RDTs and/or UMTs at point-of-care facilities for malaria diagnosis at community level rather than in a hospital.

Methods

Study location

This study was conducted between May and July 2020 at the Family Medicine Clinic of Wesley Guild Hospital (WGH), Ilesa, Osun State, Nigeria. The WGH in Ilesa is one of six units of the Obafemi Awolowo University Teaching Hospital Complex (OAUTHC) in Ile-Ife, Osun State. The WGH serves as a primary, secondary, and tertiary health facility for patients from Ilesa and its environs. Malaria transmission is present in the study area throughout the year, with a peak period during the wet season (April–October). *P. falciparum* is the most prevalent malaria parasite in southwestern Nigeria.[10]

Study design and population. This was a hospital-based, descriptive cross-sectional study. All patients who attended the family medicine clinic at WGH and who presented with febrile illness and other symptoms of malaria were eligible for inclusion in the study.

The inclusion criteria were individuals aged 18 years and above, those who gave their written consent to participate in the study, and individuals with complaints of fever and other symptoms suggestive of malaria.

We excluded critically ill patients who may require hospital admission. To minimize false-positive results owing to HRP-2 detection after treatment, we also excluded patients with a history of treatment for malaria within the previous 3 weeks.

Sample size determination. The sample size was calculated using the Leslie and Kish formula:[11]

$N = p\,(1-p)\,z^2/d^2$, where N is the desired sample size; p is malaria prevalence of 51.1% in adults, from a previous local study using microscopy;[12] z is standard normal deviation of 1.96 (corresponds to 95% confidence interval) [CI]; and d is standard error or degree of accuracy = 0.05.

Thus, $N = (3.8416 \times 0.511 \times 0.489)/d^2 = 0.9599351664/0.0025$; $N = 383.97$.

Sampling technique. A systematic random sampling technique was used to recruit individuals who fulfilled the inclusion criteria. The medical records of patients with febrile illness at the study center showed that in the year 2019, an average of 25 patients were seen daily.[13] This translated to 125 patients per week (Monday through Friday) and 1625 (sample frame) patients over the study period of 3 months (13 weeks). Using the formula, $K = N/n$, where K is the sample interval, N is the sample frame (1625), and n is the minimum sample size, K was approximately 4. The first eligible patient on each clinic day was chosen using simple random sampling; thereafter, every fourth eligible patient was chosen using systematic random sampling until the minimum sample size was attained. A sticker was placed on the medical records folder of the selected patients to avoid resampling at a subsequent visit.

Recruitment procedure. The data were collected using a pretested standardized semi-structured questionnaire developed by the researchers and administered by an interviewer. The questionnaire was pretested in 25 adult febrile patients who presented to the family medicine clinic of another tertiary hospital located approximately 30 km from the study center. Pretesting lasted for 3 days, with the aim to determine the applicability and feasibility of the questionnaire. The questionnaire was modified to address any issued observed in the pretest and validity assessment. The time needed to complete the questionnaire was approximately 10 minutes.

Data collection. Data were collected using the standardized interviewer-administered questionnaire and a data collection form. The questionnaire was used to collect information regarding individuals' sociodemographic characteristics, and the data form was used to record the clinical parameters of patients. All patient details were deidentified. The reporting of this study conforms to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement.[14]

Clinical parameters of participants

A mercury-filled thermometer (U-MEC®; Wuxi Hongguang Medical Equipment Co. Ltd., Jiangsu, China) calibrated in degrees Celsius was used to measure patients' body temperature, to the nearest 0.1°C.

The malaria diagnosis methods used were as follows.

Fyodor® UMT strip kit. The Fyodor® UMT kit is a commercial product from Fyodor Biotechnologies Nigeria Ltd., a subsidiary of Fyodor Biotechnology Corp. (Baltimore, MD, USA). The kit is marketed by Geneith Pharmaceutical Limited in Nigeria. Each kit contains five malaria test strips, five urine sample collection cups, and the manufacturer's instructions for use.[6] Fyodor® UMT strips can be stored at temperatures between 2°C and 30°C; hence, there is no need for refrigeration. The kit has a shelf life of 24 months from the date of its manufacture. The UMT relies on clinical malaria infection commonly resulting in elevated levels of HRP-2 or its protein fragments in the urine, against which conjugated recombinant monoclonal antibody reagents have been developed.[6] This qualitative assay consists of a nitrocellulose membrane strip containing relevant antibody reagent and control, which are each immobilized at the specific individual site on the membrane.[6]

The UMT strip was dipped into a fresh urine sample for approximately 2 minutes. The strip was then incubated in the foil pouch included in the kit for 20 minutes. Two visible lines appearing on the strip (test and control line) indicate a positive test result, and a single line indicates

a negative result. If the control line did not appear or a darkly stained background obscured the test line, this was considered an invalid test and the test was repeated.

SD BIOLINE Malaria Ag P.f/Pan test. This test is a commercial product (product code 05FK63 SD) from Access Bio Inc (Monmouth Junction, NJ, USA), with embedded HRP-2 and pan-specific parasite lactate dehydrogenase (pLDH), for point-of-care testing (lancet, capillary tube, and alcohol swab included). Each box contains 25 text kit sachets, 25 alcohol swabs, 25 capillary tubes for blood collection, and a 10-mL bottle of lysis buffer. This RDT kit was chosen because of its long shelf life (24 months) and wide storage temperature range (1°C–40°C). This test kit has the advantage of not requiring refrigeration. After cleaning the patient's skin with an alcohol swab following standard aseptic technique, approximately 3 mL of blood was collected into an EDTA tube. The capillary tube was used to add 5-μL aliquots of blood to the sample well of the test cassette. Four drops of buffer solution were dispensed into the cassette, and the test result was read after 15 minutes. The presence of a red control line (C) and a red test line (T) indicates a positive result, and a red control line and no red test line indicates a negative result. No visible red control line was considered an invalid result and the test was repeated using a new, unopened test packet.

Blood smear microscopy. A few drops of capillary blood were taken from the EDTA bottle for the preparation of thick and thin smears for examination by microscopy. Freshly prepared 3% Giemsa solution (pH 7.2) was used for staining. The slides were left to air dry. The thin smear was used for species identification and the thick smear for detection of malaria parasites, parasite count, and parasite density. The malaria parasite count was done by adding one drop of immersion oil to each slide, which was then mounted and viewed under 100× objective lens. By counting alongside white blood cells (WBCs), the number of parasites was counted until 200 WBCs was reached. The number of parasites per 200 WBCs at 100× magnification using oil immersion microscopy was taken as the parasite count. The parasite density was quantified against WBCs, assuming an average total WBC count of 8000\μL, using the formula below:

$$\text{Parasites}/\mu\text{L} = \text{parasite count} \times 8000/\mu\text{L}.^{15,16}$$

According to the parasite count/μL and the classification of Nmorsi et al. in children with *P. falciparum* malaria, patients were classified as having mild (1–999/μL), moderate (1000–10,000/μL), or severe (>10,000/μL) parasitemia. Hyperparasitemia was defined as a parasite count > 250,000/μL.[16]

The procedure for the determination of malaria infection using RDTs, UMTs, and blood smear microscopy was carried out by two medical laboratory scientists in WGH who were blinded to the other's results. When there were discrepancies in the results, a senior scientist repeated the test for quality control. The senior scientist also ensured that the authorized standard operating procedure was followed for all investigations.

Statistical analysis. The data were analyzed using IBM SPSS version 20 (IBM Corp., Armonk, NY, USA). The sociodemographic characteristics of participants are described using number and frequency. Mean values were compared using the Student *t*-test. The outcome variables, i.e., parasite densities and the results of RDTs and UMTs, are expressed as category and proportion. The degree of agreement between blood smear microscopy and

RDTs, between blood smear microscopy and UMTs, and their respective Cohen's kappa values was calculated. Taking the results of malaria blood smear microscopy as the gold standard, we determined the sensitivity, specificity, and predictive values of RDTs and UMTs. The positive predictive value (PPV) and negative predictive value (NPV) of RDTs and UMTs were also calculated.

Cross-tabulation and chi square tests were used to identify the association between microscopy and other categorical variables. For all variables, a *P*-value <0.05 was considered statistically significant. We also calculated 95% CIs.

Ethical considerations

Ethical approval was obtained from the OAUTHC, Ile-Ife Ethical Review Committee (ERC/2016/12/01). All participants were thoroughly informed about the risks and advantages of the procedures. Written informed consent was obtained from each participant before recruitment. Additionally, assurance was given to each participant regarding the highest possible level of confidentiality and privacy. Each participant was informed that they had the right to decline participation or to withdraw from the study at any point without any prejudice, loss of benefits, or penalty. Confidentiality of all information was maintained via anonymous questionnaires. Access to the respondent information was restricted to only the researchers. The collected data were stored on a password-protected personal computer.

Results

Sociodemographic characteristics of participants

The sociodemographic characteristics of respondents showed that among the total of 384 included study participants, a total of 157 (40.9%) were aged 36–59 years, 290 (75.5%) were women, and 252 (65.6%) were married. As for education, 149 (38.8%) and 136 (35.4%) had secondary and tertiary education levels respectively, and 46 (12.0%) participants had no formal education. Most respondents (n = 271, 70.6%) were employed and 278 (72.4%) earned NGN 18,000.00 or more monthly. More than half of participants (n = 218, 56.8%) had a history of malaria in the previous 2 months; 339 (88.3%) knew about malaria prevention (Table 1).

Malaria prevalence among study participants. The results showed that only *P. falciparum* (100.0%) was detected in all samples that were positive for malaria infection using RDTs and microscopy. *P. vivax*, *P. malariae, and P. ovale* were not detected. The malaria prevalence was 58.3% (95% CI: 53.0–63.1), 20.6% (95% CI: 16.6–25.0), and 54.2% (95% CI: 49.0–59.2) using microscopy, RDTs, and UMTs, respectively (Table 2).

Degree of malaria parasitemia via blood smear microscopy. We found that most patients (85.7%) who were tested for malaria infection using blood smear microscopy had parasite density <1000 parasites/μL, indicating mild parasitemia (Table 3).

Degree of agreement between blood smear microscopy and RDTs. The percent agreement between blood smear microscopy and RDTs was 50.8% and the expected agreement was 45.1%; Cohen's kappa 0.104. The sensitivity of RDTs was 25.4% and the specificity was 86.3%. The PPV was 72.2% and the NPV was 45.2% (Table 4).

Degree of agreement between blood smear microscopy and UMTs

The percent agreement between blood smear microscopy and UMTs was 52.1%

Table 1. Sociodemographic characteristics of study participants, Wesley Guild Hospital, Ilesa, Nigeria (2019).

Variables	Frequency (n)	Percent (%)
Age group (y)		
18–35	139	36.2
36–59	157	40.9
≥60	88	22.9
Educational level		
No formal education	46	12.0
Primary	53	13.8
Secondary	149	38.8
Tertiary	136	35.4
Employment status		
Employed	271	70.6
Unemployed	113	29.4
Income Median NGN 25,500 (IQR: NGN 17,000–NGN 43,000)		
<NGN 18,000	106	27.6
≥NGN 18,000	278	72.4
Ethnicity		
Yoruba	305	79.4
Other	79	20.6
Sex		
Female	290	75.5
Male	94	24.5
History of malaria in past 2 months		
Yes	218	56.8
No	166	43.2
Knowledge about malaria prevention		
Yes	339	88.3
No	45	11.7
Marital status		
Single	90	23.4
Married	252	65.6
Widowed	42	10.9
Religion		
Christianity	309	80.5
Islam	75	19.5
TOTAL	384	100

IQR, interquartile range.

and the expected agreement was 50.7%; Cohen's kappa 0.03. The sensitivity of UMTs was 55.4% and the specificity was 47.5%. The PPV was 59.6% and the NPV was 43.2% (Table 5).

Table 2. Malaria prevalence using three diagnostic methods.

Prevalence of Malaria	Frequency N = 384	Percentage (%)
Microscopy		
Positive	224	58.3
Negative	160	41.7
Prevalence (95% CI)	58.1% (53.0–63.1)	
Rapid diagnostic test		
Positive	79	20.6
Negative	305	79.4
Prevalence (95% CI)	20.6% (16.6–25.0)	
Urine malaria test		
Positive	208	54.2
Negative	176	45.8
Prevalence (95% CI)	54.2% (49.0–59.2)	

CI, confidence interval.

Table 3. Parasitemia in patients positive for malaria infection using microscopy.

Variable	Frequency n = 224	Percentage (%)
Malaria parasite density		
Mild (≤1000/μL)	191	85.7
Moderate (1001–2000/μL)	20	8.5
Severe (>2000/μL)	13	5.8
Range (min.–max.)	40–38280	

Discussion

This was a hospital-based, descriptive cross-sectional study aimed at determining the malaria prevalence and degree of agreement between RDTs and UMTs and each in comparison with the gold standard, blood smear microscopy.

The malaria prevalence in this study varied with the method used for the diagnosis of malaria. The malaria prevalence was 58.3%, 20.6%, and 54.2% for microscopy, RDTs, and UMTs, respectively. The prevalence using microscopy diagnosis was consistent with the 54.8% found in Ekiti, southwestern Nigeria.[17] However, the

Table 4. Degree of agreement between microscopy and RDT (N = 384).

Microscopy						
RDT	Negative	Positive	Total	Agreement	Expected agreement	kappa
Negative	138 (86.2%)	167 (74.6%)	305	50.78%	45.10%	0.10
Positive	22 (13.8%)	57 (25.4%)	79			
Total	160	224	384			

Values in the table are n (%) unless otherwise indicated.
Note: Sensitivity = TP/(TP + FN) = 57/(57 + 167) = 25.4%, 95% CI (19.7–31.2). Specificity = TN/(TN + FP) = 138/(138 + 22) = 86.3%, 95% CI (80.9–91.6). Positive predictive value = TP/(TP + FP) = 57/(57 + 22) = 72.2%. Negative predictive value = TN/(TN + FN) = 138/(138 + 167) = 45.2%.
RDT, rapid diagnostic test; TP, true positive; TN, true negative.

Table 5. Degree of agreement between microscopy and urine malaria strip test (N = 384).

Microscopy						
UMT	Negative	Positive	Total	Agreement	Expected agreement	kappa
Negative	76 (47.5%)	100 (44.6%)	176	52.08%	50.69%	0.03
Positive	84 (52.5%)	124 (55.4%)	208			
Total	160	224	384			

Values in the table are n (%) unless otherwise indicated.
Note: Sensitivity = TP/(TP + FN) = 124/(124 + 100) = 55.4%. Specificity = TN/(TN + FP) = 76/(76 + 84) = 47.5%. Positive predictive value = TP/(TP + FP) = 124/(124 + 84) = 59.6%. Negative predictive value = TN/(TN + FN) = 76/(76 + 100) = 43.2%.
UMT, urine malaria test; TP, true positive; TN, true negative.

prevalence was higher than the 27.3% found in Sokoto, northwestern Nigeria.[18] The reason for the similar prevalence values found in southwestern Nigeria can be attributed to the endemicity of malaria in this region whereas seasonal variation in geographic zones may explain the difference observed between southwestern and northwestern Nigeria. A study carried out across the six geopolitical regions of the country in 2010 concluded that the malaria prevalence was higher in southwestern than in northern Nigeria.[19] This variation may be owing to differences in climatic conditions, and environmental factors among the different locations.[18,20]

In this study, the malaria prevalence using blood RDTs was close to the 26.4% found in Zamfara, northwestern Nigeria.[21] These similar results may be owing to similar study designs and settings, as both studies were hospital-based. However, our findings were lower than the reported prevalence of 49.5% found in Ibadan, southwestern Nigeria.[22] The disparity in prevalence when compared with our study might be because of differences in study populations. The Ibadan study was conducted among all age groups (children and adults inclusive) whereas our study was amongst adults only.

In our study, the malaria prevalence using UMTs was 54.2%. This was higher than the reported prevalence of 46.7% found in southeastern Nigeria[23] and 44.1% in Gombe, northeastern Nigeria.[24] This may be owing to different seasonal variations and climate and environmental factors. However, a lower prevalence of 25% was obtained in a community-based study in Lagos, southwest Nigeria;[25]

however, the Lagos study was community-based whereas ours was hospital-based. The 25% prevalence might also reflect challenges with urine collection for UMTs in the community because of unfamiliarity with these new test kits.[26]

Degree of agreement between blood smear microscopy and RDTs

We observed a percentage agreement of 50.8% with Cohen's kappa of 0.104 between blood smear microscopy detection of malaria and antigen detection of malaria using RDTs; the expected agreement was 45.1%. This means that approximately half of participants could be diagnosed with malaria using blood smear microscopy and using RDTs. The kappa value of 0.104 indicates only slight agreement between blood smear microscopy and RDTs in our study. This was significantly lower than the kappa reported by Fagbamigbe of 0.55, indicating moderate agreement between blood smear microscopy and RDTs in that study.[27] The kappa value in our study was also significantly lower value than that in a study by Falade et al. (0.60), also indicating moderate agreement between blood smear microscopy and RDTs.[19] Although RDTs are widely accepted as a diagnostic method for malaria, there are certain inconsistencies in the related research findings; for this reason, microscopy remains the gold standard for the diagnosis of malaria. A study in Nanoro, Burkina Faso showed a significantly lower degree of agreement between RDTs and blood smear microscopy, with a kappa of 0.02, indicating negligible agreement.[28] Despite inconsistency among study results regarding RDTs, the performance of RDTs in our study is encouraging, suggesting that RDTs can potentially offer anyone with suspected malaria infection access to a reliable malaria test that can be administered by a trained health worker at a community health center, eliminating the need to attend a tertiary health facility for testing.

Degree of agreement between blood smear microscopy and UMTs

In terms of malaria detection by blood smear microscopy and antigen detection of malaria using UMTs, the observed percentage agreement in this study was 52.1%; the expected agreement was 50.7%, and the Cohen's kappa was 0.03. This indicates only slight agreement between blood smear microscopy and UMTs in our study. This kappa value was much lower than that in another observational study of 0.665, indicating substantial agreement,[23] as well as that observed in Makurdi by Okete et al. in which the kappa was 0.57, indicating strong agreement.[29] The very low kappa value in our study may be owing to several factors such as parasite antigen production, antigen content in urine, and the time that urine samples were collected. The low sensitivity of UMTs in this study suggested that the sensitivity of UMT kits must be further improved prior to use in the field in malaria-endemic settings.

Sensitivity, specificity, and predictive values of RDTs compared with microscopy. In this study, the sensitivity of serum RDTs was 25.4% and the specificity was 86.3%. The PPV was 72.2% and the NPV was 45.2%. A sensitivity of 25.4% means that RDTs can yield a positive result for an individual with malaria in only 25% of cases; the specificity of 86.3% indicates that RDTs can yield a negative result for individuals without malaria in approximately 86% of cases. The sensitivity and specificity of RDTs in this study were lower than the values among outpatients in a tertiary hospital in Nigeria, with sensitivity and specificity reported as 73.7% and 97.3%, respectively.[30] The values in this study were also

lower than those observed by Awokola et al. in Ilesa, Osun State, with RDT sensitivity of 93.7% and specificity of 95.0%.[31] The study by Ilesanmi et al. in Ibadan, southwest Nigeria reported a sensitivity and specificity of 50.0% and 97.7%, respectively, which were also higher than our findings.[32] The lower sensitivity and specificity of RDTs obtained in our study may be the result of the low detection limits of these tests.[6,22]

The PPV indicated the percentage of patients with a positive test result who actually have the disease; the PPV was 72.2% for RDTs in our study. The NPV refers to the percentage of patients with a negative test result who do not have the disease; the NPV or RDTs in this study was 45.2%. It is important to note that predictive values are greatly influenced by the prevalence of the disease, meaning that results from one clinical setting cannot be extrapolated to other settings with a different disease prevalence in the population. Undetected positive cases may be owing to low-level parasitic infection that is undetectable using RDTs.[6,22]

Sensitivity, specificity, and predictive values of UMTs compared with blood smear microscopy. The sensitivity of UMTs in this study was found to be 55.4% and the specificity was 47.5%. The PPV was 59.6% and the NPV was 43.2%. The sensitivity of UMTs in this study was lower than that observed in a study from southeastern Nigeria in which the sensitivity was 83.75%; the specificity was also lower than that in the same study (83.4%).[23] The sensitivity in our study was lower than the value observed in Makurdi by Okete et al., which was 79%.[29] The lower sensitivity and specificity values in this study compared with other reports could be owing to parasite antigen production, antigen content in urine, and the time of urine collection.[23] The PPV and NPV of UMTs in this study were very low compared with the studies in both Enugu (PPV: 77.9%, NPV: 88.07%) and Gombe.[23,24] This might be owing to the ability of all HRP-2 antigen malaria test kits to detect parasite antigen after malaria illness. In addition, the degree of parasitemia affects the sensitivity and specificity and could also affect the PPV and NPV.

Relevance of the study. Our study findings showed that RDTs are a promising tool to screen for malaria in resource-constrained settings and may be used at the point of care in the community rather than in a hospital. Additionally, our study participants with malaria parasitemia were treated with anti-malaria medication, in line with the national protocol.

In addition to microscopy, RDTs, and UMTs, there are several emerging diagnostic techniques that will likely have a role in future comprehensive malaria programs. These include magnetic resonance relaxometry,[32,33] magnetic deposition microscopy,[34] novel photoacoustics,[25] biosensors and lab-on-a-chip techniques,[35] and multi-omics-based sensors.[36] Apart from these, there are new techniques that function with the aid of machine learning; these include rapid and object classification using low-field nuclear magnetic resonance (NMR) relaxometry,[37] hemozoin-based techniques,[38] spectroscopy-based techniques such as impedance spectroscopy, terahertz spectroscopy,[39] and whole-genome sequencing.[40] While these novel technologies are being developed, however, RDTs and UMTs will remain a mainstay in malaria diagnosis for a long time, especially in developing countries.

Limitations. The study was performed at a single center and only included 384 patients. The sample size was too small to be representative and the results might not apply to other centers. This study was cross-sectional; therefore, recommendations based on the study findings are not as strong as those based on findings from

interventional or comparative studies. This was a hospital-based study; thus, the malaria prevalence might not be a true reflection of the malaria prevalence in the community.

Conclusion

In this study, the malaria prevalence among study respondents varied and was largely dependent on the method used for the diagnosis of malaria. The malaria prevalence using microscopy was 58.3%; the prevalence was 20.6% using RDTs and 54.2% using UMTs. There was a low degree of agreement between microscopy and RDTs, with Cohen's kappa 0.104, and between microscopy and UMTs, with Cohen's kappa 0.03. This study revealed that RDTs are a promising diagnostic tool for malaria in resource-limited settings. However, UMT kits need further improvement in sensitivity for field use in malaria-endemic settings. Further research should focus on large studies involving a community-based general population of adults to better evaluate the degree of agreement between RDTs and UMTs as well as the agreement of each test in comparison with microscopy.

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Author contributions

JAO: Conceptualization of the study, data acquisition, and analysis and drafting of the initial manuscript. ISB: Literature review, data curation, and critical revision of the protocol for methodological and intellectual content. OOO: Data analysis, and critical revision of the protocol for methodological and intellectual content. AOI: Literature review, data analysis, and critical revision of the protocol for methodological and intellectual content. OFO: Literature review, review of the manuscript for intellectual content. OOF: Literature review, drafting of the initial manuscript, and review of the manuscript for intellectual content. All authors have read and approved the final version of the manuscript prior to submission.

Availability of data and materials

The datasets for this study are available from the corresponding author on reasonable request.

Declaration of conflicting interests

The authors declare that there is no conflict of interest.

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