Bulletin of the National Research Centre

RESEARCH

Open Access

Prevalence of malaria infection and factors associated among HIV-infected adult patients attending HIV care and treatment clinic at Kitete regional referral hospital in Tabora region, Tanzania: a cross-sectional study

Hamad Nnimbo[1*], Doreen Kamori[2], Nsiande Lema[3] and Abdallah Mohamed[4]

Abstract

Background HIV and malaria are serious public health concerns, particularly in Tanzania. HIV-infected individuals are more likely to get malaria and its complications. However, data on the interaction of the two diseases in Tanzania are limited. This cross-sectional study aimed to determine the prevalence of malaria infection and associated factors among HIV-infected adults attending HIV care and treatment clinic at Kitete regional referral hospital in Tabora region, Tanzania.

Methodology The cross-sectional study was carried out between March and May 2022 at Kitete regional referral hospital in Tanzania. A total of 246 HIV-infected adults were selected by systematic random sampling. Malaria was diagnosed using both malaria rapid diagnostic test (mRDT) and malaria microscopy. Social demographic data were collected using a structured questionnaire, while clinical history and laboratory parameters were extracted from patients' files. Data were analyzed using STATA version 15.1, and a p value < 0.05 was considered statistically significant. The study included consenting HIV+ adults and excluded pregnant women and recent antimalarial users.

Results Twenty-six out of 242 participants 10.7% (95% CI 6.9–15.6%) tested positive for malaria using mRDT, while 20 out of 242 participants 8.3% (95% CI 4.9–13.1%) tested positive for malaria using blood smear for malaria microscopy. Independent factors associated with malaria infection were living in rural areas (aOR = 2.81, 95% CI = 1.06–7.45, p = 0.038), poor adherence to anti-retroviral therapy (aOR = 3.66, 95% CI = 1.04–12.7, p = 0.043), HIV viral load of ≥ 1000 copies/mL (aOR = 3.2, 95% CI = 1.00–10.5, p = 0.02, CD4 count ≤ 350 cells/μL (aOR = 2.8, 95% CI = 1.10–7.30, p = 0.03), while using mosquito nets (aOR = 0.27, 95% CI = 0.08–0.90, p = 0.033) and receiving health education (aOR = 0.26, 95% CI = 0.09–0.71, p = 0.009) were protective factors.

Conclusions The study reveals a concerning prevalence of malaria infection among adult HIV patients at Kitete regional referral hospital. Risk factors identified include a high HIV viral load, low CD4 count, lack of health education, rural residence, and non-use of mosquito nets. The results emphasize the necessity for focused health education, enhanced access to preventive measures, and consistent adherence to ART to reduce the risk of malaria in this vulnerable population.

*Correspondence:
Hamad Nnimbo
nnimbo3@gmail.com
Full list of author information is available at the end of the article

Keywords HIV, Malaria, Prevalence, Tanzania

Background

Malaria is a preventable and treatable disease transmitted by infected female Anopheles mosquitoes and remains a significant global health concern. In 2021, there were 247 million reported cases worldwide, resulting in 619,000 deaths. The WHO African Region bore the majority of the burden, accounting for 95% of cases and 96% of deaths (World Health Organization 2023c). Simultaneously, HIV claimed 40.4 million lives globally, with the WHO African Region hosting two-thirds of the 39 million people living with HIV. In 2022, the region experienced 630,000 deaths and 1.3 million new infections (World Health Organization 2023b). Tanzania has a high burden of both malaria and HIV/AIDS, with a 7.9% prevalence of malaria cases of malaria (Ministry of Health et al. 2022) and a 4.7% prevalence of HIV (Ministry of Health 2023).

People living with HIV/AIDS are at a significantly increased risk of acquiring malaria infection and developing serious disease and its complications than others (Roberds et al. 2021; Guerra et al. 2022). Tanzania has embraced the WHO's guidance, advocating for the utilization of co-trimoxazole prophylaxis treatment among individuals with HIV. This measure is aimed at reducing the vulnerability to opportunistic infections and malaria (Ministry of Health 2017). However, co-trimoxazole stockouts are common in HIV programs, especially in sub-Saharan African countries (Gils et al. 2018). This situation leaves HIV-positive individuals in high malaria prevalence areas vulnerable to recurring malaria infections (Orishaba et al. 2020).

Screening for malaria is crucial for swift and accurate identification, especially for individuals at higher risk, such as HIV-infected individuals. This enables effective treatment, reduces illness, prevents drug resistance, and addresses various potential causes of fever, including malaria prevention (World Health Organization 2023a).

In areas with high malaria incidence, clinical management of HIV/AIDS patients is impaired with malaria infection (Osii et al. 2020). Other comorbidities like TB infection also increase manifestation of clinical malaria in people living with HIV/AIDS (Ibrahim et al. 2019). Biological/clinical parameters like CD4 count (Osii et al. 2020) and HIV viral load (HVL) levels are reported to be affected mostly during malaria infection in people living with HIV/AIDS (Obase et al. 2023). There is limited data on malaria infection among adults living with HIV in Tanzania, with previous studies focusing on pregnant women and children (Mirzohreh et al. 2022).

Therefore, this cross-sectional study was conducted to determine the prevalence of malaria infection and associated factors among HIV-infected adult patients attending HIV Care and Treatment Clinic at Kitete Regional Referral Hospital in Tabora region. By understanding the prevalence of malaria and associated risk factors, the Ministry of Health and other stakeholders can improve malaria prevention strategies and develop targeted interventions to reduce the incidence of malaria in this population. Ultimately, this study seeks to contribute to the global effort to reduce the burden of malaria and improve the health outcomes of people living with HIV/AIDS.

Methods

Study design

This was a cross-sectional analytical study design which was conducted for months from March to May 2022 among HIV-infected adults attending HIV care and treatment clinic at Kitete regional referral hospital in Tabora region, Tanzania.

Study area

The study was conducted at Kitete regional referral hospital (KRRH) located in Tabora region. Tabora region is among malaria endemic regions in Tanzania (Ministry of Health et al. 2020). According to Tanzania impact survey, the region has a prevalence of 5.1% of HIV infection among adults (Ministry of Health et al. 2017). KRRH is major government health facility in which its CTC serves about 3800 clients, among them 2200 are adults from age of 18+ years. The clinic operates during all working days of the week with a one day of special high viremia clinic. During each clinic schedule, at least 20 clients are saved per day. This CTC is staffed with healthcare professionals, including clinicians, nurses, and laboratory personnel, working full time to provide comprehensive care and treatment.

Study population

HIV-infected adults' clients (above 18 years) attending Care and Treatment Clinic at Kitete Region Referral Hospital in Tabora region, Tanzania.

Inclusion criteria

HIV-infected adult clients (18+ years) attending HIV care and treatment clinic at KRRH who were willing to provide consent.

Exclusion criteria

HIV-infected adult clients who were on antimalarial drug for either treatment or prophylaxis in the past fourteen days (mRDTs detecting pLDH/HRP2 antigens may stay positive for up to two weeks post-antimalarial treatment) (Dalrymple et al. 2018) and participants who did not provide informed consent.

Sample size estimation

The sample size was estimated by using the following formula for sample size calculation (Smith 2015)

$$n = \frac{Z^2 \times P(1-P)}{e^2}$$

where Z = standard normal distribution value at 95% CI which is 1.96, P = prevalence of malaria among HIV-infected individuals = 17.4% (Bedimo et al. 2017), and e = the margin of error, taken as 5% (0.05).

To account for a 10% non-response rate, a total of 246 participants were recruited in the study, as illustrated in Fig. 1.

Sampling method

To ensure a representative sample of adult HIV clients, a systematic random sampling method was used during the data collection period. The sampling frame consisted of 2200 files of eligible participants who were scheduled to attend the clinic. The sampling interval was determined by dividing the total number of files in the sampling frame by the desired sample size of 246, resulting in a sampling interval of 9. To select participants, a starting point was randomly chosen between 1 and 9. Then,

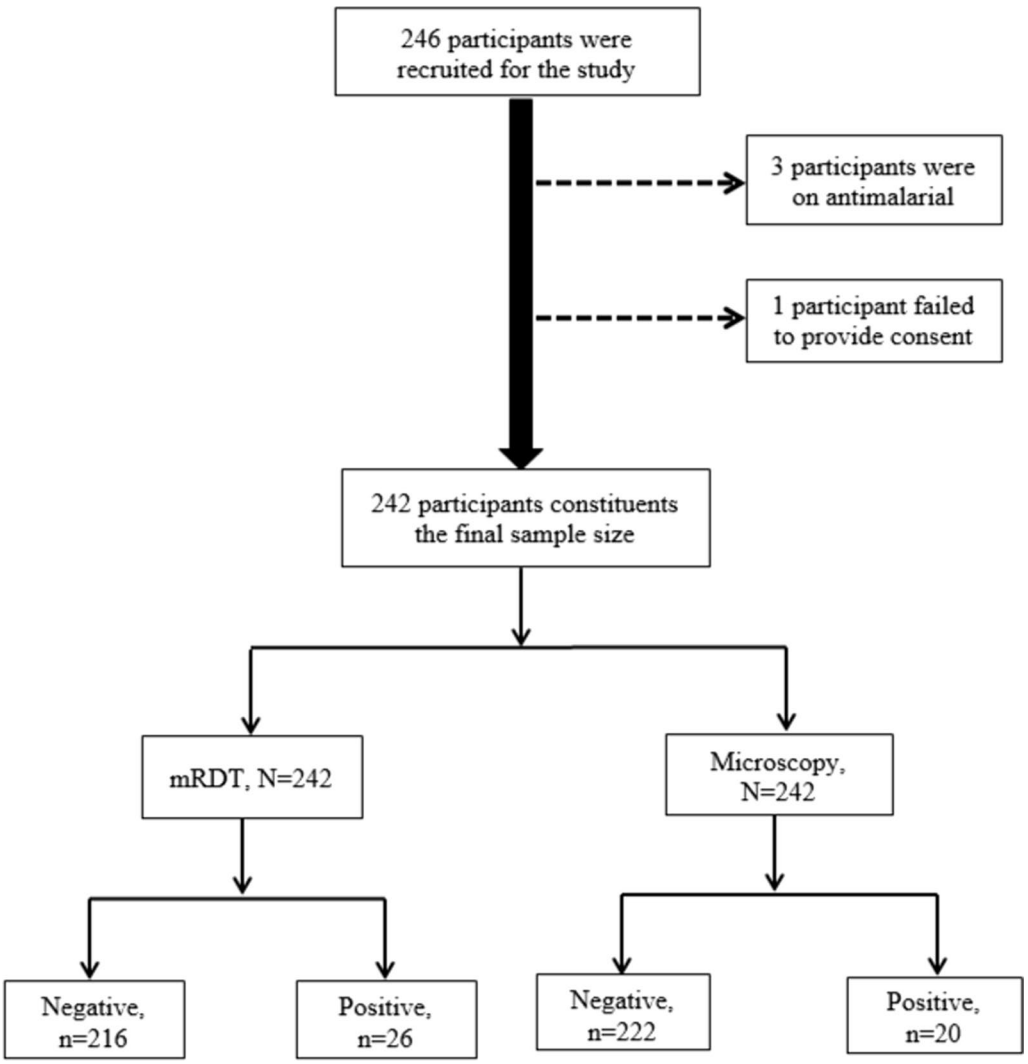

Fig. 1 Flowchart showing study participants recruitment

starting from the 6th client attending the clinic on the first day of data collection, every 9th client was included until 246 clients were selected. If a participant missed, the next participant in the defined interval was selected as a replacement.

Data collection

Questionnaire was administered to collect social demographic characteristics including (age, sex, marital status, place of residence, occupation and education level, use of mosquito net). The recent clinical history and laboratory parameters (adherence to ART, duration on ART, CD4 count, HIV viral load (HVL), clinical stage of HIV, and other comorbidities were extracted from participant's care and treatment cards (CTC2).

Variables

Dependent variable

Dependent variable of this study was the presence or absence of malaria infection which was determined using microscopy and malaria rapid diagnostic test.

Independent variables

Independent variables were social demographic characteristics (sex, age, marital status, level of education, occupation, place of residence, use of mosquito net and health education on malaria), clinical history and laboratory parameters included: CD4 count, HIV viral load and clinical stage of HIV, duration on ART treatment, adherence to ART, TB infection and other comorbidities (hypertension, diabetes and cancer).

Laboratory diagnosis of malaria

2 mL were obtained from a 4 mL blood sample collected routinely in a BD Vacutainer® Ethylenediaminetetraacetic acid (EDTA) tube from HIV clients attending the HIV Care and Treatment Center (CTC) at KRRH. The 4 mL blood sample is commonly collected at the HIV Care and Treatment Center (CTC) for routine laboratory investigation (Mnzava et al. 2023). The 2mls were used for malaria testing simultaneously by malaria rapid diagnostic test (mRDT) and malaria microscopic examination by blood smear (Opoku Afriyie et al. 2023). The mRDT used was the First Response® Malaria Ag. pLDH/HRP2 Combo Card Test, manufactured by Premier Medical Corporation Private Limited in Gujarat, India. This mRDT detects Plasmodium falciparum histidine-rich protein 2 (PfHRP2) and Plasmodium falciparum lactate dehydrogenase (PfLDH), as well as other Plasmodium species (Pan). Despite exhibiting a slightly lower specificity rate, this mRDT demonstrates reasonably good sensitivity (Domfeh et al. 2023). Moreover, its availability in the local context makes it a practical choice for widespread use. The mRDTs were processed and interpreted following the manufacturer's instructions.

Thick and thin blood smears were made on grease-free slides and were dried in the air. The thick smears were stained with Giemsa stain, and the thin smears were first fixed with methanol and then stained with Giemsa for the detection and identification of the malaria species, respectively, by using oil immersion, and smears were then observed under microscope at (100X) objective lens (Dhorda et al. 2020). Thick blood films detected malaria parasites in each specimen, with species differentiation in thin films. Positive results required agreement from two microscopists, with discrepancies resolved by a third for accuracy (Lin et al. 2022). A negative result was recorded for the slide after examining 200 high-power fields, and no parasites were observed (Ogunfowokan et al. 2020). Malaria parasite density was estimated based on the standard operating procedure, using an assumed average white cell count of 8000/μL (Goselle et al. 2020). For analysis purposes, a positive result was defined as the presence of malaria parasites detected through either the mRDT or blood smear examination.

Bias mitigation strategies

In this study, several strategies were employed to address bias. Selection bias was mitigated through random sampling. Measurement bias was reduced using standardized questionnaires and blinded microscopy techniques. Reporting bias was minimized by adhering to a predefined analysis plan.

Data management analysis

The data collected for the study were initially entered into an Excel spreadsheet version 2019. The data were then cleaned and checked for completeness and accuracy before being exported to STATA version 15.1 for further analysis. All categorical variables were summarized into frequencies where continuous variables were summarized using median (interquartile range). The prevalence of malaria infection in adults living with HIV was obtained by using proportion whereby the numerator was the number of participants who were positive for malaria infection by either mRDT or blood smear techniques, and the denominator was the total number of eligible participants enrolled into study. Subgroups were examined by stratifying the dataset. Descriptive and inferential statistics were performed; inferential statistics included the chi-square test for categorical variable associations, and logistic regression was employed to assess factors associated with malaria infection, with consideration for the observed prevalence falling within the accepted range for utilizing logistic regression in a cross-sectional study (Gnardellis et al. 2022). Bivariate logistic

regression was initially used to evaluate unadjusted risk factor associations with malaria infection. Subsequently, multivariate logistic regression was employed to analyze factors linked to malaria infection in HIV-infected adults, while accounting for potential confounding variables (Schuster et al. 2021).

Results

In the Results section, the exclusion of details regarding parasite density and species identification was implemented to streamline the presentation. The primary focus remains on the overall prevalence evaluated through both mRDT and microscopic examination, ensuring a concentrated and consistent reporting of the main findings. The complete dataset, including parasite density and species identification, is available upon request.

Socio-demographic characteristics of the study participants

The study successfully recruited 242 eligible participants with a male-to-female ratio of 1:2. The median age of the participants was 49.5 years (IQR 40–58), and the median duration on ART was 72 months (IQR 24–132). Of the participants, 171 (70.7%) were urban residents, and 140 (57.9%) had a primary education level. In terms of employment, 155 (64.1%) participants reported being self-employed. A high percentage of participants reported using mosquito nets 219 (90.5%). Additionally, 89 (36.8%) participants were married. These findings are summarized in Table 1.

Table 1 Socio-demographic characteristics of the study population attending ART clinic at Kitete Region referral hospital, Tabora region, from March to May 2022 ($N=242$)

Variable	Number	Percentage
Age groups (years)		
Median (IQR) 49.5 years (IQR 40–58)		
≤ 20	9	3.7
21–30	15	6.2
31–40	41	16.9
41–50	72	29.8
≥ 51	105	43.4
Gender		
Female	149	61.6
Male	93	38.4
Place of resident		
Rural	71	29.3
Urban	171	70.7
Education level		
No formal education	39	16.1
Primary education	140	57.9
Secondary education	43	17.8
College and above	20	8.3
Occupation status		
Employed	13	5.4
Peasant	62	25.6
Self-employed	155	64.1
Unemployed	12	5.0
Use of mosquito net		
No	23	9.5
Yes	219	90.5
Marital status		
Divorced	46	19.0
Married	89	36.8
Widow/Widower	47	19.4
Single	60	24.8

Participant's clinical history and laboratory parameters

Among the study participants, 163(67.4%) reported receiving health education on malaria. Almost half of the respondents 102(42.2%) were in WHO HIV clinical stage one. The vast majority of participants 223(92.1%) had been on ART for over 6 months and were on first-line ART regimen 226(93.4%). Additionally, most participants 195(80.6%) reported good adherence to ART. A small minority 27(11.2%) had comorbidities such as hypertension, diabetes type 2, or cancer. The majority of participants 222(91.7%) had no history of TB infection, were virally suppressed 215(88.4%), and had a CD4 count greater than 350 cells/μL 173(71.5%). These findings are summarized in Table 2.

Prevalence of malaria infection in adults living with HIV/AIDS

The study found that 26 out of 242 participants 10.7% (95% CI 6.9–15.6%) tested positive for malaria using mRDT, while 20 out of 242 participants 8.3% (95% CI 4.9–13.1%) tested positive for malaria using blood smear for malaria microscopy. These findings are summarized in Fig. 2.

Distribution of prevalence of malaria infection by socio-demographic factors

The study found that non-mosquito net users had a significantly higher prevalence of malaria infection at 26.1% ($n=6$) compared to mosquito net users at 9.1% ($n=20$) ($p=0.012$). Participants who reported not receiving malaria health education had a higher prevalence of malaria infection at 16.5% ($n=13$) compared to those who reported receiving such education at 8.0% ($n=13$) ($p=0.046$) in Table 3.

Table 2 Participant's clinical history and laboratory parameters ($N=242$)

Variable	Number (N)	Percentage
WHO clinical stage		
Stage 1	102	42
Stage 2	88	36.4
Stage 3	34	14.1
Stage 4	18	7.4
Duration on ART (months)		
≤6 months	19	7.9
>6 months	223	92.1
Types of ART regimen		
First-line ART	226	93.4
Second-line ART	13	5.4
Third line ART	3	1.2
TB status		
No	222	91.7
Yes	20	8.3
Viral load (copies/ml)		
<1000	215	88.4
≥1000	27	11.2
CD4 count (cells/μL)		
≤350	69	28.5
>350	173	71.5
Other comorbidities*		
No	215	88.4
Yes	27	11.2
Health education on malaria		
No	79	32.6
Yes	163	67.4
Adherence on ART		
Good	222	91.7
Poor	20	8.3

*Hypertension ($n=20$, 74.1%), Diabetes type 2 ($n=6$, 22.2%), and Cancer ($n=1$, 3.7%)

Distribution of prevalence of malaria infection by clinical and laboratory factors

Moreover, participants with poor adherence to ART had a significantly higher prevalence of malaria infection at 35.0% ($n=7$) compared to those with good adherence ($p=0.001$).

Furthermore, participants with comorbidities had a higher prevalence of malaria infection at 22.2% ($n=6$) compared to those without comorbidities at 9.3% ($n=20$) ($p=0.041$). Additionally, participants with HIV-TB co-infection had a higher prevalence of malaria infection at 25.0% ($n=5$) compared to those with only HIV infection at 9.5% ($n=21$) ($p=0.032$).

Regarding clinical and laboratory parameters, participants with HVL greater than or equal to 1000 copies/ml had a higher prevalence of malaria infection at 22.2% ($n=6$) compared to those with HVL below 1000 copies/ml at 9.3% ($n=20$) ($p=0.041$). Moreover, participants with a CD4 cell count below or equal to 350 cells/μL had a higher prevalence of malaria infection at 21.7% ($n=15$) compared to those with a CD4 count above 350 cells/μL at 6.4% ($n=11$) ($p=0.001$).

The socio-demographic characteristics including age and gender, clinical factors including WHO HIV clinical stages, type of ART, other comorbidities, duration on ART, TB infection were not statistically significant predictors of malaria infection ($p>0.05$) in Table 4.

Factors associated with malaria infection

In Table 5, a logistic regression model analysis was used to determine the factors associated with malaria infection. Using bivariate and multivariate logistic regression analysis, it was found that the participants whose residence was in rural area had 2.8 times increased risk of malaria infection compared to urban residents (aOR=2.81; 95%CI=1.06-7.45, $p=0.038$). Poor adherence to ART increased the risk of contracting malaria infection about

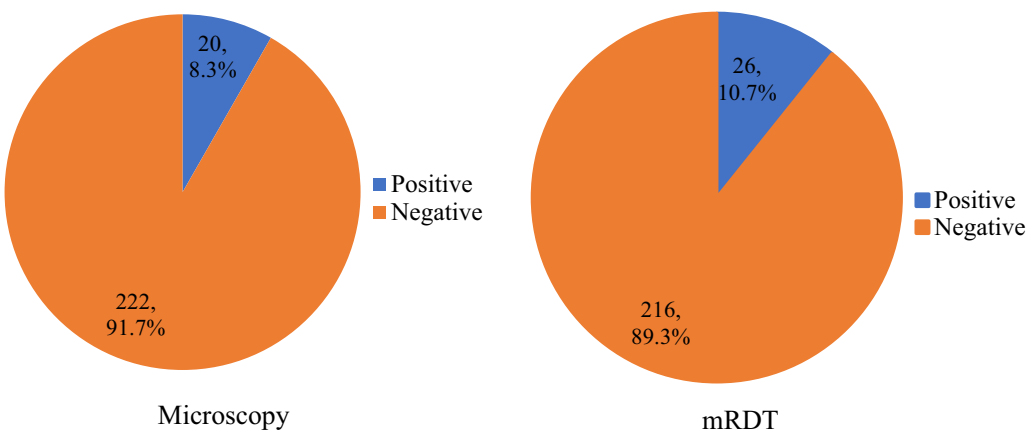

Fig. 2 Prevalence of malaria infection by mRDT and malaria microscopy methods

Table 3 Distribution of prevalence of malaria infection by socio-demographic factors

Characteristics	Number positive (%), *n* = 26	Number negative (%), *n* = 216	*p* value
Age groups (years)			
Median (IQR) 49.5 years (IQR 40–58)			
≤ 20	0 (0.0)	9 (100)	0.433
21–30	1 (6.7)	14 (93.3)	
31–40	6 (14.6)	35 (85.4)	
41–50	5 (6.9)	67 (93.1)	
≥ 51	14 (13.3)	91 (86.7)	
Gender prevalence			
Female	14 (9.4)	135 (90.6)	0.391
Male	12 (12.9)	81 (87.1)	
Place of resident			
Rural	14 (19.7)	57 (80.3)	0.004
Urban	12 (7.0)	159 (93.0)	
Education level			
No formal education	7 (18.0)	32 (82.1)	0.396
Primary education	14 (10.0)	126 (90.0)	
Secondary education	4 (9.3)	39 (90.7)	
College and above	1 (5.0)	19 (95.0)	
Occupation status			
Employed	1 (7.7)	12 (92.3)	0.973
Peasant	7 (11.3)	55 (92.3)	
Self-employed	17 (11.0)	138 (89.0)	
Unemployed	1 (8.3)	11 (91.3)	
Marital status			
Divorced	5 (10.8)	41 (89.1)	0.461
Married	8 (9.0)	81 (91.0)	
Widow/widower	8 (17.0)	39 (83.0)	
Single	5 (8.3)	55 (91.7)	
Use of mosquito			
No	6 (26.1)	17 (73.9)	0.012
Yes	20 (9.1)	199 (90.8)	
Health education on malaria infection			
No	13 (16.5)	66 (83.5)	0.046
Yes	13 (8.0)	150 (92.0)	

Table 4 Distribution of prevalence of malaria infection by clinical and laboratory factors

Characteristics	Number positive (%), *n* = 26	Number negative (%), *n* = 216	*p* value
No	6 (26.1)	17 (73.9)	0.012
Yes	20 (9.1)	199 (90.8)	
WHO HIV clinical stage			
Stage 1	7 (8.8)	93 (91.2)	0.153
Stage 2	7 (8.0)	81 (92.1)	
Stage 3	6 (17.7)	28 (82.4)	
Stage 4	4 (22.2)	14 (77.8)	
Duration on ART			
≤ 6 months	2 (10.5)	17 (89.5)	0.975
> 6 months	24 (10.8)	199 (89.2)	
Types of ART regimen			
First-line ART	25 (11.1)	201 (88.9)	0.774
Second-line ART	1 (7.7)	12 (92.3)	
Third line ART	–	3 (100)	
Adherence on ART			
Good	19 (8.6)	203 (91.4)	0.001
Poor	7 (35.0)	13 (65.0)	
Other comorbidities*			
No	20 (9.3)	195 (90.7)	0.041
Yes	6 (22.2)	21 (77.8)	
TB status			
No	21 (9.5)	201 (90.5)	0.032
Yes	5 (25.0)	15 (75.0)	
Viral load			
< 1000 copies/mL	20 (9.3)	195 (90.7)	0.041
≥ 1000 copies/mL	6 (22.2)	21 (77.8)	
CD4 count			
≤ 350 cells/μl	15 (21.7)	54 (78.3)	< 0.001
> 350 cells/μl	11 (6.4)	162 (93.6)	

*Hypertension (*n* = 20, 74.1%), Diabetes type 2 (*n* = 6, 22.2%), and Cancer (*n* = 1, 3.7%)

3.66 times compared to moderate and good adherence, respectively (aOR = 3.66; 95%CI = 1.04-12.7, $p = 0.043$) (Table 4).

Participants with HVL greater than or equal to 1000 copies/mL had a 3.2 times higher risk of getting malaria infection (aOR = 3.2, 95% CI = 1.00–10.5, $p = 0.02$) compared to those with HIV viral load level of less than 1000 copies/ml. Similarly, participants with CD4 count less than or equal to 350 cells/μL had 2.8 times more likely to develop malaria infection (aOR = 2.8, 95% CI = 1.10–7.30, $p = 0.03$) compared to the participants who had CD4 count of greater than 350cells/μL (Table 4).

When compared to participants who did not use mosquito nets, using mosquito net was a protective factor against malaria infection (aOR = 0.27, 95% CI = 0.08–0.90, $p = 0.033$). Similarly, having received health education on malaria infection was a protective factor compared to participants who reported to have not received health education on malaria (aOR = 0.26, 95% CI = 0.09–0.71, $p = 0.009$).

Table 5 Factors associated with malaria infection in a study population

Variables	Malaria infection		OR (95%, C1)	*p* value	aOR (95%, C1)	*p* value
	Yes	No				
	n = 26 (%)	*n* = 216 (%)				
Place of residence						
Rural	14 (19.7)	57 (80.3)	3.25 (1.42–7.45)	0.005	2.81 (1.06–7.45)	0.038
Urban	12 (7.0)	159 (93.0)	1		1	
Use of mosquito net						
No	6 (26.1)	17 (73.9)	1		1	
Yes	20 (9.1)	199 (90.8)	0.28 (0.10–0.80)	0.018	0.27 (0.08–0.90)	0.033
Adherence on ART						
Good	19 (8.5)	203 (91.5)	1		1	
Poor	7 (35.0)	13 (65.0)	5.63 (1.98–19.0)	0.001	3.66 (1.04–12.7)	0.043
Other comorbidities*						
No	20 (9.3)	195 (90.7)	1		1	
Yes	6 (22.2)	21 (77.8)	2.78 (1.00–7.70)	0.048	2.17 (0.62–7.70)	0.227
TB status						
No	21 (9.5)	201 (90.5)	1		1	
Yes	5 (25.0)	15 (75.0)	3.2 (1.05–9.66)	0.04	3.05 (0.83–11.20	0.092
Viral load (copies/ml)						
< 1000	20 (9.3)	195 (90.7)	1		1	
≥ 1000	6 (22.2)	21 (77.8)	2.78 (1.00–7.70)	0.048	3.2 (1.00–10.5)	0.02
CD4 count (cells/μl)						
≤ 350	15 (21.7)	54 (78.3)	4.1 (1.77–9.45)	0.001	2.8 (1.10–7.30)	0.03
> 350	11 (6.4)	162 (93.6)	1		1	
Health education on malaria						
No	13 (16.5)	66 (83.5)	1		1	
Yes	13 (8.0)	150 (92.0)	0.44 (0.19–1.00)	0.05	0.26 (0.091–0.71)	0.009

*Hypertension (*n* = 20, 74.1%), Diabetes type 2 (*n* = 6, 22.2%), and Cancer (*n* = 1, 3.7%)

Discussion

Prevalence of malaria infection among HIV-infected adult patients

The study revealed that among adults living with HIV/AIDS attending the HIV care and treatment clinic at Kitete Regional Referral Hospital, the prevalence of malaria infection was 10.7% using mRDT and 8.3% using blood smear examination. Notably, the observed prevalence in this population surpassed the average malaria prevalence of 7.9% on Tanzania's mainland, which varies across regions. However, it is essential to highlight that this prevalence remains lower than the exceptionally high prevalence of 23.4% in Tabora (Ministry of Health et al. 2022). Similarly, when considering the methods individually, the prevalence of malaria infection identified by mRDT was notably higher, while blood smear microscopy indicated a lower prevalence. The prevalence difference between the two methods may be due to test sensitivity or low parasitemia levels. Considering mRDT is more sensitive than microscopy, especially in endemic areas (Lin et al. 2022). This study proposes using mRDT for malaria detection in HIV-positive patients in high-transmission areas with a high HIV/AIDS prevalence. However, further research is necessary to determine diagnostic method sensitivity and specificity in this population and explore geographical and environmental factors affecting malaria prevalence. Moreover, the prevalence found in this study was lower than reported in other studies in Tanzania, including 24.9% in the Pwani region (Idindili et al. 2011) and 22.4% in the lake Zone regions (Morona et al. 2018). It was also lower than that reported in some other studies carried out in populations with HIV infection in numerous African nations, such as 14.1% in Cameroon (Sandie et al. 2019) and 37% in Malawi (Munyenyembe et al. 2020). However, the observed prevalence in this study is significantly higher than the prevalence of 1.4% reported in Sudan (AL-Nahari et al. 2019). The difference in prevalence observed among these studies and the current study could be attributed to geographical differences in the study populations as well as differences in the level of malaria endemicity. According to the malaria endemicity

stratification in Tanzania, Tabora Urban, where our study site is located, is classified as an area with moderate malaria transmission (Ministry of Health et al. 2020). However, patients attending this health facility come from different transmission strata, including high-transmission areas.

Factors associated with malaria infection among HIV-infected adult patients

This study found that several factors were associated with increased risk of malaria infection among adults living with HIV, including rural place of residence, not using mosquito nets, poor adherence to ART, high HIV viral load, and low CD4 count. Additionally, not receiving health education on malaria was also associated with increased risk of malaria infection. However, comorbidities such as hypertension, cancer, and diabetes type 2 were not found to be associated with malaria infection in this study.

Analysis of factors associated with malaria infection among adults living with HIV showed that place of residence, use of mosquito net, having received health education on malaria, level of CD4 count, and HIV viral load are associated with malaria infection in adults living with HIV.

This study suggests that participants whose residence was in rural had 2 times increased risk of malaria infection compared to urban residents. This increased risk is attributed to lower socioeconomic status, limited access to healthcare and preventative measures, and the prevalence of breeding sites in rural areas. Notably, these findings align with parallel studies in African countries such as South Africa (Ebhuoma et al. 2022), Kenya (Omondi et al. 2023), and Cameroon (Nyasa et al. 2021), highlighting a consistent and cross-national pattern of rural–urban disparities in malaria vulnerability among this population.

This study underscores the critical role of mosquito nets particularly insecticide-treated nets (ITNs) as a recommended preventative measure against malaria (Bertozzi-Villa et al. 2021). Among participants, non-users had 3 times increased risk of malaria infection compared to users. Nevertheless, barriers such as cost and limited health education in Tanzania pose challenges. While the study emphasizes the efficacy of ITNs, addressing insecticide resistance becomes a critical aspect of ensuring sustained effectiveness in malaria prevention efforts (Lindsay et al. 2021). Urgent interventions, including affordable distribution and targeted health education campaigns, are imperative to optimize the impact of this simple yet powerful preventive measure, significantly reducing malaria risk in this vulnerable population.

Good adherence to antiretroviral therapy (ART) among HIV patients is crucial, as poor adherence is associated with a 3 times increased risk of malaria infection. This increased risk might be linked to reduced CD4 levels and heightened viral replication (Angelo & Alemayehu 2021). In contrast to poor adherence to ART, good adherence not only boosts the body's immunity but is also reported to impact malaria. The combination of zidovudine, lamivudine, and lopinavir/ritonavir (LPV/r) in first-line HIV treatment has the potential to mitigate malaria risk, impacting Plasmodium infection stages, as noted by (Azevedo et al. 2020). Thus, maintaining adherence to ART not only supports effective HIV management but may also contribute to reducing the risk of malaria in co-infected individuals.

The HIV viral load test is an essential method for monitoring antiretroviral therapy (ART) in individuals with HIV infection. The current study reveals a significant association between a high HIV viral load (HVL $\geq$ 1000 copies/ml) and a 3 times increased risk of malaria infection compared to individuals with a lower HIV viral load (HVL $<$ 1000 copies/ml). This finding aligns with similar observations reported in other studies done by (Guerra et al. 2022) in Brazil (Njoku-Obi 2020). This can be explained by ability of HIV to influence gametocytes, leading to increased malaria parasitemia and gametocytemia through induced immunosuppression (Roberds et al. 2021). Additionally, high HIV viral load may threaten the emergence of malaria resistance genes, notably against Artemisinin and Lumefantrine as reported by (Onwuzurike et al. 2021) in Nigeria. These findings underscore the intricate interplay between HIV and malaria, highlighting potential challenges in managing co-infected individuals and emphasizing the need for tailored interventions.

The CD4 count is used to assess the immunological response in individuals with HIV infection. In this study, an association between CD4 counts in HIV patients and malaria risk was observed. 2 times increase in risk was found among participants with CD4 counts $\leq$ 350 cells/μL compared to those with counts $>$ 350 cells/μL. An unbalanced immune response, particularly with CD4 cell involvement, may compromise the defense mechanism, heightening susceptibility to malaria or impacting infection severity (Guerra et al. 2022)(Simon-Oke et al. 2020). Contrastingly, a study conducted in Nigeria by (Enuma et al. 2022) found that the compromised immune state, as indicated by CD4 counts, did not significantly correlate with an increased prevalence of malaria among HIV-positive individuals, especially those on antiretroviral therapy (ART). This discrepancy suggests that certain ART medications, especially some of those within first-line HIV treatment, may have the potential to mitigate

malaria risk by impacting Plasmodium infection stages (Azevedo et al. 2020). This current study suggests the need for more research to comprehend the relationship between CD4 counts, immune status, and malaria susceptibility in HIV-positive individuals, aiming for improved care and public health strategies.

Health education involves teaching individuals to manage health and prevent diseases, through diverse approaches (Farea et al. 2020). In the context of this study, health education refers to information and instruction provided to individuals regarding malaria prevention and management. The findings indicate a significant association between the absence of health education on malaria and a 3 times higher risk of contracting malaria infection. This underscores the importance of accurate knowledge about malaria, impacting individuals' perceptions and practices, and contributing to effective malaria prevention. The study by (Balami et al. 2019) highlighted the significance of integrating malaria health education into routine care of special groups to enhance the well-being of individuals. The findings from this study support a proactive health education approach, emphasizing its potential positive impact on individual health, particularly for HIV-infected individuals.

This study found no significant association between malaria and comorbidities (hypertension, cancer, diabetes type 2) among adults with HIV/AIDS. Similarly, there was no significant link between malaria and HIV-TB co-infection. These non-significant associations may be influenced by study design, sample size, and contextual differences. While these findings suggest that these comorbidities and HIV-TB co-infection may not be major contributors to malaria risk in this population, further research is warranted to understand the nuanced interactions and inform tailored public health strategies.

Limitations

In addressing potential measurement bias, the study employed standardized questionnaires. Despite these efforts, variations in participant responses introduce the possibility of imprecision in the collected data. Additionally, the study took measures to mitigate reporting bias through adherence to a predefined analysis plan. Nevertheless, it is crucial to recognize the persistent potential for selective reporting or emphasis on specific data elements.

Conclusions

This study highlights a concern malaria prevalence among HIV-infected adults individuals at KRRH in Tabora region, emphasizing the significance of tailored interventions. Factors such as rural residence, non-use of mosquito nets, poor adherence to ART, high HIV viral load, and low CD4 count were identified as significant risk factors for malaria infection. The findings underscore the need for targeted health education, improved access to preventive measures, and sustained adherence to ART to mitigate malaria risk in this vulnerable population.

Abbreviations

aOR	Adjusted odds ratio
AIDS	Acquired immunodeficiency syndrome
ART	Antiretroviral therapy
CD4	Cluster of differentiation 4
CI	Confidence interval
CTC	Care and Treatment Clinic
EDTA	Ethylenediaminetetraacetic acid
HIV	Human Immunodeficiency Virus
HVL	HIV viral load
IQR	Interquartile range
KRRH	Kitete Regional Referral Hospital
mRDT	Malaria rapid diagnostic test
MOH	Ministry of Health
OR	Odds ratio
PfHRP2	Plasmodium falciparum histidine-rich protein 2
PfLDH	Plasmodium falciparum lactate dehydrogenase
PLWHIV	People living with HIV
TB	Tuberculosis
WHO	World Health Organization

Acknowledgements

The authors extend sincere gratitude to the organizations and individuals who supported and assisted in the development of this research work. Special acknowledgment is given to the Tanzania Field Epidemiology and Laboratory Training Program (TFELTP) and the Department of Epidemiology and Biostatistics at Muhimbili University of Health and Allied Sciences (MUHAS) for their invaluable contributions. The authors also appreciate the Ministry of Health, particularly the administration of Kitete Regional Referral Hospital, for granting permission to conduct the study. Their collaboration and assistance played a pivotal role in the successful completion of this research.

Author contributions

HN, NL, and DK conceived and designed the study. HN and AM conducted interviews and laboratory tests during data collection. Data entry, cleaning, and analysis were carried out by HN and DK. The initial draft of the manuscript was prepared through collaboration among HN, NL, and DK, with all authors contributing to the review and approval of the final manuscript. The integrity and accuracy of the data analysis are collectively assumed by all authors. The final manuscript underwent thorough review and received approval from each author.

Funding

This study did not receive any funding.

Availability of data and materials

Upon a valid request, the corresponding author can grant access to the data generated and analyzed in this study.

Declarations

Ethics approval and consent to participate

Ethical clearance for the study was granted by the Research and Publication Committee of Muhimbili University of Health and Allied Sciences (MUHAS) with the reference number MUHAS-REC-02-2022-979. Additionally, authorization to conduct the research was secured from the Medical Officer in-charge (MOI) of Kitete Regional Referral Hospital (KRRH). Prior to their inclusion, participants provided informed consent, and confidentiality was maintained by assigning unique study codes rather than using personal names. Participants were briefed on the study's objectives, potential benefits, and risks, as well as

their rights. Those testing positive for malaria were expeditiously referred for clinical care in adherence to established malaria treatment guidelines.

Consent for publication
Not applicable.

Competing interests
The authors affirm that they have no competing interests or affiliations that may present a conflict of interest.

Author details
[1]Department of Health, Nyang'hwale District Council, Geita, Tanzania. [2]Department of Microbiology and Immunology, Muhimbili University of Health and Allied Sciences, Dar es Salaam, Tanzania. [3]Tanzania Field Epidemiology and Laboratory Training Program, Dar es Salaam, Tanzania. [4]Department of Laboratory, Kitete Regional Referral Hospital, Tabora, Tanzania.

Received: 8 September 2023 Accepted: 2 November 2023
Published online: 08 December 2023

References

Al-Nahari W, Abdelkreem E, Abdueghni S, Omer A (2019) Estimation of *Plasmodium falciparum* among HIV patients in Khartoum-Sudan. Int J Sci Res 8(8):15–17

Angelo AT, Alemayehu DS (2021) Adherence and its associated factors among adult hiv-infected patients on antiretroviral therapy in South Western Ethiopia, 2020. Patient Prefer Adherence 15:299–308. https://doi.org/10.2147/PPA.S298594

Azevedo R, Mendes AM, Prudêncio M (2020) The impact of antiretroviral therapy on malaria parasite transmission. Front Microbiol 10(January):1–9. https://doi.org/10.3389/fmicb.2019.03048

Balami AD, Said SM, Zulkefli NAM, Bachok N, Audu B (2019) Effects of a health educational intervention on malaria knowledge, motivation, and behavioural skills: a randomized controlled trial PACTR201610001823405 PACTR. Malar J 18(1):1–14. https://doi.org/10.1186/s12936-019-2676-3

Bedimo H, Tadesse M, Disassa H, Beyene MB (2017) Concurrent plasmodium infection, anemia and their correlates among newly diagnosed people living with HIV / AIDS in Northern Ethiopia. Acta Trop 169:8–13. https://doi.org/10.1016/j.actatropica.2017.01.007

Bertozzi-Villa A, Bever CA, Koenker H, Weiss DJ, Vargas-Ruiz C, Nandi AK, Gibson HS, Harris J, Battle KE, Rumisha SF, Keddie S, Amratia P, Arambepola R, Cameron E, Chestnutt EG, Collins EL, Millar J, Mishra S, Rozier J, Bhatt S (2021) Maps and metrics of insecticide-treated net access, use, and nets-per-capita in Africa from 2000–2020. Nat Commun 12(1):1–12. https://doi.org/10.1038/s41467-021-23707-7

Dalrymple U, Arambepola R, Gething PW, Cameron E (2018) How long do rapid diagnostic tests remain positive after anti-malarial treatment? Malar J 17(1):1–14. https://doi.org/10.1186/s12936-018-2371-9

Dhorda M, Ba EH, Kevin Baird J, Barnwell J, Bell D, Carter JY, Dondorp A, Ekawati L, Gatton M, González I, Guérin PJ, Incardona S, Lilley K, Menard D, Nosten F, Obare P, Ogutu B, Olliaro PL, Price RN, Sokhna C (2020) Towards harmonization of microscopy methods for malaria clinical research studies. Malar J 19(1):14. https://doi.org/10.1186/s12936-020-03352-z

Domfeh SA, Darkwa BY, Gablah RK, Adu-Asamoah E, Obirikorang C (2023) Evaluation of four malaria rapid diagnostic test kits used at the Enyiresi Government Hospital in the Eastern Region of Ghana. J Parasitol Res. https://doi.org/10.1155/2023/4226020

Ebhuoma O, Gebreslasie M, Ogunsakin RE (2022) Socio-economic status as predictors of malaria transmission in KwaZulu-Natal, South Africa. A retrospective study. Afr Health Sci 22(2):204–215. https://doi.org/10.4314/ahs.v22i2.24

Enuma JN, Sanni FO, Matur MB, Jearr NE, Erhabor T, Egbulefu II (2022) Malaria an opportunistic infection in HIV/AIDS patients?—A Nigerian experience. Afr J Lab Med 11(1):1–6. https://doi.org/10.4102/ajlm.v11i1.1842

Farea BA, Muharram AA, Baktayan NA (2020) Impact of health education on KAP towards malaria among basic schools pupils in Taiz Governorate. Republic of Yemen 2013: pre and post intervention study, pp 324–333. https://doi.org/10.4236/health.2020.124027

Gils T, Bossard C, Verdonck K, Owiti P, Casteels I, Mashako M, Van Cutsem G, Ellman T (2018) Stockouts of HIV commodities in public health facilities in Kinshasa: barriers to end HIV. PLoS ONE 13(1):1–12. https://doi.org/10.1371/journal.pone.0191294

Gnardellis C, Notara V, Papadakaki M, Gialamas V, Chliaoutakis J (2022) Overestimation of relative risk and prevalence ratio: misuse of logistic modeling. Diagnostics 12(11):1–10. https://doi.org/10.3390/diagnostics12112851

Goselle ON, Ajiji GY, Jambol A, Sunday JT, Idoko OS, Udoh SS, Ejete OC, Ahmadu YM, Awobode HO, Imandeh GN, Matur BM (2020) Could the level in parasitaemia of *Plasmodium* determine sensitivity to various diagnostic tests? Am J Mol Biol 10(03):224–245. https://doi.org/10.4236/ajmb.2020.103015

Guerra CVC, da Silva BM, Müller P, Baia-da-Silva DC, Moura MAS, Araújo JDA, Silva JCSE, Silva-Neto AV, da Silva Balieiro AA, da Costa-Martins AG, Melo GC, Val F, Bassat Q, Nakaya HI, Martinez-Espinosa FE, Lacerda M, Sampaio VS, Monteiro W (2022) HIV infection increases the risk of acquiring *Plasmodium vivax* malaria: a 4-year cohort study in the Brazilian Amazon HIV and risk of vivax malaria. Sci Rep 12(1):1–9. https://doi.org/10.1038/s41598-022-13256-4

Ibrahim A, Olayinka AT, Muhammed S, Balogun MS, Dahiru A, Ajayi I, Ahmadu I, Song A, Abdullahi H (2019) Lipid profile of HIV/AIDS patients attending antiretroviral treatment clinic in Zaria, North-Western Abstract. BioRxiv 10(7):1–24

Idindili, B., Jullu, B., Hattendorf, J. A. N., Mugusi, F., Antelman, G., & Tanner, M. (2011). HIV and parasitic co-infections among patients seeking care at health facilities in Tanzania. *Tanzania Journal of Health Research*, *13*(4). https://doi.org/10.4314/thrb.v13i4.3 HIV

Lin K, Li M, Wang D, Luo F, Lu S, Michael MG, Mlacha Y, Chaki P, Xiao N, Zhou XN (2022) Evaluation of malaria standard microscopy and rapid diagnostic tests for screening—Southern Tanzania, 2018–2019. China CDC Wkly 4(28):605–608. https://doi.org/10.46234/ccdcw2022.132

Lindsay SW, Thomas MB, Kleinschmidt I (2021) Threats to the effectiveness of insecticide-treated bednets for malaria control: thinking beyond insecticide resistance. Lancet Glob Health 9(9):e1325–e1331. https://doi.org/10.1016/S2214-109X(21)00216-3

Ministry of Health (2017) Monitoring patients on ART. In: National guidlines for the management of HIV nad AIDS, no 255, pp 143–172

Ministry of Health (2023) HIV/AIDS in Tanzania. https://nacp.go.tz/hiv-aids-in-tanzania/#:~:text=tanzania mainland is experiencing a, of 4.7% 25 in general population. Accessed 04 Oct 2023

Ministry of Health, Community Development, Gender, and C, NMC Programme (2020). National Malaria Strategic Plan. In: National Malaria Strategic Plan 2021–2025

Ministry of Health Dodoma, Ministry of Health Zanzibar, National Bureau of Statistics Dodoma, Office of Chief Government Statistician Zanzibar, The DHS Program ICF, Rockville, Maryland, USA (2022) Tanzania demographic and health survey and malaria indicator survey 2022 key indicators report

Ministry of Health, Tanzania, Ministry of Health Zanzibar, National Bureau of Statistics, Office of Chief Government Statistician, U.S. President's Emergency Plan for AIDS Relief (PEPFAR), The United States Centers for Disease Control and Prevention (CDC), Atlanta, ICAP at Columbia University (2017) Tanzania HIV impact survey. In: Ministry of Health, Tanzania, vol 1

Mirzohreh ST, Safarpour H, Pagheh AS, Bangoura B, Barac A, Ahmadpour E (2022) Malaria prevalence in HIV-positive children, pregnant women, and adults: a systematic review and meta-analysis. Parasit Vectors 15(1):1–15. https://doi.org/10.1186/s13071-022-05432-2

Mnzava D, Okuma J, Ndege R, Kimera N, Ntamatungiro A, Nyuri A, Byakuzana T, Abilahi F, Mayeka P, Temba E, Fanuel T, Glass TR, Klimkait T, Vanobberghen F, Weisser M (2023) Decentralization of viral load testing to improve HIV care and treatment cascade in rural Tanzania: observational study from the Kilombero and Ulanga Antiretroviral Cohort. BMC Infect Dis 23(1):222. https://doi.org/10.1186/s12879-023-08155-6

Morona D, Zinga M, Mirambo MM, Mtawazi S, Silago V (2018) Short communication on High prevalence of Plasmodium falciparum malaria among Human Immunodeficiency Virus seropositive population in the Lake Victoria zone. Tanzan J Health Res 20(1):20–23

Munyenyembe AU, Gausi K, Hiestand J, Mallewa J, Mandala W (2020) The effect of frequent exposure to *P. falciparum*, hiv-infection and other co-morbidities on development of severe malaria in Malawian adults. Infect Drug Resist 13:63–68. https://doi.org/10.2147/IDR.S230112

Njoku-Obi T (2020) Epidemiological studies of malaria parasite on HIV patients attending General Hospital Awo-Omamma, Oru East, Imo State, Nigeria. Access Microbiol 2(7A):1–11. https://doi.org/10.1099/acmi.ac2020.po0086

Nyasa RB, Fotabe EL, Ndip RN (2021) Trends in malaria prevalence and risk factors associated with the disease in Nkonghombeng; a typical rural setting in the equatorial rainforest of the South West Region of Cameroon. PLoS ONE 16(5 May):1–20. https://doi.org/10.1371/journal.pone.0251380

Obase BN, Bigoga JD, Nsagha DS (2023) Malaria and HIV co-infection among pregnant women in Africa: prevalence, effect on immunity and clinical management: review. Int J Transl Med 3:187–202. https://doi.org/10.3390/ijtm3020014

Ogunfowokan O, Ogunfowokan BA, Nwajei AI (2020) Sensitivity and specificity of malaria rapid diagnostic test (mRDTCareStatTM) compared with microscopy amongst under five children attending a primary care clinic in southern Nigeria. Afr J Prim Health Care Fam Med 12(1):1–8. https://doi.org/10.4102/phcfm.v12i1.2212

Omondi CJ, Odongo D, Otambo WO, Ochwedo KO, Otieno A, Lee M-C, Kazura JW, Githeko AK, Yan G (2023) Malaria diagnosis in rural healthcare facilities and treatment-seeking behavior in malaria endemic settings in western Kenya. PLOS Global Public Health 3(7):e0001532. https://doi.org/10.1371/journal.pgph.0001532

Onwuzurike PA, Enweani IB, Ekejindu IM (2021) HIV and Malaria co-infection and the impact of viral load and HAART usage on the development of *Plasmodium falciparum* Artemisinin and Lumefantrine resistant genes in Nnewi, Anambra State, Nigeria. World J Adv Res Rev 12(3):505–516. https://doi.org/10.30574/wjarr.2021.12.3.0710

Opoku Afriyie S, Addison TK, Gebre Y, Mutala AH, Antwi KB, Abbas DA, Addo KA, Tweneboah A, Ayisi-Boateng NK, Koepfli C, Badu K (2023) Accuracy of diagnosis among clinical malaria patients: comparing microscopy, RDT and a highly sensitive quantitative PCR looking at the implications for submicroscopic infections. Malar J 22(1):1–11. https://doi.org/10.1186/s12936-023-04506-5

Orishaba P, Kalyango JN, Byakika-Kibwika P, Arinaitwe E, Wandera B, Katairo T, Muzeyi W, Nansikombi HT, Nakato A, Mutabazi T, Kamya MR, Dorsey G, Nankabirwa JI (2020) Increased malaria parasitaemia among adults living with HIV who have discontinued cotrimoxazole prophylaxis in Kitgum district, Uganda. PLoS ONE 15(11 November):1–14. https://doi.org/10.1371/journal.pone.0240838

Osii RS, Otto TD, Garside P, Ndungu FM, Brewer JM, Brewer JM (2020) The impact of malaria parasites on dendritic cell—T cell interaction. Front Immunol 11(July):1–16. https://doi.org/10.3389/fimmu.2020.01597

Roberds A, Ferraro E, Luckhart S, Stewart VA (2021) HIV-1 impact on malaria transmission: a complex and relevant global health concern. Front Cell Infect Microbiol 11(April):1–14. https://doi.org/10.3389/fcimb.2021.656938

Sandie SM, Sumbele IUN, Tasah MM, Kimbi HK (2019) Malaria parasite prevalence and haematological parameters in HIV seropositive patients attending the regional hospital Limbe, Cameroon: a hospital-based cross-sectional study. BMC Infect Dis 19(1):1–11. https://doi.org/10.1186/s12879-019-4629-4

Schuster NA, Twisk JWR, Ter Riet G, Heymans MW, Rijnhart JJM (2021) Noncollapsibility and its role in quantifying confounding bias in logistic regression. BMC Med Res Methodol 21(1):136. https://doi.org/10.1186/s12874-021-01316-8

Smith SM (2015) Determining sample size. In: Qualtrics, p 7

Simon-Oke IA, Ade-Alao AO, Ologundudu F (2020) The impact of HIV-associated immunosuppression on the Plasmodium falciparum chloroquine resistance transporter gene (PfCRT) of HIV patients in Akure, Nigeria. Bull Natl Res Centre. https://doi.org/10.1186/s42269-020-00401-0

World Health Organization. (2023a). Diagnostic testing. https://www.who.int/teams/global-malaria-programme/case-management/diagnosis#:~:text=prompt%20malaria%20diagnosis%20either%20by,and%20for%20strong%20malaria%20surveillance. Accessed 05 Oct 2023.

World Health Organization. (2023b). HIV and AIDS. https://www.who.int/news-room/fact-sheets/detail/hiv-aids. Accessed 04 Oct 2023.

World Health Organization. (2023c). Malaria. https://www.who.int/news-room/fact-sheets/detail/malaria. Accessed 04 Oct 2023.

Publisher's Note