

# Bottlenecks to Intervention Scale Up: Supply and Demand Side Perspectives From a Large, Community-based Trial of Malaria Testing

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## Research Article

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# Abstract

**Background:** Maximizing the impact of community-based programs requires understanding how the supply of and demand for the intervention interact at the point of delivery. We present results from a large-scale community health worker study designed to increase the availability of and demand for malaria diagnostic testing in a rural, malaria-endemic region in western Kenya between 2015 and 2017.

**Methods:** Community Health Workers (CHWs) provided free malaria Rapid Diagnostic Test(mRDT) in the community. Those with a positive malaria test were provided with a discounted first-line antimalarial over-the-counter. We conducted a community-based survey to collect individual study outcomes at 12- and 18-months post-implementation. In addition, we collected monthly testing data from the 244 participating CHWs and also conducted in-depth interviews with a random sample of 70 CHWs.

**Results:** From the survey, 55% (n=948/1738) reported having a malaria test for their recent illness with 38% having been tested by a CHW. Being aware of a local CHW (95% CI:1.10-2.04) and belonging to a wealthy household (95% CI:1.14-2.06) were associated with higher malaria testing uptake from any source. Poorer households were more likely to receive a test from a CHW. School-aged children between 5-17 years were more than twice as likely to be tested by a CHW (95% CI:1.47-4.14). Both confidence in AL treatment (95% CI:1.54-4.92) and perceived accuracy of an RDT performed by a CHW (95% CI:1.12-5.27) were strongly and positively associated with testing by a CHW. In adjusted analyses, specific CHWs attributes were significantly associated with higher testing rates including formal employment (95% CI:0.05-2.70), those serving more than 50 households (95% CI:0.70-2.74) and those serving areas with a higher proportion of positive tests (95% CI:1.05, 3.22). On both the supply side and the demand side, confidence in a test performed by a CHW was strongly correlated with the success of the intervention.

**Conclusion:** Scale-up of community-based malaria testing intervention through CHWs is feasible and effective at reaching the poorest households. In order to maximize the impact of such interventions, it is important to recognize factors that may restrict both delivery and demand for such services.

## Background

Despite decades of control efforts, malaria remains a major public health problem. In 2019, an estimated 229 million cases of malaria occurred worldwide. Most malaria cases in 2019 were in the World Health Organization (WHO) African Region (215 million or 94%). In the same year, there were an estimated 409 000 deaths from malaria globally, with Africa again accounting for 94%. Children under 5 years are the most vulnerable group affected by malaria and in 2019, 67% of malaria deaths were in this group (1).

Prompt malaria diagnosis either by microscopy or rapid diagnostic tests (RDTs) is recommended by WHO for all patients with suspected malaria before they are given treatment (2). Already, 95 countries have adopted the policy of testing all patients with suspected malaria before being treated, and this number is increasing. Diagnostic testing is free of charge in the public sector of almost 90 countries(3). Early and accurate diagnosis is essential both for effective management of the disease and for strong malaria

surveillance. Parasite-based diagnostic testing significantly reduces illness and death by enabling health providers to swiftly distinguish between malarial and non-malarial fevers and select the most appropriate treatment.

The Kenya National Control Program adopted the Test and Treat policy in (2010) and this has been cascaded to the community level. RDTs are recommended for parasitological diagnosis in public health facilities where microscopy is not available and through Community Health Workers in some regions. Despite these efforts, most people in rural Kenya still opt for self-treatment and seek care in the retail health sector(4, 5). Point-of-care diagnostic testing is not available in pharmacies and chemists, therefore patients who purchase antimalarials in the retail sector are not diagnosed before treatment. Studies have shown that targeting of antimalarials to true malaria cases in the retail sector is very low; as few as 20% of people purchasing antimalarials are suffering from malaria (6, 7) and as high as 70% of people with malaria do not purchase an ACT(8).

The deployment of RDTs through trained community health workers could improve access to diagnosis for populations with limited access to health facilities. We evaluated an intervention that targeted individuals who seek care in the retail sector by offering free community-based malaria diagnostic testing through CHWs. Following testing, those with a positive test result received a voucher to obtain first-line antimalarials at a nearby pharmacy at a heavily subsidized price. The intervention demonstrated a significant improvement in testing before treatment (5).

Ideally, there should be adequate demand for the commodity or opportunity, and supply should be able to meet demand. In our study, only 55 percent of those with recent illness reported having a malaria test before taking drugs and 21% still purchased antimalarials over-the-counter without a test (5), representing substantial scope for further improving the reach and impact of this intervention. In this analysis, we sought to understand whether we could identify factors that increased or decreased demand for testing and factors that may have limited supply of testing by CHWs. A comparison of constraints on the demand side and supply side could help understand the conditions under which the intervention operated well or was hindered by a mismatch in supply and demand. The results will be instrumental for improving the design of community-based interventions delivered at scale.

## **Methods**

### **Description of the main trial**

The purpose of this study was to encourage clients to receive testing for malaria before seeking treatment. This was accomplished by training and equipping community health workers (CHWs) to perform rapid-diagnostic tests (RDTs) for malaria and to provide clients who test positive for malaria with a voucher that allows them access to subsidized high-quality antimalarial drugs through participating pharmacies. (5)

The study was conducted in Webuye East, Webuye West and Kiminini Sub-counties in Kenya, three regions with high rates of malaria transmission. At the initiation of the study, there were 32 active community units, 8 in Webuye West, 10 in Webuye East and 14 in Kiminini.(9) A community unit consists of approximately 1000 households, 10 CHWs, and one Community Health Extension Worker (CHEW).

CHWs work on a volunteer basis, while CHEWs are employees of Kenya's Ministry of Health (MOH). Though there are no formal education requirements for CHWs, the ability to read and write are criteria for selection by the MOH. The role of CHWs as defined by the MOH is to promote good health through providing health education, basic treatments (such as first-aid), and referrals to health care facilities. The CHWs are not paid for their involvement in this malaria study, but receive some compensation via mobile phone airtime and a small performance-based biannual bonus given to the cluster-specific CHW association.

In order to improve access to malaria testing, CHWs from 16 intervention CUs were trained to administer rapid diagnostic tests (RDTs) for malaria to clients experiencing symptoms in their community units. CareStart HRP2-based RDTs were used, which detect for malaria cases caused by *Plasmodium falciparum* which is the main species of parasite responsible for the majority of malaria cases in Kenya (10). The study team provided CHWs with the necessary supplies to conduct the RDT testing. CHWs could perform tests in the location(s) of their choice (e.g., in their own homes, at clients' homes, etc.), as long as the location allowed for proper and sufficiently private performance of the procedure. We identified 41 eligible private medicine retail outlets, where owners of 36 shops agreed to participate. The outlet had to be willing to sell quality-assured Artemisinin-based Combination Therapies (ACTs) to patients with positive malaria results at a subsidized rate. The study reimbursed the difference in ACT costs between the market price and the study subsidized price. The CHWs were informed about the participating medicine shops within their community units.

The CHWs tested febrile patients at community level and issued ACT vouchers to patients with positive results. The voucher redemption period was three days where by after that the Medicine shops were not allowed to collect the voucher. Patients with positive malaria results bought ACTs from medicine shops by redeeming their vouchers and leaving the voucher at the shop. The study team collected the redeemed vouchers from the medicine shops on a bi-weekly basis as we reimbursed the difference in costs.

## Community surveys

A community-based survey was conducted to collect individual-level study outcomes based on a population-based survey sampling strategy. This was a repeated cross-sectional household survey at 4 time points: baseline (pre-intervention), 6 months, 12 months, and 18 months post baseline. The survey was conducted in all the 32 community units, 16 Intervention and 16 control. Households were randomly selected by systematic random sampling and one person with fever in the last four weeks was interviewed in any household. We restrict our analysis here to the 12 and 18 month surveys in order to evaluate the effects of interest in the time-period when the intervention effect could be measured (9).

Basic demographic information about the participants and the households were collected. Socioeconomic scores were calculated from an asset index and then grouped into quintiles as described previously. Euclidean distance from a household to the nearest health facility was calculated from GPS coordinates. In the final survey, participants' beliefs about their illness, malaria risk, diagnostic testing, and treatment were elicited by asking them about the severity of their illness, their confidence in positive test result and a negative test result, and how certain they were that they would recover from malaria after treatment with AL. "Perceived prevalence" was defined as the proportion of fevers that the respondent believed would be due to malaria among 10 people with fever from their village. High perceived prevalence was assigned to those who responded 8–10 out of 10, medium prevalence to those who responded 4–7 out of 10 and low to those who responded 0–3 out of 10.

## Midpoint CHW Survey

As part of the process evaluation, at the midpoint of this study, interviews were conducted with a random sample of 70 CHWs who were trained to conduct RDTs (intervention CUs). The primary objective of these interviews were to determine the CHWs' satisfaction with their role in the malaria project and the feasibility of their continued involvement. Secondary objectives included eliciting the main challenges the CHWs have faced in implementing the study, determining unanticipated burdens on the CHWs' other activities (including their responsibilities as CHWs outside of the study as well as their non-CHW responsibilities) and identifying changes in the types of services they provide and the recipients of their services(11).

Likert-scale questions were also asked, in which the interviewers read a statement aloud and the CHWs were asked to respond how much they agreed with the statement on a five-point scale ("strongly agree", "somewhat agree," "neutral," "somewhat disagree," "strongly disagree"). For this analysis, several variables were derived from the survey data. The client score was constructed as a composite score based on four likert scale questions – whether CHWs agreed that; clients trust the results of a positive RDT by the CHW, they trust a negative RDT, they follow the CHWs advice if the test was positive, they follow advice if the test was positive. A response of 'strongly agree'=2, somewhat agree='1' and neutral/somewhat disagree/strongly disagree = 0. If the sum of these four responses was 6 or greater, the score was 'high'. If less than 6, the score was 'low'.

These same CHWs also performed an RDT under observation and were scored on each step. Those who completed at least 17 of 20 steps correctly had a 'high' score for RDT performance and < 17 had a 'low' score.

## Demand and Supply

To investigate factors that might have influenced the success of the intervention, the analysis was divided into demand and supply factors. On the demand side, we investigate factors that might influence the community member's outcome of having a test, first from any source and then from the CHW. We include only respondents with complete data on the variables of interest. On the supply side, we investigate the factors associated with the testing output (supply) at the CHW level.

# Outcome Measures

For this analysis, we only look at the clusters in the intervention arms. The primary outcome is the uptake of testing, defined as the proportion of fevers in the previous 4 weeks that receive a diagnostic test from any source. The second primary outcome is the uptake of testing from a community health worker among those with any test. We present descriptive results for individuals getting tested from any source and from a CHW across the intervention clusters.

The secondary outcome was to investigate the testing volume and the factors influencing this. This was measured by the mean monthly tests for each CHW. Monthly number of tests per CHW was available from program data collected at monthly supervision visits.

## Statistical Analysis

We conduct a mixed-effects logistic regression analysis to evaluate the primary outcome measures on the uptake of testing and investigate risk factors that might have contributed to the outcomes of the intervention reported in (9). The hierarchical nature of the data informed the adoption of multi-level modelling, since we include both individual-, and CHW- level risk factors in the analysis and account for clustering at the CU-level. The outcomes were evaluated only for the CUs in the intervention arm and summaries provided.

For the primary outcome measures to evaluate the uptake of testing, we generated two logistic models; the first model included all individuals tested at any source as the outcome and the second model included a subset of this population, those tested by a CHW as the outcome. For both models we accounted for clustering at the CU level, and then included potential individual-level covariates like respondent's age, gender, level of educational, occupation, socio-economic status, geographic proximity to health care provider, the time it took to obtain the malaria test, the level of knowledge and opinions about malaria and malaria diagnosis.

The logistic regression model is as shown below:

$$\log \left( \frac{p_{ij}}{1 - p_{ij}} \right) = \beta_0 + \beta_1 X_{1j} + \dots + \beta_m X_{mj} + u_j$$

where  $p_{ij}$  is the probability of the outcome for each individual  $i$  in cluster  $j$ ,  $\beta_0$  is the model intercept,  $\beta_{1-m}$  are the coefficients for each potential risk factor  $X_{1-m}$ , and  $u_j$  represents the random effects for cluster  $j$ .

We measured the fixed effects using an Odds Ratio (OR) and included the 95% confidence intervals. Independent categorical variables were screened for multicollinearity with a Cramér's V statistic. In case two variables showed signs of correlation ( $V > 0.7$ ), the variable least associated with the response variable was omitted (12).

For the secondary outcome measure, we used a linear regression model adjusted for clustering at the CU level. This model investigates the outcome of testing volume by the CHWs and includes potential CHW-level covariates like CHW age, years of experience/workload, number of households responsible, number with previous CHW experience, number of hours spent on community health, and training in malaria case management or RDTs.

The linear regression model is as shown below:

$$Y_{ij} = \beta_0 + \beta_1 X_{1j} + \dots + \beta_m X_{mj} + u_j + \epsilon_{ij}$$

where  $Y_{ij}$  is the outcome for each individual  $i$  in cluster  $j$ ,  $\beta_0$  is the model intercept,  $\beta_{1-m}$  are the coefficients for each potential risk factor  $X_{1-m}$ ,  $u_j$  represents the random effects for cluster  $j$ , and  $\epsilon_{ij}$  is the error term.

All statistical analysis was done in STATA version 15 (StataCorp).

## Results

A total of 292 CHWs in 16 Intervention CUs were trained to perform RDTs and 36 retail shops were enrolled to redeem vouchers. The intervention was launched on July 21, August 17, and September 22, 2015 in Bokoli, Kiminini, and Ndivisi sub-counties western Kenya, respectively and continued until May 5, 2017.

### *Demand for malaria diagnostic testing*

The community-based demand analysis relies on 1738 complete surveys from participants in randomly selected households in intervention clusters with an acute illness in the last four weeks (Table 1). Community members were interviewed at 12 or 18 months (47.2% and 52.8% respectively) following the initiation of the intervention. 55% (n = 948) of participants reported having a malaria test for their recent illness while 38.4% (n = 364/948) of those tested reported having had the test at CHW. Among all surveyed participants, 41% (n = 710) were male and 59% (n = 1028) were female. 21.2% (n = 368) of the recent fevers were aged < 5 years, 43.3% (n = 752) were 5–17 years while 36% (n = 618) were 18 > years. Only 21.4% (n = 371) of the participants had completed their secondary education while 45% (n = 778) had completed their primary education. On average, the distance to the nearest public health facility was approximately 2km while the nearest drug shop was approximately 1.3km away.

Table 1  
Characteristics of community survey participants

Variables (N = 1738)	Participant characteristics (N = 1738)	%
Tested	948	54.6
Tested at CHW	364/948	38.4
Patient is male	710	40.9
Patient age		
Under 5	368	21.1
5–17 y	752	43.3
18 + y	618	35.6
Education level of respondent		
Not completed primary	589	33.9
Completed primary	778	44.8
Completed secondary	371	21.3
Distance to nearest public health facility (mean, sd)	2.1(sd = 1.2)	1.9(1.1–2.9)
Distance to nearest drug shop	1.3(sd = 0.7)	1.3(0.7–1.7)
Survey timepoint		
12 months	821	47.2
18 months	917	52.8

We first examined demand-side factors that were correlated with uptake of malaria testing for their most recent illness (Table 2). Respondents who delayed seeking care beyond the first 24 hours had higher odds of receiving a test. Being aware of your local CHW increased the odds of having a test from any source, facility or CHW (Adj. OR = 1.50, 95% CI: 1.10–2.04). Respondents from the wealthiest households were 53% more likely to have a test (Adj. OR = 1.53 95%CI: 1.14–2.06). We however noted that being an adult at least 18 years old was negatively associated to taking a test (Adj. OR = 0.59, 95% CI:0.43–0.82). Distance to a health facility greater than 2km (Adj. OR = 0.86, 95% CI:0.67 – 0.11) and use of ITN (Adj. OR = 1.27, 95%CI:0.93–1.74) were not significantly correlated with testing uptake.

Table 2

Association between participant characteristics and having a malaria diagnostic test (either microscopy or RDT) from any source before taking any treatment.

Participant characteristics (N = 1738)	Univariate analysis		Multivariate analysis	
	Unadjusted Odds Ratio	P-value	Adjusted Odds Ratio (95%CI)	P-value
Time to seek care ( <i>Reference = same day</i> )				
Next day	<b>1.21[1.05,1.42]</b>	<b>0.01</b>	<b>1.23[1.06,1.43]</b>	<b>0.01</b>
After two days	1.01[0.78,1.32]	0.94	1.13[0.86,1.48]	0.38
More than two days	0.94[0.73,1.22]	0.66	1.12[0.87,1.44]	0.37
Use an ITN	1.37[0.99,1.92]	0.06	1.27[0.93,1.74]	0.13
Distance to public health facility > 2km	0.83[0.64,1.06]	0.14	0.86[0.67,1.11]	0.26
Aware of a CHW in their village	<b>1.43[1.01,2.05]</b>	<b>0.04</b>	<b>1.50[1.10,2.04]</b>	<b>0.01</b>
Patient age ( <i>Reference = 1-4y</i> )				
5 to 17y	0.76[0.54,1.08]	0.12	0.79[0.56,1.12]	0.18
18 + y	<b>0.59[0.43,0.81]</b>	<b>&lt; 0.01</b>	<b>0.59[0.43,0.82]</b>	<b>&lt; 0.01</b>
Patient is male	1.02[0.86,1.23]	0.78	0.94[0.80,1.10]	0.43
Respondent education level ( <i>Reference = none</i> )				
Completed primary	1.12[0.93,1.36]	0.23	1.08[0.87,1.33]	0.48
Completed secondary	<b>1.41[1.04,1.90]</b>	<b>0.03</b>	1.25[0.93,1.70]	0.14
Wealth quintile ( <i>reference = 0-20th</i> )				
20–40th	1.04[0.68,1.62]	0.83	1.02[0.65,1.59]	0.94
40–60th	1.14[0.86,1.50]	0.36	1.08[0.82,1.43]	0.59
60–80th	1.10[0.79,1.53]	0.56	1.03[0.73,1.46]	0.86
> 80th	<b>1.59[1.15,2.21]</b>	<b>&lt; 0.01</b>	<b>1.53[1.14,2.06]</b>	<b>&lt; 0.01</b>

We further focused our analysis on those who were tested for malaria by a CHW (Table 3). Out of 948 participants who reported having a test, 38.4% reported having taken a test from a CHW (364/948). We note that wealthier participants prefer being tested at the health facility (Adj. OR for testing at a CHW =

0.32, 95%CI:0.17–0.60), and those with education above secondary school have lower odds of taking a test at the CHW (Adj. OR = 0.68, 95%CI:0.44–1.07). Delaying testing beyond two days also reduced the odds of testing by a CHW. On the other hand, school-aged children between 5–17 years were more than twice as likely to be tested by a CHW compared to those below 5 years old (Adj. OR = 2.39, 95%CI: 1.43–4.01).

Table 3

Association between patient characteristics having a malaria rapid diagnostic test (mRDT) from a CHW before taking any treatment.

Participant Characteristics (took a test from CHW (n = 948))	Univariate analysis		Multivariate analysis	
	Unadjusted Odds Ratio	P-value	Adjusted Odds Ratio	p-value
Time to malaria test ( <i>Reference = same day</i> )			-	-
Next day	0.96[0.71,1.31]	0.80	0.96[0.69,1.33]	0.81
After two days	0.73[0.44,1.21]	0.22	0.68[0.42,1.10]	0.12
More than two days	0.81[0.49,1.34]	0.41	0.87[0.50,1.52]	0.62
Use an ITN	<b>0.57[0.41,0.78]</b>	<b>&lt; 0.01</b>	0.77[0.55,1.06]	0.11
Distance to public health facility > 2km	1.32[0.80,2.20]	0.28	1.29[0.82,2.03]	0.27
Patient age ( <i>Reference = 1-4y</i> )			-	-
5 to 17y	<b>2.43[1.49,3.95]</b>	<b>&lt; 0.01</b>	<b>2.39[1.43,4.01]</b>	<b>&lt; 0.01</b>
18 + y	0.98[0.67,1.43]	0.91	1.09[0.72,1.66]	0.68
Patient is male	1.23[0.98,1.54]	0.07	1.02[0.82,1.26]	0.85
Respondent education level ( <i>Reference = none</i> )			-	-
Completed primary	0.86[0.69,1.09]	0.22	0.96[0.75,1.22]	0.74
Completed secondary	<b>0.45[0.29,0.68]</b>	<b>&lt; 0.01</b>	<b>0.68[0.44,1.07]</b>	<b>0.10</b>
Wealth quintile ( <i>reference = 0-20th</i> )			-	-
20–40th	1.13[0.65,1.94]	0.671	1.11[0.63,1.96]	0.72
40–60th	0.83[0.63,1.09]	0.175	0.79[0.58,1.05]	0.11
60–80th	<b>0.67[0.47,0.96]</b>	<b>0.028</b>	<b>0.66[0.45,0.97]</b>	<b>0.03</b>
> 80th	<b>0.26[0.13,0.53]</b>	<b>&lt; 0.001</b>	<b>0.32[0.17,0.62]</b>	<b>&lt; 0.01</b>

We next focused on the final survey at 18 months to understand how individual perceptions about malaria testing and treatment, malaria risk, and illness severity affected uptake of testing or testing at a CHW (Table 4). After adjusting for demographic characteristics, patient perceptions were differentially related to testing overall and testing specifically with a CHW. Both confidence in AL treatment (Adj. OR = 2.75, 95% CI: .1.54–4.92) and confidence in the accuracy of an RDT performed by a CHW (Adj. OR = 2.43, 95% CI: 1.12–5.27) were strongly positively associated with testing at a CHW. Those who reported their illness as severe were more likely to be tested (Adj. OR = 2.37, 95% CI: 1.58–3.58 ) but had a lower odd of testing at a CHW (Adj. OR = 0.44, 95% CI: 0.22–0.87). Confidence in an RDT result, either positive or negative was not significantly correlated with receiving a test for a recent illness, but those who reported a high confidence in a negative RDT result had substantially higher odds of testing with a CHW than in a facility, although this did not reach statistical significance at the 95% level (Adj OR = 1.58, 95%CI: 0.89–2.83). Finally, those who reported that between 4–7 or 8–10 fevers of 10 had increasingly higher odds of receiving a test from a CHW (medium prevalence Adj. OR = 2.52, 95%CI: 1.26–5.06, high prevalence Adj. OR = 2.70, 95% CI: 1.17–6.22).

Table 4

Relationship between participant beliefs and perceptions and uptake of testing from any source or uptake of testing from a CHW. Models are adjusted for patient age, gender, household wealth quintile and the education level of the respondent in addition to the variables in the table.

Had a malaria test (N = 703)	Univariate analysis		Multivariate analysis	
	Odds Ratio	P-value	Odds Ratio	P-value
Confidence in a positive RDT result	1.02[0.67,1.54]	0.93	0.87[0.53,1.41]	0.57
Confidence in a negative RDT result	1.34[0.87,2.03]	0.19	1.24[0.72,2.14]	0.43
Confidence in AL treatment	1.27[0.94,1.71]	0.12	1.06[0.81,1.40]	0.63
Trust an RDT by a CHW as much as one at a facility	0.85[0.55,1.32]	0.48	<b>0.66[0.44,0.97]</b>	<b>0.03</b>
Illness is severe	<b>2.36[1.64,3.39]</b>	<b>&lt; 0.001</b>	<b>2.37[1.58,3.58]</b>	<b>&lt; 0.001</b>
Prevalence ( <i>Reference is low</i> )			-	-
Medium	1.51[0.89,2.57]	0.13	1.48[0.85,2.58]	0.16
High	1.12[0.70,1.80]	0.64	1.05[0.63,1.77]	0.85

Had a test with a CHW (N=428)	Univariate analysis		Multivariate analysis	
	Odds Ratio	P-value	Odds Ratio	P-value
Confidence in a positive RDT result	1.45[0.89,2.34]	0.13	1.04[0.64,1.71]	0.86
Confidence in a negative RDT result	1.61[0.99,2.64]	0.06	1.58[0.89,2.83]	0.12
Confidence in AL treatment	<b>2.67[1.52,4.70]</b>	<b>&lt;0.01</b>	<b>2.75[1.54,4.92]</b>	<b>&lt;0.01</b>
Trust an RDT by a CHW as much as one at a facility	<b>2.91[1.29,6.58]</b>	<b>0.01</b>	<b>2.43[1.12,5.27]</b>	<b>0.03</b>
Illness is severe	0.60[0.35,1.03]	0.06	<b>0.44[0.22,0.87]</b>	<b>0.01</b>
Prevalence ( <i>Reference is low</i> )			-	-
Medium	<b>2.87[1.48,5.56]</b>	<b>&lt;0.01</b>	<b>2.52[1.26,5.06]</b>	<b>0.01</b>
High	<b>2.85[1.31,6.23]</b>	<b>0.01</b>	<b>2.70[1.17,6.22]</b>	<b>0.02</b>

### *Supply of diagnostic testing by CHWs*

In total, 32,404 RDTs were conducted by the CHWs over the intervention period and 33.7% (n = 10,870) percent were positive. All RDT interpretations were counterchecked by the study team. Those with a positive test received a voucher for a discounted quality-assured ACT. These vouchers were redeemed at a participating outlet by 93.9% of voucher recipients. We had no instances of stock out of RDTs among our CHWs. We explored factors that may be associated with the CHWs ability to conduct RDTs. We examined the association between testing volume, defined as the mean number of RDTs conducted per month, and the different CHW demographic characteristics (Table 5). Of the 244 trained CHWs, 147 (60.3%) were above 40 years of age, 72 (29.5%) were male. There were 107 (43.8%) CHWs who had not completed secondary education.

Table 5  
Association between mean number of tests performed per month and CHW characteristics

Mean number of tests per month	4.60 (SD = 3.07)	Univariate Analysis		Multivariate Analysis	
		N = 244		N = 244	
CHW characteristics	N (sample proportion)	Coeff (95%CI)	P-value	Coeff (95%CI)	P-value
Male	72 (29.5)	-0.30[-1.28,0.68]	0.52	-0.28[-1.24,0.68]	0.54
Age (Ref = < 40 years)	97 (39.7)	-	-	-	-
> = 40 years	147 (60.3)	-0.21[-1.06,0.63]	0.60	-0.42[-1.12,0.28]	0.23
Married	202 (82.8)	0.37[-0.57,1.30]	0.42	0.22[-0.92,1.35]	0.69
Education (Ref = below secondary)	107 (43.8)	-	-	-	-
Completed Secondary	137 (56.2)	0.45[-0.33,1.23]	0.24	0.23[-0.40,0.87]	0.44
Formal Employment	33 (13.5)	<b>1.13[-0.01,2.28]</b>	<b>0.05</b>	<b>1.37[0.05,2.70]</b>	<b>0.04</b>
Previously trained in mRDT	46 (18.8)	-0.46[-1.64,0.72]	0.42	<b>-1.40[-2.44, -0.37]</b>	<b>0.01</b>
Households <sup>1</sup> (Ref < = 50)	134 (54.9)	-	-	-	-
50–100	66 (27.1)	<b>2.14[0.63,3.64]</b>	<b>&lt; 0.01</b>	<b>1.73[0.70,2.74]</b>	<b>&lt; 0.01</b>
> 100	44 (18.0)	1.18[-0.40,2.76]	0.13	<b>1.49[0.74,2.24]</b>	<b>&lt; 0.01</b>
Cluster-level test positivity <sup>2</sup> (Ref < = 25%)	141 (58.8)	-	-	-	-
High (> 25%)	103 (42.2)	<b>2.54[0.97,4.10]</b>	<b>&lt; 0.01</b>	<b>2.14[1.05,3.22]</b>	<b>&lt; 0.01</b>
<sup>1</sup> Number of households for which the CHW reported being responsible					
<sup>2</sup> Percentage of mRDTs conducted by the CHWs in that cluster which turned positive over the study period.					

In a univariate and multivariate analysis, formal employment, previous RDT training, number of households and RDT-positivity rate at the cluster-level were associated with volume of tests done. Sex, age, being married and education level were not significantly associated with testing volume. CHWs who were formally employed performed on average 1.37 more tests per month (95% CI: CI: 0.05–2.70) but

those who reported being trained previously on RDTs performed 1.4 fewer tests per month (95%CI: -2.44,-0.37). We also noted that CHWs serving areas with a high proportion of positive tests (proportion RDT + ve > 25%) tested on average 2 more clients per month than those in lower prevalence areas (Adj coefficient = 2.14, 95%CI: 0.63–3.64). CHWs who were responsible for at least 50 households tested more clients (Adj coeff = 1.73, 95%CI: 0.70,2.74), although this did not increase further with when the number of households exceeded 100 (Adj coeff = 1.49, 95%CI: 0.74–2.24).

We also did univariate and multivariate analyses to test the association between testing volume and CHW perceptions about their role at the midpoint survey (Table 6). High client score was significantly associated with higher testing volume performed by CHWs who perceived that their clients trusted their tests (Adj. coeff = 1.37, 95%CI: 0.11–2.62). The CHWs competency at conducting all 20 steps of the RDT process (RDT score), the number of different activities to which CHWs were committed, whether they named RDT testing as their most important activity, or whether they cited extrinsic motivation (money, airtime, or other) as important reasons for continuing their work were all not significantly correlated with average tests performed per month.

Table 6

Association between testing volume and CHW perceptions about their role at the midpoint survey. Multivariate odds ratios are adjusted for age, gender, education level, formal employment. The analysis includes a random sample of CHWs selected for midpoint evaluation.

	N = 70	Univariate Analysis		Multivariate Analysis <sup>1</sup>	
		Characteristics	Coeff (95%CI)	P-value	Coeff (95%CI)
RDT Score <sup>2</sup> (Ref = Low)	-	-	-	-	-
High	54/70 (77.1)	0.19[-1.25,1.64]	0.78	0.11[-1.34,1.57]	0.87
Number of different activities last month (Ref= <=3)	-	-	-	-	-
> 3 activities	19/70 (27.1)	0.35[-1.56,2.26]	0.70	-0.45[-2.04,1.15]	0.56
Most important activity is malaria testing	48/70 (68.6)	0.88[-0.25,2.01]	0.12	0.07[-1.16,1.32]	0.90
Cited extrinsic motivators as important <sup>3</sup>	28/70 (40.0)	0.33[-1.52,2.17]	0.71	0.67[-0.92,2.25]	0.38
Client Score <sup>4</sup> (Ref = Low)	-	-	-	-	-
High	48/70 (68.6)	<b>1.46[0.10,2.83]</b>	<b>0.04</b>	<b>1.37[0.11,2.62]</b>	<b>0.04</b>
Years of experience as a CHW (Ref: <=5y)	-	-	-	-	-
> 5 years	38/70 (54.3)	-0.35[-2.68,1.98]	0.75	-0.51[-2.56,1.55]	0.61
<sup>1</sup> Multivariable models are also adjusted for CHW demographic factors (age, gender, education, employment, and cluster-level prevalence)					
<sup>2</sup> RDT score - CHW scored > 17 correct steps on a 20-step checklist for RDT preparation and interpretation conducted 6 months after training					
<sup>3</sup> CHW cited money, non-monetary incentives or desire for recognition as important motivators for their role as a CHW					
<sup>4</sup> Client score was derived from four questions where the CHW reported how confident clients were in the testing they provided.					

## Discussion

This study demonstrated that it is feasible for CHWs to offer malaria testing using RDTs in the community. With the use of CHWs, large-scale malaria testing intervention can reach the underserved population who cannot afford to visit the health facilities for care and those who seek care in the retail

sector. The existence of CHWs with the ability to test for malaria using RDT provides a great opportunity, however, various factors may affect the demand and supply of testing using RDT by CHWs.

Here we examine the outcomes of a community-based diagnostic intervention to understand how to improve intervention design and maximize the impact of such programs. We organized the analysis around the target group (community members) and their uptake or demand for the diagnostic testing intervention, and the supply of testing by the CHWs responsible for delivering the intervention. We were able to separate the determinants of uptake of malaria diagnostic testing generally from the determinants of uptake of RDTs performed by a CHW. These contrasting but complementary analyses helped us identify bottlenecks to intervention coverage at the community level.

Analysis of community survey data revealed that increased demand for malaria diagnostic testing before treating a fever is positively correlated to education level and wealth, but lower among adults, findings which are consistent with other published studies (13–16). We also find that being aware of the local CHW increased demand for testing. This is similar to other studies that have evaluated the contribution of CHWs to population health-seeking behavior(15, 17). In the context of our program, this is especially important because the testing was initiated by the community member seeking out a CHW rather than a door-to-door campaign initiated by the CHW. Malaria testing by a CHW provides an opportunity for reducing health disparities by ensuring the poor and underserved population get access to testing and are able to make an informed choice on how to manage their illness. Our results show that community members with a lower socioeconomic score were more likely to receive a test from a CHW. Malaria testing by the CHW was free and this finding therefore aligns well with the intention of the intervention. Testing by a CHW was also more common among those with high confidence in the reliability of a test done by a CHW and also among those with high confidence in artemether-lumefantrine, the treatment offered through the CHW testing program. Taken together, these results suggest that the community awareness of and perception of the CHW is key in improving demand. In contrast, although testing was high among those who considered their illness to be very severe, these individuals were less likely to be tested by a CHW. This result is appropriate and consistent with the goals of the program which included immediate referral of more severe cases.

From the perspective of the providers responsible for delivering the intervention, we did not observe a strong correlation between demographic characteristics and testing volume, but we did note that CHWs with concurrent formal employment tested more patients on average than those without which could indicate greater visibility or mobility in the community. We also observed that the monthly testing volume increased when the number of households under a CHWs purview exceeded 50, but did not increase further when households exceeded 100, suggesting a threshold effect whereby more households created more demand for testing but the ability to meet the demand is saturated after some threshold beyond 100 households. Finally, we report that testing rates were higher in clusters with high RDT-positivity rates, possible reflecting a greater awareness of malarial illness or higher demand for malaria services in areas with higher malaria burden. This could also reflect higher confidence in a test among CHWs or

communities members who have experience with some tests turning positive as has been seen in the healthcare setting (18).

A deeper analysis of CHW perception of the intervention was undertaken in a smaller random sample of participating CHWs. We showed that testing volume is not affected by competing CHW-related priorities, but is positively correlated with how they perceive their clients' confidence in testing and the likelihood of the client accepting the RDT result and advice. This aligns well with the picture from the demand-side where we observe that confidence in an RDT performed by a CHW is strongly correlated to testing with a CHW.

This study had several limitations. First, we are not able to estimate the effect of free testing on the uptake of testing. Considering the study utilized diagnosis dependent subsidies to test the rational use of ACT, a similar study that deploys free testing in the absence of a conditional voucher would be required to resolve this. Second, Although the 12th and 18th -month data could provide some insight on understanding drivers to demand and supply of Malaria testing, seeking provider (CHW) and patient perspective would provide a better understanding of what to guard against when rolling out such an intervention. Finally, though our survey design used repeated cross-sectional sampling, it is possible that the same household and/or febrile individual was surveyed at multiple survey time points and any resulting correlation was not explicitly modeled in our regression analysis.

## Conclusion

In summary, scale up of health interventions through CHWs is feasible and effective at reaching the poorest households. However, in order to to maximize the impact of community-based interventions, it is important to recognize factors that may restrict both delivery and demand for such services. It is critical to not only create awareness of CHW services but foster trust in both the CHWs ability to deliver services and the health intervention itself. Engendering confidence in the CHWs proficiency is likely to have a synergistic effect on both demand for services and commitment to delivering services.

## List Of Abbreviations

ACT, CHEW HIV, CHWs, CUs, GPS, MOH, RDTs, WHO

## Declarations

### **Ethics approval and consent to participate:**

Ethical approval was granted by Moi University Institutional Research and Ethics Committee (*Formal Approval No. 0001403*) and Duke University Institutional Review Board (*Pro00063384*). Written consent was obtained from participants during household interviews and from CHWs prior to collecting midpoint evaluation data. All study methods were carried out in accordance with ethical guidelines and regulations set out by both Moi University and Duke Ethical Review Boards.

**Consent to publish:**

Not applicable

**Availability of data and materials:**

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

**Competing interests:**

The authors declare that they have no competing interests

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