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# Evaluation of host biomarkers to support the development of a point-of-care diagnostic test to guide antibiotic use in bacterial/non-bacterial acute febrile illness cases



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# Evaluation of host biomarkers to support the development of a point-of-care diagnostic test to guide antibiotic use in bacterial/non-bacterial acute febrile illness cases

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# ABSTRACT

## Background

Globally, acute febrile illness (AFI) is one of the main reasons individuals present to primary healthcare facilities, particularly children. Differentiating bacterial from non-bacterial AFI is often difficult, in case of doubt, it is unsurprising that healthcare providers prescribe antibiotics to avoid negative outcomes in their patients which leads to an increase in the spread of antimicrobial resistance. Host biomarkers have the potential to inform the aetiology of AFI, but which biomarkers are most appropriate in resource-limited settings remains unclear, and also if its possible to utilize markers in the same way in different global settings.

## Methods

We conducted the Biomarker for Fever Diagnostic (BFF-Dx) study to evaluate 18 different host biomarkers, in a prospective study of 1915 patients with non-severe AFI in Brazil (n=500), Malawi (n=1000), and Gabon (n=415) using a standardized approach. Bacterial and non-bacterial classifications were made based on a 2-step process using laboratory testing and a clinical panel.

## Findings

The most widely known biomarkers, hematology biomarkers and C-reactive protein (CRP), remain the best-performing in this non-severely ill population with area under the receiver operating characteristic (AUROCs) of 0·8 (white blood cell count) or 0·71 (CRP) in the best cases. None of the evaluated novel host biomarkers exhibited high performances in distinguishing bacterial from non-bacterial infections in any of the settings (AUROC<0·70 in most cases) and variation across locations was observed.

## Interpretation

There is a continued need for innovation in the host-biomarker space as the available markers do not meet the needs of diverse populations around the globe. This highlights the importance

of targeted evaluations in non-severe patients in multiple settings to understand true potentials for real-life use. The findings highlight that not one-marker fits all settings and novel innovations remain urgently needed.

**Keywords**

Antimicrobial Resistance, AMR, CRP, Host Biomarkers, Prospective study, biomarker, non-malaria fever, primary health care, Malawi, Brazil, Gabon

## INTRODUCTION

Globally, acute febrile illness (AFI) is one of the leading reasons individuals, particularly children aged less than 5 years, present to primary healthcare facilities [1]. AFI has various causes, both infectious and non-infectious, that vary according to geography, age group, and season [1]. In malaria-endemic settings, malaria was long considered the primary cause of all fevers; however, the introduction of rapid diagnostic tests (RDTs) for malaria in the past decade has disproved this. Modelling estimates suggest that approximately 70% of all fevers can be attributed to non-malarial causes, even in malaria-endemic settings [2]. In the Integrated Management of Childhood Illness (IMCI), introduced by the World Health Organization (WHO) and UNICEF in the mid-1990s and subsequently implemented in more than 100 countries, the standard "fever" algorithm currently includes a malaria RDT but no diagnostic test for other infections [3]. Hence, at primary care level, the only evidence-based treatment decision that can be made relies on the malaria RDT, resulting in extremely high levels of antibiotic use in malaria-negative patients [4]. In this context of limited knowledge about the causes of AFI and limited diagnostic and human capacity, it is unsurprising that healthcare providers prescribe antibiotics to avoid negative outcomes in their patients.

To assist healthcare providers with clinical decision-making, a simple diagnostic tool is required to differentiate patients with AFI of bacterial and non-bacterial aetiology and provide appropriate care. In well-resourced settings, in both high-income countries (HICs) and low- and middle-income countries (LMICs), some nonspecific host-biomarkers are used for this purpose, most frequently C-reactive protein (CRP) and procalcitonin (PCT), although these biomarkers are less useful in settings with a higher frequency of comorbidities [5]. Thus, in 2015, an international group of experts was convened to define the target product profile (TPP) of such a tool, specifically for low-resource settings, to guide product development and implementation as part of integrated treatment management guidelines [6]. Since then, the

ongoing viral pandemic (SARS-CoV-2) has further highlighted the challenge of differential diagnosis and shows yet again that better antimicrobial stewardship interventions are needed to counter the overprescribing of antibiotics in patients with viral infections [7].

Host biomarkers other than CRP and PCT have been evaluated for distinguishing bacterial from non-bacterial infections, including human neutrophil lipocalin (HNL), heparin-binding protein (HBP), and chitinase 3-like protein 1 (CHI3L1) [8]. There are also some commercially available tests. ImmunoXpert™, from MeMed, uses a biomarker combination comprising CRP, interferon gamma-inducible protein 10 (IP-10), and TNF-related apoptosis-inducing ligand (TRAIL), while FebriDx®, from Lumos Diagnostics, uses an MxA and CRP biomarker combination. While these biomarker signatures show promise, they have only been evaluated in limited settings. Any potential impact of co-infections or comorbidities, common in LMICs, on their effectiveness is unknown. Other characteristics of host-biomarker studies that hamper direct comparisons include: (i) just one/a few biomarkers in the study; (ii) small sample sizes, increasing the probability of recruiting unrepresentative study populations; (iii) narrow population subgroups (e.g. children only, hospitalised only, respiratory infections only, etc), limiting the generalisability of study results to the broader AFI population; (iv) studies conducted in one country, so co-infections/comorbidities may not be comparable with those of other countries; (v) retrospective studies that used convenience sampling and case-control study designs, increasing the risk of bias; and (vi) the lack of a standard definitions for classifying bacterial versus non-bacterial infections [9].

Here, we describe the Biomarker for Fever Diagnostic (BFF-Dx) study, specifically designed to evaluate host biomarkers to distinguish bacterial from non-bacterial infections in line with the published TPP and the final use case of such diagnostic tests. To our knowledge, this is the largest study to have evaluated host biomarkers in the intended target population from the intended use setting. We prospectively evaluated 18 host-biomarkers in three distinct settings,

in Brazil, Gabon, and Malawi with the main objective to provide a performance comparison of host biomarkers in the non-severe AFI population from resource-limited settings [10]. The described comparison was conducted within the pragmatic context of diagnostic product development and aimed to identify host biomarkers or biomarker combinations for utilization in next-generation rapid diagnostic tests.

# METHODOLOGY

## Study settings

This multinational, cross-sectional study was conducted in Brazil, Gabon, and Malawi; Gabon and Malawi were selected as high-malaria endemicity settings, while Brazil was selected as a low-malaria endemic setting. The study sites were UPA Manguinhos and Family Health Clinics Armando Palhares in Rio de Janeiro, Brazil; the Clinical Trials Unit Center of Medical Research Lambaréné (CERMEL), Lambaréné, Gabon; and Malawi Epidemiology and Intervention Research Unit (MEIRU), Chilumba campus, Malawi. The enrolment sites were an urban primary healthcare facility, a hospital in a semi-rural setting, and a rural primary healthcare facility in Brazil, Gabon, and Malawi, respectively. Participants were recruited from October 2018 to July 2019, May to November 2019, and April 2017 to April 2018, in Brazil, Gabon, and Malawi, respectively. The study protocol was submitted to clinicaltrial.gov (NCT03047642) and ethical approval was obtained from all relevant institutional committees in Brazil, Gabon and Malawi and all details of the design have been previously published [10]. Reporting complies with the STARD-15 checklist.

## Study population and study procedure

Participants were obtained through convenience sampling and included both children and adults, aged between 1 and 65 years, who presented at the outpatient clinics with a history of fever of ≤7 days duration (Brazil and Gabon) or fever at presentation (Malawi). Patients with signs of severe illness were not included in the study. The overarching study protocol was slightly adapted to each site due to local requirements (logistical or ethical). Detailed criteria for inclusion by study sites have been published previously [10]. Outcomes were based on the TPP criteria and while no patient input was used, external expert input was used to define target population and criteria. Only patients who met the eligibility criteria and who provided written

consent (patient or guardian for children) were enrolled in the study. Data and samples were systematically collected and analysed as previously described. To ensure consistent quality and comparability of data testing was performed using the same standard operating procedures at all sites or were performed after shipment to one reference lab [10].

**Bacterial/non-bacterial classification and biomarker selection and testing**

A two-step process was used to classify the patients into "bacterial" and "non-bacterial" groups. Briefly, the cause of fever (bacterial/non-bacterial) was first classified according to laboratory-determined parameters ("electronic group"). Next, cases that could not be classified by laboratory-determined parameters were assessed by a panel of three independent clinical experts. These assessments, which were based on a patient's history and clinical and laboratory data, were then compared. If the three panel members unanimously assigned a diagnostic label, patients were considered to have "bacterial" or "non-bacterial" infections; if two out of three panel members reported a classification of "bacterial" or "non-bacterial", these patients were considered to have "probable bacterial infection" or "probable non-bacterial infection", respectively.

Data were analysed based on three groups of patients: 1) the "electronic group", i.e. subjects with a cause of fever defined based on laboratory parameters; 2) the "strict group", which comprised the electronic group and the patients that were unanimously classified by the clinical panel of three experts; and 3) the "loose group", which comprised the electronic and strict groups as well as those patients for whom two of the clinical experts agreed they had either probable bacterial or probable non-bacterial infection. Subjects with undetermined cause of fever according to the three classification criteria considered ("electronic group", "strict group", "loose group") were excluded from the statistical analysis. This outcome-oriented

approach, based on methods previously developed for host-biomarker studies and described previously, was used to ensure the total intended-use population of any future test was represented in the final analysis [10, 11].

The evaluated biomarkers were selected based on previously reported performances, and haematological markers as well as CRP were included as comparators (Table 1 and Supplementary Table 1) [8, 12].

At the end of data collection, all biomarker data were analysed to assess the percentage of missing values and the percentage of values below the lower limit or above the upper limit of detection of the used tests. Biomarkers with more than 50% of missing data or more than 95% of saturated values below the lower limit of quantification of the used test, were excluded from the following statistical analysis.

**Table 1**. Novel biomarkers identified in the literature and evaluated in the BFF-Dx study, including sample type used, evaluation method, and sample origin.

| Abbreviation | Biomarker name | Sample type | Evaluation method | Sample origin |
|---|---|---|---|---|
| AGP | A-1-acid glycoprotein | EDTA-plasma | Luminex | B, G, M |
| C2 | Complement 2 | EDTA-plasma | Luminex | B, G, M |
| C4b | Complement C4b | EDTA-plasma | Luminex | B, G, M |
| CHI3L1 | Chitinase-3-like protein 1 | EDTA-plasma | Luminex | B, G, M |
| CRP | C-reactive protein | EDTA-plasma | CRP Nycocard/ NycoCardReader II, ELISA | B, G, M |
| Gal-9 | Galectin-9 | EDTA-plasma | Luminex | B, G, M |
| HBP | Heparin-binding protein | EDTA-plasma | ELISA | B, M |
| HNL | Human neutrophil lipocalin | Heparin-activated plasma time-controlled activation# | ELISA | M |
| | | EDTA-plasma | ELISA | B, G, M |
| HP | Haptoglobin | EDTA-plasma | Luminex | B, G, M |
| IFN-gamma | Interferon gamma | EDTA-plasma | Luminex | B, G, M |
| IL-4 | Interleukin-4 | EDTA-plasma | Luminex | B, G, M |
| IL-6 | Interleukin-6 | EDTA-plasma | Luminex | B, G, M |
| IP-10 | Gamma-induced protein 10 | EDTA-plasma | Luminex | B, G, M |
| LBP | Lipopolysaccharide binding protein | EDTA-plasma | Luminex | B, G, M |
| NGAL | Neutrophil gelatinase-associated lipocalin | Frozen heparin-activated plasma | Luminex | M |
| | | EDTA-plasma | Luminex | B, G, M |
| PCT | Procalcitonin | EDTA-plasma | Luminex; ELISA | B, G, M |
| sPLA2 | Secretory phospholipase 2 | EDTA-plasma | Luminex | B, G, M |
| sTREM-1 | Soluble triggering receptor expressed on myeloid cells 1 | EDTA-plasma | Luminex | B, G, M |
| TRAIL | TNF-related apoptosis-inducing ligand | EDTA-plasma | Luminex | B, G, M |

B, Brazil; G, Gabon; M, Malawi

# Whole blood samples were collected in lithium heparin tubes and activation was performed within 60 min prior to freezing and subsequent ELISA testing [13]. All biomarkers were tested using the same standard operating procedures (SOPs) and all sites were trained on the SOPSs. For CRP and PCT different devices were used at different sites, repeat testing was performed at the central facility (NMI).

## Statistical analysis

a. Kruskal-Wallis Analysis and Definition of Covariates Influence on Biomarkers

A Kruskal-Wallis test, adjusted by Benjamini-Hochberg, was performed for each biomarker to identify which covariates significantly affect the biomarker value. The covariates studied were country (i.e., the country of origin of the patients), age, sex, malaria status, comorbidities (i.e., presence of one or more diseases among cardiovascular, neurological, respiratory, renal, genitourinary, connective tissue, cancer, or infectious diseases), malnutrition status calculated based on WHO body mass index criteria, self-reported use of antibiotics prior to visiting the health facility, axillary temperature ≥38°C, and positive result to Chikungunya test. The Kruskal-Wallis test was performed for each of the three patient groups defined in the previous section ("electronic", "strict", "loose"). The results of the Kruskal-Wallis test allowed the identification of covariates that most significantly impacted the biomarker distribution ($p<0.001$, adjusted by Benjamini-Hochberg). The most significant covariates were considered for defining subgroups of patients in which the following univariate analyses were performed, or included as covariates in the multivariate analyses.

a. Univariate analysis

As exploratory step, it was studied the ability of each biomarker to discriminate between bacterial and non-bacterial infections was assessed by the area under the receiver operating characteristic curve (AUROC). In particular, subjects were ranked based on the values of the single variable of interest (i.e. based on ordered values) and, using this as score, calculated the ROC curve and the corresponding area under the curve. Such univariate analysis was conducted for each patient group ("electronic", "strict", "loose") and specific patient subgroup (Malaria status, Country and Age).

b. Multivariate analysis

Multivariate classification models were developed to assess the discrimination ability of combinations of biomarkers and covariates. For the multivariate analysis, both linear (logistic regression) and non-linear classification models (RuleFit) were explored [14]. The candidate features for each model included a group of host-biomarkers and some additional covariates (age, temperature, fever duration, diastolic blood pressure, respiration rate, and pulse rate). Regarding host-biomarkers, three different groups of biomarkers were considered: haematology biomarkers only (i.e. white blood cell, neutrophil, red blood cell, lymphocyte counts), protein biomarkers only (i.e. novel biomarkers + CRP), and haematology plus protein biomarkers (i.e. all biomarkers).

For each patient subgroup and each candidate feature set, three multivariate models were developed: i) a logistic regression model with stepwise (SW) feature selection; ii) a logistic regression model with features selected based on recursive feature addition (RFA; a variant of the method proposed in [15]); iii) RuleFit, a non-linear model in which a set of rules from an ensemble of decision trees (typically from a tree-based model like a Random Forest or Gradient Boosted Trees) is generated and then fit a sparse linear regression model (regularized with LASSO), where the features are the rules generated from the trees [14, 15]. To further tackle the number of biomarkers and variables included in the best models, we introduced an additional selection step, employing a plateau seeking approach. The primary objective of this approach was to pinpoint a concise set of variables capable of attaining an AUROC score similar to that of our comprehensive model, which already incorporated the most impactful and previously selected variables. This was to ensure that our model is not only effective in terms of performance but also efficient in its variable inclusion.

Each model was trained and tested using the following pipeline. The data were randomly split into training and test sets (80% and 20% of the data, respectively) stratifying by the outcome variable. Missing data in the training and test sets were imputed using the MICE (multiple

imputation by chained equation) algorithm. The n_imp parameter for MICE imputation was set to 1, resulting in a single imputed dataset; however, the imputation process was integrated in a robust bootstrapping pipeline, generating ten independent datasets. This approach ensured variability in our results, stemming not only from the MICE imputation but also from the bootstrapping process. This dual approach guarantees that each imputed dataset is distinct [16]. All quantitative variables were scaled into the range [0,1] by subtracting their minimum value and dividing by the difference between the maximum and minimum values in the training set. The categorical variables with n categories were encoded using n-1 binary "dummy" variables. The model was then trained on the imputed and scaled training set, and its performance was assessed on the imputed and scaled test set by computing the AUROC. The AUROC on the test set was also calculated for single host biomarkers, to allow a fair comparison of the performance of the multivariate classification models vs. single host biomarkers.

To assess the robustness and variability in the results of the developed models, the entire pipeline were bootstrapped, i.e. it was run ten times with different random training-test set splits. Finally, the mean and the standard deviation (SD) or the minimum and maximum reached of the AUROC across the ten training-test splits were calculated for each multivariate model and each single host biomarker.

c. Software

All statistical analyses and model development were performed using the R programming language (version 4.1.2). Specifically, the *mice* package was used for data imputation, while the *pre* and *stats* packages were used for RuleFit and logistic regression model development, respectively.

**Role of the funding source**

The funding organisations had no role in the study design, data collection, analysis and interpretation of data. Further they had no role in writing of the report or decision to submit for publication.

# RESULTS

## Study population

In total, 1915 patients with AFI were included in the study (Brazil: n=500; Gabon: n=415; Malawi: n=1000). Just under half (862/1915, 45%) of participants at each study site were male. Children aged <5 years comprised 45/500 (9%), 182/415 (43·9%), and 367/1000 (36·7%) participants in Brazil, Gabon, and Malawi, respectively; the median (range) age was 3 (2–4) years (Table 2). Detailed baseline characteristics of patients and analyses of differences will be described in a separate manuscript (Alabi et al in preparation).

**Table 2: Baseline characteristics of patients.**

| | Brazil | Gabon | Malawi | All |
|---|---|---|---|---|
| 0–5 years (median, IQR, n) | 3, [2-4], 45 | 3, [2-5],182 | 3, [2-4], 367 | 3, [2-4], 594 |
| 5–15 years (median, IQR, n) | 11, [8-14], 85 | 9, [7-12], 214 | 9 [7-12], 276 | 9, [7-12], 575 |
| >15 years (median, IQR, n) | 34, [24-45], 370 | 16, [16-16·5], 19 | 28, [21-38], 357 | 30, [21-42], 746 |
| Male (%, n) | 49·6%, 248 | 45·1%, 187 | 42·7%, 427 | 45·0%, 862 |
| Temperature, °C (median, IQR, n) | 37·7, [36·7-38·4], 500 | 36·8, [36·4-37·4], 415 | 38·1, [37·1-38·8], 999 | 37·8, [37·3-38·5], 1914 |
| WBC count, $10^9$/L (median, IQR, n) | 7·28, [5·47-10·39], 494 | 7·7, [5·7-10], 411 | 6·7, [5·1-9·1], 985 | 7·1, [5·3-9·8], 1890 |
| Neutrophil count, $10^9$/L (median, IQR, n) | 4·97, [3·63-7·4], 494 | 2·77, [1.96-3·9], 408 | 4·3, [3·1-6·8], 906 | 4·1, [2·8-6], 1812 |
| RBC count, $10^9$/L (median, IQR, n) | 40·1, [36·5-43·2], 494 | 33·2, [29·4-35·8], 412 | 36·2, [33·1-39·5], 984 | 36·3, [33-40·2], 1892 |
| Lymphocyte count, $10^9$/L (median, IQR, n) | 1·15, [0·7-1·99], 493 | 2·73, [1·8-4·16], 411 | 1·5, [1·1-2·2], 982 | 1·63, [1-2.6], 1883 |
| CRP NycoCard# – mg/L (median, IQR, n) | 70·5, [35-98·75], 498 | 28, [5-73], 415 | 47, [12-106·5], 987 | 49, [13-98], 1900 |
| Malaria-positive by RDT on-site (% all, n) | 0·2%, 1 | 56·4%, 234 | 45·9%, 458 | 36·2%,693 |
| Malaria-positive by qPCR or microscopy (% all, n) | - | - | 50·5%, 505 | - |
| HIV-positive by RDT (% all, n) | 1·4%, 7 | 1·2%, 5 | 4·2%, 42 | 2·8%,54 |
| History of antibiotic-use pre-presentation (% all, n) | 8·8%, 44 | 2·41%, 10 | 7·2%, 71 | 6·5%,124 |
| History of antipyretic-use pre-presentation (% all, n) | 83·2%, 416 | 79·76%, 331 | 55·1%, 551 | 62·2%,1298 |

# NycoCard was found to be equivalent to reference testing in the relevant range (Supplementary Figure 1). CRP, C-reactive protein; IQR, interquartile range; qPCR, quantitative PCR; RBC, red blood cell; RDT, rapid diagnostic test; WBC, white blood cell; -: data not availabl

**Bacterial and non-bacterial outcomes by classification groups**

Using the electronic classification grouping, 15·1% (290/1915) of cases were bacterial infections, 20·2% (387/1915) were non-bacterial infections, and 64.5% (1238/1915) had an undetermined cause of fever (Figure 1). Under the strict classification grouping, 24·3% (366/1509), 66.9% (1010/1509), and 9·0% (133/1509) were classified as bacterial, non-bacterial, and undetermined infections, respectively, while using the loose classification grouping 25·7% (491/1915), 67·3% (1286/1915), and 7·0% (133/1915) were classified as bacterial, non-bacterial, and undetermined infections, respectively (Figure 1). Subjects with undetermined cause of fever/infections were excluded from the following univariate and multivariate analyses.

**Exclusion of biomarkers with too many missing or saturated values**

The biomarkers C4b, HNL and PCT had more than 50% missing values and were therefore excluded. The high number of missing values is due to fact that biomarkers were analysed in groups based on the required dilution using Luminex platform. For some biomarkers the dilution was not optimal, and it was only possible to re-measure biomarkers with a different dilution a limited number of times. IFN-gamma and sTREM-1 were excluded due to more than 95% of values saturated to the minimum/maximum level detectable by the measurement instrument. All the biomarkers retained in the analysis had less than 12% missing values (Supplementary Table 3).

**Identification of relevant subgroups for analyses**

According to the Kruskal-Wallis analysis on the "electronic group", the variables "country", "malaria status" and "age" had a strong ($p<0{\cdot}001$) or high ($0{\cdot}001<p<0{\cdot}01$) effect on many of the host biomarkers (Supplementary Table 4). The variables "sex", "comorbidities", "history of antibiotic use" showed no ($p>0{\cdot}05$) or slight ($p<0{\cdot}05$) associations with all the host biomarkers. The effects of "chikungunya status" and "fever above 38°C" were generally significant ($p<0.01$), but the sample sizes for these groups were either too small or exhibited an imbalance. Primarily centered on populations grouped by study country and malaria status variables - both of which were strongly associated with the biomarker value in the "strict" and "loose" groups (Supplementary Table 5, 6) - other significant covariates were also included in the multivariate analysis. This inclusion was due to their influence, and factors like the study country were considered as variables in the overall scenario.

**Individual host-biomarker performance – univariate analysis**

The performance of 18 host biomarkers was consistent across the three patient classification groups in each of the settings (Table 3). White blood cell (WBC) and neutrophil counts were the most effective biomarkers for differentiating bacterial and non-bacterial infections. For the malaria-negative population, the mean (95% confidence interval) of AUROC for WBCs was between 0·60 (0·48–0·72) and 0·83 (0·77–0·88) and for neutrophils it was between 0·67 (0·57–0·77) and 0·80 (0·74–0·86) across the three countries and the three groups ("electronic", "strict", "loose"). Neutrophil and WBC counts showed the highest AUROCs in the Brazilian population, between 0·80 (0·74–0·86) and 0·83 (0·77–0·88), respectively. All protein biomarkers showed relatively poor performances (<0·7 in most cases, Table 4) in all three settings. Galactin-9, CRP, IP-10, and NGAL were the best-performing protein biomarkers across the three settings and criteria. Protein biomarkers showed better performances in Malawi

and Gabon, as in Brazil most protein biomarkers showed performances of <0·6. When the biomarker results were stratified by age, the AUROCs were slightly higher for children (≤15 years) compared with those seen for adults in the malaria-negative population (Supplementary Tables 9-11). Among the malaria-positive population, WBC, lymphocyte, and neutrophil counts were the best-performing biomarkers in both Gabon and Malawi (in most cases between 0·6 and 0·7).

**Table 3: Univariate analysis of 18 individual biomarkers[#] among malaria-negative patients.** Common biomarkers such as CRP and haematological biomarkers were included for reference. In this context we defined performance as follows: green (AUROC ≥0·7), yellow (AUROC > 0·65 and <0.7), orange (AUROC 0·5–0·65), and red (AUROC <0·6).

| | Brazil AUROC** (CI), N | | | Gabon AUROC** (CI), N | | | Malawi AUROC** (CI), N | | |
|---|---|---|---|---|---|---|---|---|---|
| | Electronic | Strict | Loose | Electronic | Strict | Loose | Electronic | Strict | Loose |
| **Haematological biomarkers** | | | | | | | | | |
| **Lymphocyte count** | 0·67 (0·59-0·74), 257 | 0·66 (0·59-0·72), 408 | 0·66 (0·6-0·72), 442 | 0·58 (0·45-0·71), 81 | 0·52 (0·4-0·63), 167 | 0·55 (0·45-0·65), 222 | 0·66 (0·57-0·74), 254 | 0·51 (0·45-0·58), 303 | 0·52 (0·47-0·58), 461 |
| **Neutrophil count** | 0·77 (0·7-0·84), 257 | 0·8 (0·74-0·86), 408 | 0·79 (0·73-0·84), 442 | 0·78 (0·66-0·89), 80 | 0·72 (0·62-0·83), 165 | 0·67 (0·57-0·77), 219 | 0·77 (0·58-0·93), 243 | 0·73 (0·67-0·79), 273 | 0·7 (0·65-0·76), 414 |
| **RBC count** | 0·61 (0·52-0·69), 258 | 0·58 (0·51-0·65), 408 | 0·58 (0·51-0·64), 442 | 0·55 (0·41-0·68), 81 | 0·52 (0·41-0·63), 167 | 0·53 (0·43-0·63), 222 | 0·66 (0·46-0·86), 255 | 0·53 (0·46-0·59), 305 | 0·56 (0·5-0·61), 463 |
| **WBC count** | 0·81 (0·75-0·87), 257 | 0·83 (0·77-0·88), 408 | 0·82 (0·77-0·87), 442 | 0·67 (0·54-0·79), 81 | 0·6 (0·48-0·72), 167 | 0·61 (0·5-0·71), 222 | 0·88 (0·76-0·98), 255 | 0·72 (0·66-0·78), 304 | 0·68 (0·63-0·73), 461 |
| **Protein biomarkers** | | | | | | | | | |
| **AGP** | 0·59 (0·51-0·68), 252 | 0·54 (0·47-0·61), 402 | 0·52 (0·46-0·59), 434 | 0·77 (0·65-0·9), 80 | 0·7 (0·59-0·82), 163 | 0·65 (0·55-0·75), 220 | 0·86 (0·76-0·96), 258 | 0·54 (0·48-0·6), 309 | 0·54 (0·49-0·59), 466 |
| **Chitinase 3-like 1** | 0·58 (0·5-0·66), 246 | 0·54 (0·47-0·6), 394 | 0·55 (0·49-0·61), 424 | 0·6 (0·46-0·74), 79 | 0·6 (0·48-0·72), 162 | 0·62 (0·52-0·72), 217 | 0·89 (0·79-0·99), 255 | 0·5 (0·43-0·56), 304 | 0·5 (0·44-0·55), 462 |
| **CRP*** | 0·61 (0·52-0·69), 259 | 0·61 (0·54-0·68), 412 | 0·62 (0·55-0·68), 446 | 0·71 (0·59-0·82), 81 | 0·65 (0·55-0·75), 167 | 0·63 (0·53-0·72), 224 | 0·85 (0·75-0·95), 256 | 0·6 (0·54-0·67), 305 | 0·58 (0·53-0·63), 462 |
| **IP-10/IP-10/CRG-2** | 0·6 (0·52-0·68), 252 | 0·53 (0·46-0·59), 402 | 0·53 (0·47-0·59), 434 | 0·6 (0·48-0·73), 80 | 0·51 (0·4-0·62), 164 | 0·52 (0·43-0·62), 221 | 0·86 (0·76-0·95), 258 | 0·6 (0·53-0·66), 309 | 0·61 (0·56-0·66), 466 |
| **Galectin-9** | 0·63 (0·55-0·71), 252 | 0·56 (0·49-0·63), 401 | 0·57 (0·5-0·63), 433 | 0·7 (0·58-0·83), 80 | 0·6 (0·48-0·71), 163 | 0·54 (0·43-0·64), 219 | 0·91 (0·82-0·8), 258 | 0·61 (0·55-0·67), 309 | 0·63 (0·57-0·68), 466 |
| **hCC2** | 0·51 (0·43-0·6), 244 | 0·51 (0·44-0·58), 392 | 0·52 (0·46-0·59), 424 | 0·55 (0·41-0·69), 77 | 0·52 (0·4-0·64), 159 | 0·51 (0·41-0·61), 216 | 0·59 (0·49-0·69), 258 | 0·55 (0·49-0·62), 309 | 0·55 (0·5-0·6), 466 |
| **HBP***** | 0·67 (0·52-0·81), 113 | 0·68 (0·55-0·8), 144 | 0·64 (0·51-0·76), 151 | .. | .. | .. | 0·53 (0·39-0·68), 63 | 0.55 (0.44-0·66), 106 | 0·52 (0·41-0·63), 124 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **HPTGN** | 0·48 (0·4-0·57), 248 | 0·51 (0·44-0·58), 398 | 0·51 (0·45-0·58), 430 | 0·64 (0·5-0·78), 77 | 0·62 (0·51-0·74), 159 | 0·55 (0·45-0·66), 214 | 0·54 (0·45-0·64), 457 | 0·51 (0·45-0·58), 307 | 0·51 (0·46-0·57), 464 |
| **IL-4** | 0·58 (0·5-0·65), 249 | 0·53 (0·47-0·59), 398 | 0·54 (0·48-0·59), 429 | 0·46 (0·4-0·52), 79 | 0·49 (0·45-0·53), 163 | 0·51 (0·47-0·55), 220 | 0·58 (0·54-0·63), 457 | 0·48 (0·42-0·53), 306 | 0·47 (0·42-0·51), 463 |
| **IL-6** | 0·49 (0·43-0·54), 247 | 0·49 (0·44-0·54), 395 | 0·48 (0·43-0·52), 426 | 0·51 (0·47-0·55), 80 | 0·51 (0·48-0·55), 164 | 0·51 (0·47-0·55), 221 | 0·66 (0·47-0·58 | 0·61 (0·55-0·67), 307 | 0·59 (0·54-0·64), 465 |
| **LBP** | 0·58 (0·5-0·66), 248 | 0·54 (0·48-0·61), 397 | 0·52 (0·46-0·58), 429 | 0·69 (0·56-0·83), 78 | 0·67 (0·55-0·78), 160 | 0·6 (0·5-0·71), 217 | 0·52 (0·42-0·57 | 0·54 (0·47-0·61), 267 | 0·53 (0·47-0·59), 394 |
| **Lipocalin-2/NGAL** | 0·49 (0·41-0·57), 249 | 0·51 (0·44-0·57), 396 | 0·51 (0·44-0·57), 428 | 0·67 (0·54-0·8), 79 | 0·6 (0·49-0·72), 163 | 0·58 (0·48-0·68), 219 | 0·62 (0·46-0·56 | 0·65 (0·59-0·72), 265 | 0·61 (0·56-0·67), 392 |
| **sPLA/Lp-PLA2** | 0·54 (0·46-0.62), 252 | 0·53 (0·46-0·59), 402 | 0·52 (0·45-0·58), 434 | 0·58 (0·44-0·71), 80 | 0·54 (0·43-0·65), 164 | 0·58 (0·48-0·68), 221 | 0·58 (0·47-0·58 | 0·55 (0·49-0·61), 308 | 0·56 (0·51-0·61), 466 |
| **TRAIL** | 0·56 (0·49-0·64), 252 | 0·53 (0·47-0·59), 402 | 0·53 (0·48-0·59), 434 | 0·5 (0·5-0·5), 74 | 0·5 (0·49-0·5), 156 | 0·49 (0·48-0·5), 212 | 0·51 (0·51-0·51), 457 | 0·62 (0·56-0·68), 306 | 0·62 (0·57-0·67), 463 |

*CRP was measured with a NycoCard device. **AUROC has a value between 0 and 1, where 1 corresponds to an effect classifier, 0·5 to one that assigns classes randomly. #Freeze–thaw experiments to evaluate the stability of the biomarkers after five cycles (referred to as "treated") were performed with Luminex 9- and 2-plexes. Three samples each were freeze–thawed up to six times and compared with samples after the first thawing (referred to as "untreated"; biomarkers were considered stable with 80–120% recovery). Samples were analysed in triplicate and showed good stability up to five freeze–thaw cycles for all analytes showing acceptable results, except for the C2 and C4b biomarkers (C2: 2/3 [66·7%] samples were stable; C4b: two samples failed the sixth freeze–thaw cycle). As a result, these biomarkers were excluded as they would never be suitable as the basis of a diagnostic test. ***HBP was evaluated in a small group of patients in Malawi and Brazil; however, HBP did not show promise and was not evaluated further.

**Combinations of host-biomarkers and additional covariates – multivariate analysis**

The best-performing biomarkers in the univariate analysis were compared with the best performances from the multivariate analyses, which several feature-selected biomarkers and covariates (Table 4 and Supplementary Tables 15-20). In most cases the best combination of biomarkers showed higher AUROCs than the top-performing individual biomarkers, with a low/moderate "gain" (range 1–13%). The best-performing AUROCs were very similar, irrespective of the multivariate model used, especially for the "strict" and "loose" groups (difference in AUROC range 0·02–0·03 for Malawi and Brazil). Biomarkers identified as top performing by the multivariate analyses differed depending on the model used. While SW and RFA selected three to five biomarkers or combinations, RuleFit selected more biomarkers (ten variables on average) to be part of the signature. The relatively low increase in AUROC when comparing the top-performing single biomarker with multivariate models indicates that biomarkers in addition to the single best-performing biomarker do not make a major contribution.

**Table 4: Multivariate analysis of biomarkers among malaria-negative patients, including the gain/loss of performance when comparing multivariate analysis and single host-biomarkers comprising both haematological and protein host-biomarkers.**

| Classification group | Best multivariate model/models: mean (min-max) AUROC | Best host-biomarker: mean (min-max) AUROC | Multivariate AUROC gain/loss (%) *** multivariate and single host-biomarkers ratio |
|---|---|---|---|
| **Overall (Brazil + Gabon + Malawi)*** | | | |
| L | SW/RFA/RF:0·75 (0.69-0.81) | WBC count: 0·7 (0.64, 0.76) | +7% |
| S | SW:0.83 (0.75 - 0.91) | WBC count: 0·78 (0.72 - 0.84) | +6% |
| E | SW/RFA:0.83 (0.77 - 0.89) | WBC count: 0·77 (0.69 - 0.85) | +8% |
| **Brazil** | | | |
| L | SW: 0·82 (0.70 - 0.94) | WBC count: 0·8 (0.68 - 0.92) | +2·5% |
| S | RFA: 0·82 (0.70 - 0.94) | WBC count: 0·8 (0.68 - 0.92) | +2·5% |
| E | SW: 0·85 (0.73 - 0.97) | WBC count: 0·83 (0.69 - 0.97) | +2% |
| **Gabon**** | | | |
| L | SW/RFA: 0·7 (0.46 - 0.94) | WBC count: 0·7 (0.64 - 0.76) | .. |
| S | SW/RFA: 0·76 (0.52 – 0.96) | WBC count: 0·78 (0.72 - 0.84) | -3% |
| E | RFA: 0·77 (0.63 - 0.91) | WBC count: 0·77 (0.69 - 0.85) | .. |
| **Malawi** | | | |
| L | SW/RFA: 0·74 (0.62 - 0.86) | neutrophil count: 0·72 (0.66 - 0.78) | +3% |
| S | SW: 0·73 (0.61 - 0.85) | neutrophil count: 0·72 (0.58 - 0.86) | + 1% |
| E | RFA: 0·72 (0.60 - 0.84) | WBC count: 0·7 (0.56, 0.84) | + 2% |

E, electronic classification group; S, strict classification group; L, loose classification group; RF, RuleFit; RFA, logistic recursive feature addition; SW, stepwise logistic regression.

* In the "Overall" scenario, the model was developed using the data of all countries and the variable indicating the country was used as a covariate in the model.

**Multivariate performances for Gabon were computed using as a predictor model the model trained in the "Overall" scenario (all participants from the three analysed countries) then evaluated using Gabon data only. Indeed, the sample size of Gabon data was not sufficient to allow the development of a reliable model specific for this country.

*** Performance comparison was computed as: [ (multivariate AUROC – univariate AUROC) / univariate AUROC ] * 100
Green (gain, i.e. the multivariate models show better performances than univariate models); red (loss, i.e. the univariate models show better performances than multivariate models).

## DISCUSSION

We present the most extensive and diverse host-biomarker evaluation study to differentiate bacterial from non-bacterial infections in LMICs. The study aimed to identify if next-generation host-biomarkers for distinguishing bacterial from non-bacterial cases of AFI, which could replace existing biomarkers such as CRP, PCT, and WBC/neutrophil assessments. The data show that none of the promising host-biomarkers exhibited high AUROCs in our non-severe AFI population in either low malaria prevalence (Brazil) or high malaria prevalence (Gabon, Malawi) settings. Haematology biomarkers and CRP were included a baseline to identify better-performing markers; however, they remain those with the highest AUROC values (approximately 0·60–0·70 AUROC) in our population.

Overall, the performance of all markers was underwhelming, yet not surprising. It aligns with previous data where a marked reduction in performance was observed when shifting the population from in- to outpatients [17-19]. Previously, it was hypothesised that the decrease in performance in host biomarkers between HIC and LMIC settings, or even between Africa and Asia, was due to the untreated comorbidities (e.g. diabetes, malaria, neglected tropical diseases) which contribute to inflammation and the nonspecific triggering of host biomarkers, unrelated to the current acute presentation [19, 20]. In our data the performance was indeed poorer in malaria-positive patients (AUROC <0·6); however, even in the malaria-negative population, biomarkers showed low performances (~0·6–0·7) in our cohort. Similarly, sex and arboviral status appeared to have no major effect on biomarker performance. Notably, Our data notably indicated that combining biomarkers can enhance performance. However, this improvement was not consistently observed. When combining several biomarkers and additional covariates, the "gain" in AUROC values was low/moderate (range 1–13%) compared to the top-performing individual biomarkers. From a diagnostic development perspective, a low gain in

performance would not justify the additional complexity and cost of developing a simple multiplex test.

Adding to the challenges of host-biomarker studies is the lack of consistent reference standards and that most studies have focused their analyses solely on the subpopulation of patients with a microbiologically confirmed diagnosis. This approach ignores the largest group (>70%) of patients and intended-use population of any future test [21]. The group with laboratory confirmed diagnosis will decrease further in the non-severe AFI population; presenting at primary care level. Going forward more clarity will likely follow as a recent host-biomarker test (BVtest, MeMed, Israel) was approved by the FDA and subsequent guidance will prescribe more clearly how studies have to be designed to standardize the classification of "bacterial" vs "non-bacterial" evaluated to guide prescribing for bacterial or non-bacterial infections [9, 22]. Our protocol is aligned with the FDA approved classification hence we are confident our methodology is robust.

While our study aimed to mitigate the challenges described, it still had several limitations. The study did not include a control group, so no baseline information was available for biomarker performance or asymptomatic carrier populations. The enrolment period in Brazil and Gabon lasted for less than one year and given the heterogeneity of causes of AFI across time a the performance of the biomarkers may not be generalisable to different times of the year and geographical settings, particularly in Asia. The study utilised a two-step process to classify outcomes, and the clinical classification based on recorded clinical information may have introduced subjectivity. Notably, clinicians had access to the haematology biomarker results (WBCs, neutrophils) during outcome classification, which might have introduced a bias in favour of these biomarkers. However, comparing AUROCs between all classification groups (E, L, S) suggests this potential bias had no major impact as the results are similar across groups. There were some heterogeneities in the inclusion criteria across the various study sites,

including age groups and fever criteria. In Brazil and Gabon, the inclusion criterion was a history of fever in the past 7 days, while it was fever at presentation in Malawi. Studies have found that acute fever at presentation has implications for the interpretation of host biomarkers [23]; however, our sub-analysis by acute fever showed no differences, so we do not consider that these different inclusion criteria impacted interpretation. Despite best efforts to standardise procedures, there was a level of adaptability required in the choice of testing methods by the clinical teams in each country, in particular for arbovirus and respiratory pathogen detection.

Overall, the results of this diverse study highlight the difficulties in identifying single host-biomarkers or simple host-biomarker combinations that can help solve the problem of undifferentiated prescribing at primary healthcare, particularly to be used across diverse global settings. On the seventh birthday of the original TPP for a diagnostic assay to distinguish bacterial and non-bacterial infections in resource-limited settings, a more recent consultation confirmed that the need for such an assay remains and is in fact increasingly urgent [6, 24]. Yet again, the consultation concluded primary healthcare clinics and their equivalents must have the ability to perform tests other than just malaria RDTs [24]. The lack of diagnostics infrastructure at the lower levels of health systems is well documented and requires urgent improvement to support medical staff in their decision making. While no novel host-biomarker assay meets these needs, evidence for existing biomarkers, e.g. CRP, and various haematology biomarkers, should be utilised to drive such improvements, albeit utilizing slightly different approaches and cut-offs across settings. Recent studies have shown that even simple host-biomarkers, such as CRP, can have a major impact on how clinical staff use antibiotics [25, 26]. The current study confirms that the existing biomarkers are imperfect and hence should only be used as guidance, in conjunction with expanded clinical algorithms [27, 28]. Such guidelines, alongside adopted policies and accessible haematology/biochemisty data could enable healthcare workers to use simple tools to gain additional data points to help form a more

evidence-based diagnosis that has to be guided by the local epidemiology. Optimising existing haematology or biochemistry tools and their maintenance requirements to meet the needs of low resourced settings could be one step towards more expanded use of these well-known markers. In conclusion, our study reinforces the continued need for innovation in the host-biomarker space and highlights the importance of targeted evaluations of such innovations, in diverse intended-use settings, to fully understand their true value.

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**Declaration of Interest**

SD, BLFC, CE, VH, SO, CH, AM, SL are or were employed by FIND, the global alliance for diagnostic during the study period.

**Author contribution**

SD, CE, SO, AM, AMS, SG, STA, MML, ATA conceptualised the study and study design; CE, AS, SG, STA, AMS, JKM, VH, JM, ALK, AA, JCBO, MML, PNE, JAM, PB, LB, AdRM, BCC, MAMS, AMBdF, EAdS, RdS, MCSL, JH, AG, MJ, NSM, CH, SJL, implemented the study and data collection; MA, MV, SL, SO, BDC, BLFC, SD, SP, SG, AMS, STA conducted data analysis and interpretation. BLFC, SD wrote the first draft of the manuscript and all authors contributed to the final version of the manuscript.

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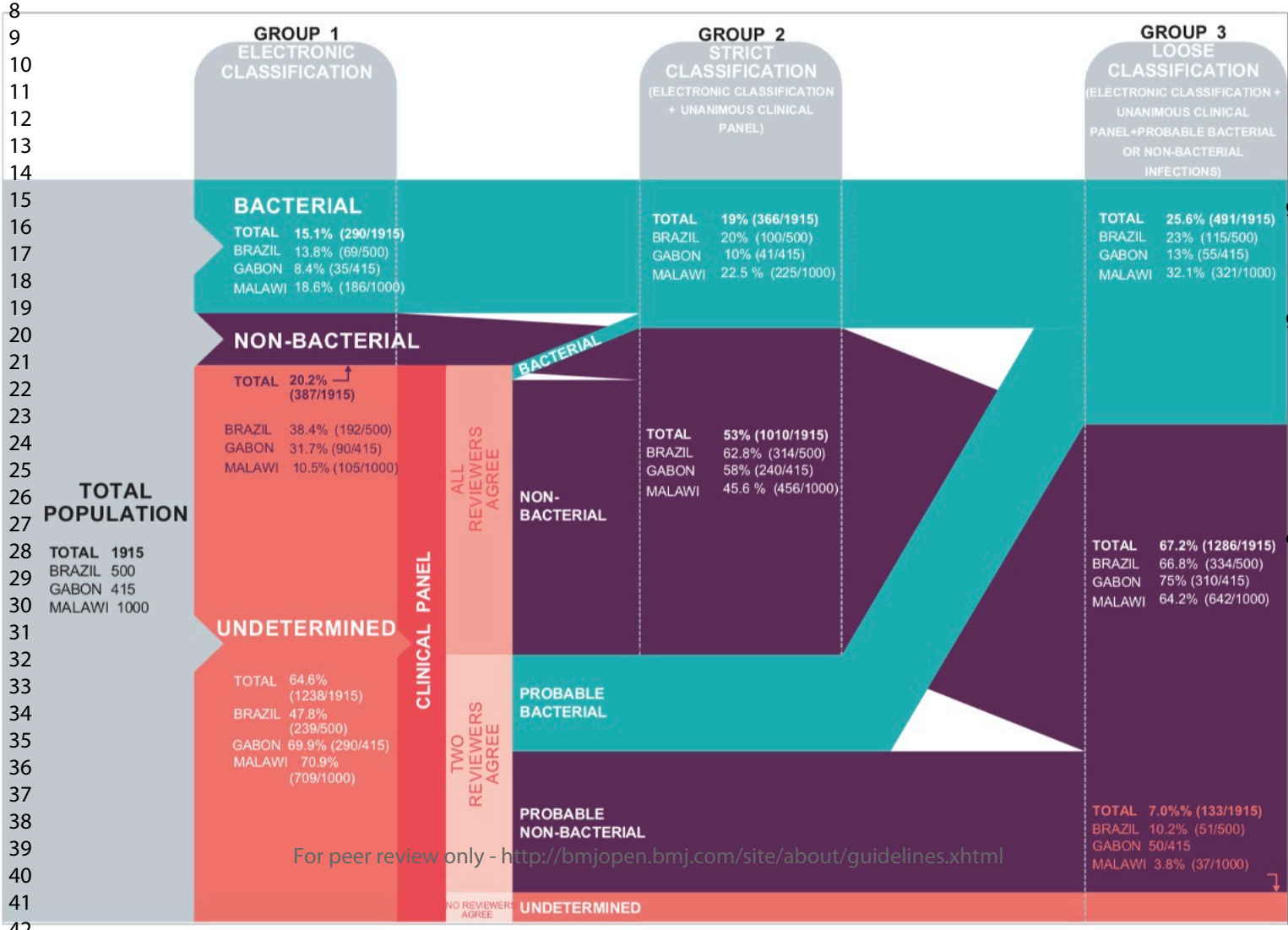
**Figure 1: Classification criteria to assign bacterial versus non-bacterial infection categories for the analysis.** The flows in different colours (turquoise=bacteria, purple=non-bacterial, red=undetermined) represent the proportion of patients that were assigned into the respective group (bacteria/non-bacteria/undetermined) after each classification step. Group 1 representing only patients assigned using laboratory data; group 2 representing patients with a unanimous decision after review by the clinical panel; group 3 after clinical panel review and group 3 including all patients, even if only 2 panel members agreed on the probable cause. The study follows the STARD-15 checklist and reporting guidelines.



# Supplementary Material

## Evaluation of host biomarkers to support the development of a point-of-care diagnostic test to guide antibiotic use in bacterial/non-bacterial acute febrile illness cases

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#corresponding author

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# Biomarker selection

Biomarkers evaluated were selected based on reported performances for distinguishing bacterial versus non-bacterial infections in prior publications, which were systematically reviewed in 2016 by Kapasi et al.[1] and other key publications (Supplementary Table 1). Biomarker performances reported in the 2016 systematic review were compared with reported performances in a later systematic review conducted in 2020.[2]

**Supplementary Table 1. Biomarkers included based on Kapasi et al.'s (2016) systematic review and other key publications.**

| **Biomarker** | **Performance, 2016 systematic review** |
|---|---|
| C-reactive protein (CRP) | 1 |
| FebriDx (MxA+CRP) | 2 |
| Galectin-9 | *2* |
| Gamma-induced protein 10 (IP-10) | 2* |
| Haptoglobin | 2[#] |
| Heparin-binding protein (HBP) | 3 |
| Human neutrophil lipocalin (HNL) | 2 |
| Interferon gamma (IFN-gamma) | 3 |
| Interleukin-4 (IL-4) | 2 |
| Interleukin-6 (IL-6) | 3 |
| Lipopolysaccharide binding protein (LBP) | 3[$] |
| Procalcitonin (PCT) | 1 |
| Secretory phospholipase 2 (sPLA2) | 2 |
| Soluble triggering receptor expressed on myeloid cells 1 (sTREM-1) | 3[§] |
| TNF-related apoptosis-inducing ligand (TRAIL) | 2* |
| | |
| *Included based on key publications in the field* | |
| **Biomarker** | **Publication** |
| A-1-acid glycoprotein | Struck et al.[3] |
| Chitinase-3-like protein 1 (CHI3L1) | Erdman et al.[4] |
| Complement 2 | Struck et al.[3] |
| Complement C4b | Struck et al.[3] |
| Neutrophil gelatinase-associated lipocalin (NGAL) | Huang et al.[5] |

Performances were scored as: 1, high-performing biomarker (meets the current TPP minimum diagnostic performance criteria, i.e. ≥0.90 and 0.80 sensitivity/specificity); 2, moderately performing biomarker (≥0.65 and 0.65 and <0.90 and 0.80 sensitivity/specificity); 3, AUROC >0.8; 4, low-performing biomarker; 5, not evaluated. *As part of the signature CRP+IP-10+TRAIL; # as part of the signature Haptoglobin+IL-10+TIMP1; $ in respiratory tract infections as part of the signature CRP+LBP; § as part of the signature sTREM+CRP; 1 only in the context of meningitis, otherwise low performance.

# Reference laboratory methodology

## Materials, equipment, and software

All assay reagents used were delivered with the commercial kits and were used as described in the corresponding kit manuals. Supplementary Table 2 shows the commercial human multi-analyte kits and ELISA kits used.

**Supplementary Table 2:** Commercial human multi-analyte kits and ELISA kits used.

| Analytes | Assay type | Provider | Reference laboratory that performed the analysis |
|---|---|---|---|
| CHI3L1, Gal-9, IL-4, IL-6, IP-10, IFN-gamma, sPLA2, sTREM-1, TRAIL | Luminex, 9-plex | Biotechne/ R&D Systems | NMI |
| NGAL, LBP | Luminex, 2-plex | Biotechne/ R&D Systems | NMI |
| C2, C4b | Luminex, 2-plex | Merck | NMI |
| HP, AGP | Luminex, 2-plex | Merck | NMI |
| PCT | Luminex, 1-plex | Biotechne/ R&D Systems | NMI |
| | Immunoassay | Elecsys BRAHMS, Roche | MVZ Limbach |
| HNL | ELISA | Diagnostics Development | NMI |

| | | | |
|---|---|---|---|
| CRP | ELISA | Biotechne/ R&D Systems | NMI |
| | Immunoassay | Elecsys BRAHMS, Roche | MVZ Limbach |
| HBP | ELISA | Axis-Shield | on-site |

NMI, The Natural and Medical Sciences Institute (NMI) at the University of Tübingen, Reutlingen, Germany; MVZ Labor, Dr. Limbach & Kollegen, Heidelberg, Germany

For data generation, the Luminex FLEXMAP 3D instrument, operated with xPONENT Software V4.2, was used for the bead-based Luminex assays. The data evaluation was performed using Bio-Rad Bio-Plex Manager Software 6.1.1. To generate the data for the ELISAs at NMI a BioTek ELx 808 absorption reader was used. The embedded software Gen5 (BioTek) was used for data evaluation. At MVZ Limbach, a Cobas 8000 immunoanalyzer (Roche Diagnostics) was used for data generation.

## Methods

All assays were processed according to the manufacturer's protocol. Standard curves, quality control (QC) samples, and blanks were analysed in duplicate; samples were assayed singly. Two or three QC samples were measured on each assay plate. QC samples were taken to cover the range of the standard curve (low, mid, and high level). All QC samples were prepared and aliquoted in larger quantities at the beginning of sample screening so that a fresh aliquot could be used for each measurement, and all QC samples underwent the same freeze–thaw cycle. The performance of the standard curves was controlled over the entire measurement period based on %CVs of the standard point duplicates (<20% and <25% for the last standard point) and percentage recovery on the basis of the nominal concentrations. If permitted by the dilution factor, samples out of the dynamic range were re-analysed with a lower or higher dilution factor.

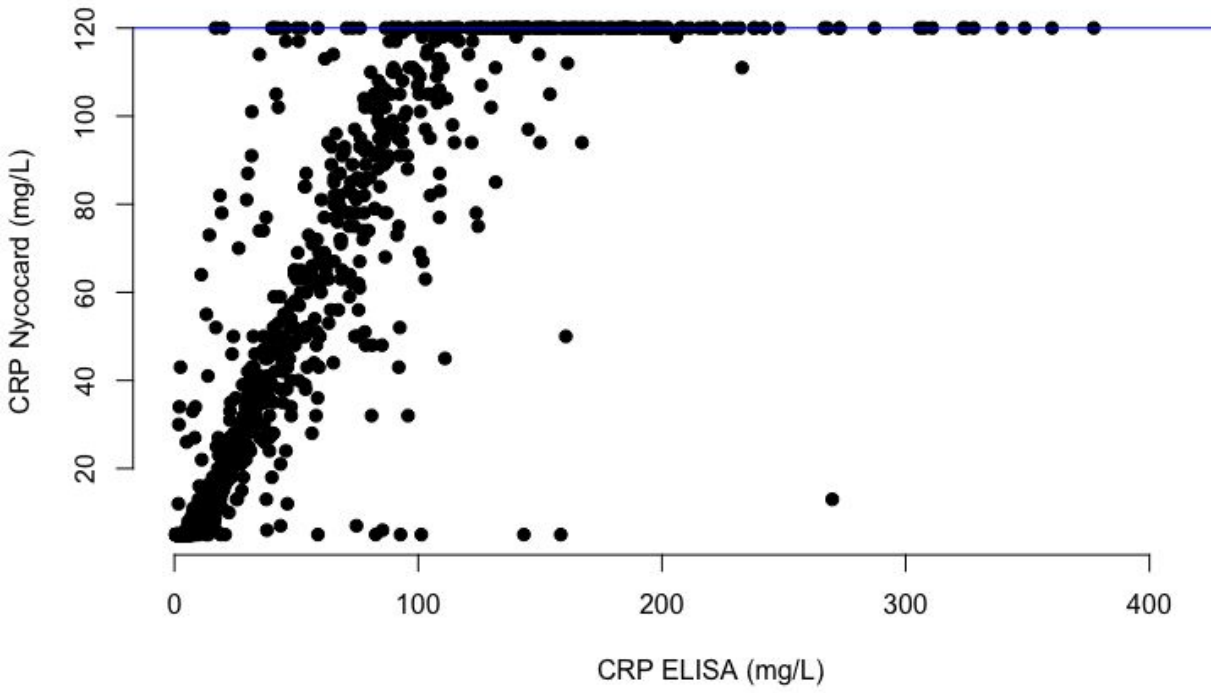
**Heparin-binding protein (HBP) assay**

The commercially available Axis-Shield heparin-binding protein ELISA for citrated plasma was validated for human EDTA plasma. Calibration curve, limit of detection (LOD), assay range, precision, parallelism, and spike-in recovery experiments were performed.

The ELISA was processed according to the assay protocol provided with the kit. Validation was performed using a fit-for-purpose approach and under consideration of the recommendations for assay validation given in guidelines from health authorities (European Medicine Agency (2011); Food and Drug Administration (2018)). This was a short validation with a limited number of samples.

Except for the percentage recovery, all analysed parameters met the criteria during the validation of the HBP ELISA using human EDTA plasma instead of the recommended citrated plasma matrix. The assay performance seemed to be stable for the sample evaluation using the kit.

**Supplementary Figure 1: Analytical assessment of CRP Nycocard vs CRP ELISA**



# Statistical analysis

This section contains additional figures and tables related to the statistical analysis.

**Supplementary Table 3: Number and percentage of missing values for the biomarkers included in the statistical analysis**

| | Electronic group¶ [n (%)] | Strict group§ [n (%)] | Loose group# [n (%)] |
|---|---|---|---|
| White blood cells | 6 (0.8%) | 11 (0.8%) | 15 (0.8%) |
| HAEMATO COUNT | 6 (0.8%) | 11 (0.8%) | 15 (0.8%) |
| Lymphocytes | 6 (0.8%) | 12 (0.9%) | 17 (1%) |
| Neutrophils | 22 (3%) | 64 (5%) | 90 (5%) |
| CRP NYCOCARD | 5 (0.7%) | 10 (0.7%) | 14 (0.8%) |
| IL-6 | 10 (1.5%) | 20 (1%) | 24 (1%) |
| Gal-9 | 10 (1.5%) | 20 (1%) | 24 (1%) |
| CHI3L1 | 10 (1.5%) | 20 (1%) | 25 (1%) |
| IP-10 | 10 (1.5%) | 20 (1%) | 24 (1%) |
| TRAIL | 10 (1.5%) | 20 (1%) | 24 (1%) |
| IL-4 | 13 (2%) | 24 (2%) | 29 (2%) |
| sPLA2 | 10 (1.5%) | 20 (1%) | 24 (1%) |
| NGAL | 29 (4%) | 138 (10%) | 197 (11%) |
| LBP | 30 (4%) | 139 (10%) | 198 (11%) |
| C2 | 10 (1.5%) | 21 (1.5%) | 25 (1%) |
| AGP | 10 (1.5%) | 21(1.5%) | 25 (1%) |
| HP | 11(1.6%) | 24 (2%) | 29 (2%) |

¶ Total number of subjects in the Electronic group: 677
§ Total number of subjects in the Strict group: 1376
# Total number of subjects in the Loose group: 1777

## Kruskal-Wallis tables

**Supplementary Table 4: Kruskal-Wallis table results for the electronic classification**

| | Age | Sex | Malaria | Country | Comorbidities | Malnutrition* | Prior antibiotics | Temperature ≥38°C | Chikungunya |
|---|---|---|---|---|---|---|---|---|---|
| White blood cells | 1.2145E-13 | 1.9808E-01 | 1.0985E-02 | 3.4408E-01 | 8.4018E-01 | 2.7154E-01 | 4.3535E-01 | 3.4408E-01 | 5.4183E-09 |
| HAEMATO COUNT | 2.8040E-45 | 1.0446E-09 | 4.3461E-28 | 1.3185E-36 | 6.8045E-02 | 9.1321E-01 | 6.9000E-01 | 9.9455E-01 | 3.6951E-08 |
| Lymphocytes | 1.3850E-45 | 8.0680E-03 | 3.1562E-29 | 4.5414E-32 | 1.0022E-05 | 4.4874E-01 | 4.5900E-01 | 5.4198E-08 | 1.9910E-11 |
| Neutrophils | 5.6495E-03 | 3.9147E-01 | 1.1337E-04 | 1.8674E-17 | 1.5980E-02 | 4.2719E-01 | 4.3608E-01 | 3.0003E-08 | 6.5439E-04 |
| CRP NYCOCARD | 1.4485E-03 | 4.2297E-01 | 1.3861E-15 | 3.0332E-07 | 2.1171E-01 | 4.6667E-01 | 8.4615E-01 | 3.0231E-03 | 2.1171E-01 |
| IL-6 | 9.2626E-06 | 2.5277E-01 | 4.6686E-34 | 4.2810E-21 | 6.1106E-03 | 7.1615E-01 | 5.8674E-02 | 2.0177E-10 | 9.2626E-06 |
| Gal-9 | 7.8084E-11 | 3.3296E-01 | 1.2731E-07 | 2.2471E-07 | 4.3173E-01 | 5.3845E-01 | 9.9020E-02 | 3.6659E-01 | 8.5282E-04 |
| CHI3L1 | 3.6874E-01 | 1.5427E-01 | 2.2593E-04 | 3.5942E-05 | 9.0961E-01 | 8.0977E-01 | 7.9973E-01 | 2.5264E-02 | 2.5264E-02 |
| IP-10 | 7.0235E-01 | 7.0235E-01 | 4.0429E-09 | 7.0486E-10 | 4.9729E-01 | 7.0235E-01 | 4.0169E-01 | 3.6086E-08 | 3.3476E-01 |
| TRAIL | 1.4108E-03 | 1.5429E-02 | 6.7710E-19 | 6.9473E-56 | 9.2177E-01 | 2.2485E-02 | 9.5591E-01 | 9.7926E-04 | 1.8702E-06 |
| IL-4 | 1.4190E-03 | 8.9566E-02 | 1.7896E-25 | 1.1179E-73 | 4.2256E-01 | 8.9341E-03 | 8.9692E-01 | 3.0403E-03 | 2.2958E-09 |
| sPLA2 | 9.5993E-05 | 9.2127E-01 | 2.8477E-20 | 5.6810E-03 | 1.5011E-01 | 9.2127E-01 | 6.1633E-01 | 7.4323E-03 | 7.4323E-03 |
| NGAL | 2.6841E-02 | 7.1924E-01 | 1.2498E-05 | 6.4604E-21 | 7.1924E-01 | 2.6841E-02 | 5.1387E-01 | 1.2498E-05 | 9.6273E-03 |
| LBP | 2.2658E-11 | 5.1481E-02 | 1.8527E-54 | 2.1544E-101 | 8.2974E-02 | 5.3837E-03 | 1.1745E-01 | 3.5938E-09 | 6.0583E-19 |
| C2 | 1.7219E-02 | 3.0063E-01 | 6.8628E-13 | 6.8628E-13 | 6.2951E-02 | 8.5874E-01 | 5.6324E-01 | 4.4637E-01 | 6.2045E-03 |
| AGP | 5.1888E-03 | 2.0274E-01 | 3.6747E-16 | 1.3445E-16 | 1.5176E-01 | 9.8963E-01 | 6.3154E-01 | 2.3325E-01 | 3.1922E-05 |
| HP | 2.9420E-07 | 2.7390E-01 | 1.8393E-25 | 2.4997E-25 | 2.7390E-01 | 2.7390E-01 | 4.0178E-01 | 7.2077E-01 | 2.9140E-03 |
| C4b | 5.6159E-19 | 6.7010E-02 | 4.5041E-81 | 1.9491E-84 | 6.7179E-03 | 6.7179E-03 | 3.3168E-01 | 1.8052E-01 | 8.0363E-18 |

Different colours based on significance: green ($p < 0.05$, slight significance); orange ($p < 0.01$, high significance); red ($p < 0.001$, strong significance). * Malnutrition status calculated based on WHO body mass index criteria.

## Kruskal-Wallis tables

**Supplementary Table 5: Kruskal-Wallis table results for the strict classification**

| | Age | Sex | Malaria | Country | Comorbidities | Malnutrition* | Prior antibiotics | Temperature ≥38°C | Chikungunya |
|---|---|---|---|---|---|---|---|---|---|
| White blood cells | 3.1149E-20 | 2.4091E-01 | 3.6749E-09 | 9.3997E-03 | 3.1632E-01 | 6.3502E-02 | 6.3502E-02 | 9.1443E-01 | 1.7973E-08 |
| HAEMATO COUNT | 6.1835E-100 | 1.9994E-04 | 5.6304E-55 | 3.7852E-68 | 1.6199E-04 | 8.0189E-01 | 7.1282E-01 | 2.9137E-01 | 1.7149E-10 |
| Lymphocytes | 8.4778E-84 | 1.5291E-01 | 2.6779E-44 | 2.7404E-58 | 6.3047E-07 | 6.1980E-03 | 4.5554E-01 | 7.1024E-22 | 8.6226E-15 |
| Neutrophils | 8.9513E-04 | 1.7152E-01 | 7.9838E-14 | 1.9134E-37 | 4.5549E-02 | 5.2789E-01 | 4.5549E-02 | 3.0001E-19 | 4.1217E-02 |
| CRP NYCOCARD | 1.6547E-02 | 5.7656E-02 | 2.4570E-38 | 6.2991E-11 | 7.4370E-01 | 3.0220E-01 | 7.4370E-01 | 9.7289E-15 | 3.0220E-01 |
| IL-6 | 2.5704E-02 | 1.2888E-01 | 2.5131E-68 | 3.4758E-27 | 1.4641E-01 | 8.1220E-01 | 6.6933E-02 | 4.3924E-26 | 2.5371E-04 |
| Gal-9 | 7.4424E-19 | 3.5455E-03 | 1.3432E-11 | 1.3757E-08 | 1.1615E-01 | 3.9116E-01 | 1.3397E-01 | 2.2573E-01 | 2.4249E-03 |
| CHI3L1 | 2.8335E-01 | 1.5433E-01 | 3.6787E-11 | 7.4319E-16 | 2.8335E-01 | 2.8335E-01 | 2.8335E-01 | 8.7744E-06 | 1.5017E-03 |
| IP-10 | 2.4521E-01 | 6.8716E-01 | 8.5656E-31 | 1.5503E-36 | 2.1157E-01 | 3.0336E-01 | 3.2906E-01 | 4.1236E-22 | 3.2906E-01 |
| TRAIL | 6.4358E-04 | 2.4206E-01 | 3.7467E-46 | 4.5806E-127 | 7.7652E-01 | 8.3869E-04 | 7.7652E-01 | 2.8337E-17 | 1.7642E-08 |
| IL-4 | 4.2108E-04 | 5.9858E-01 | 2.5949E-55 | 2.7083E-159 | 3.3368E-01 | 8.0705E-05 | 6.5563E-01 | 2.2888E-11 | 2.2888E-11 |
| sPLA2 | 3.0005E-14 | 1.1264E-01 | 4.1355E-60 | 4.7055E-09 | 6.7473E-04 | 2.2676E-01 | 3.6531E-01 | 1.0844E-09 | 4.7059E-05 |
| NGAL | 7.7462E-02 | 1.1300E-01 | 6.0927E-16 | 1.3720E-35 | 5.9955E-01 | 4.9221E-02 | 4.4419E-01 | 1.4382E-19 | 8.8808E-03 |
| LBP | 1.3509E-14 | 3.4123E-01 | 6.0660E-94 | 1.9360E-197 | 2.1248E-02 | 3.6673E-05 | 3.0644E-01 | 2.3473E-28 | 7.4289E-21 |
| C2 | 7.2674E-07 | 4.3157E-01 | 2.3145E-26 | 4.5324E-25 | 6.8236E-03 | 4.3157E-01 | 4.3157E-01 | 8.8206E-03 | 2.1062E-03 |
| AGP | 4.8513E-04 | 1.7379E-01 | 5.0587E-21 | 7.1496E-23 | 1.5900E-01 | 7.9521E-01 | 9.7767E-01 | 1.1305E-01 | 1.4880E-05 |
| HP | 1.2127E-13 | 6.3311E-01 | 1.6366E-46 | 3.0053E-46 | 2.9299E-03 | 5.6523E-01 | 5.6523E-01 | 9.0316E-01 | 4.8596E-04 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| C4b | 6.3193E-21 | 1.923 1E-02 | 1.6664E-139 | 3.1999E-147 | 1.9749E-04 | 2.6638E-04 | 9.3349 E-01 | 8.0678E-03 | 3.0903E-25 |

Different colours based on significance: green ($p < 0.05$, slight significance); orange ($p < 0.01$, high significance); red ($p < 0.001$, strong significance). * Malnutrition status calculated based on WHO body mass index criteria.

## Kruskal-Wallis tables

**Supplementary Table 6: Kruskal-Wallis table results for the loose classification**

| | Age | Sex | Malaria | Country | Comorbidities | Malnutrition* | Prior antibiotics | Temperature ≥38°C | Chikungunya |
|---|---|---|---|---|---|---|---|---|---|
| White blood cells | 2.0574E-28 | 9.875 9E-01 | 1.8484E-08 | 4.5260E-03 | 9.0171E-02 | 4.8259E-02 | 1.0890 E-01 | 7.4007E-01 | 1.8484E-08 |
| HAEMATO COUNT | 1.3083E-126 | 1.861 9E-04 | 6.2835E-56 | 7.7962E-76 | 1.1102E-06 | 7.8862E-01 | 7.9391 E-01 | 2.9434E-01 | 1.2853E-10 |
| Lymphocytes | 4.9651E-101 | 2.946 1E-01 | 4.6796E-45 | 1.6372E-67 | 4.8743E-07 | 6.6823E-04 | 2.9461 E-01 | 2.4236E-29 | 4.3110E-15 |
| Neutrophils | 1.1310E-04 | 7.267 7E-01 | 7.2742E-15 | 1.6127E-46 | 2.0313E-01 | 4.6743E-01 | 2.0038 E-01 | 1.2920E-24 | 2.9723E-02 |
| CRP NYCOCARD | 1.3614E-01 | 4.4123E-03 | 1.0347E-57 | 2.4703E-15 | 4.0226E-01 | 5.2068E-01 | 5.9738 E-01 | 6.7648E-18 | 1.3614E-01 |
| IL-6 | 9.5250E-02 | 4.8736E-02 | 8.6303E-95 | 1.9688E-31 | 1.5356E-01 | 8.2374E-01 | 9.3076 E-02 | 6.1774E-34 | 2.1766E-05 |
| Gal-9 | 2.0463E-27 | 1.4431E-03 | 1.9318E-13 | 6.8273E-10 | 2.3586E-01 | 2.3586E-01 | 3.6447E-02 | 2.3586E-01 | 3.0166E-03 |
| CHI3L1 | 2.7483E-01 | 5.354 1E-02 | 3.6128E-14 | 3.6128E-14 | 2.8535E-01 | 7.9359E-01 | 3.0946 E-01 | 1.4718E-04 | 7.1655E-04 |
| IP-10 | 4.1384E-01 | 7.867 4E-01 | 6.5193E-43 | 4.2202E-47 | 7.9605E-02 | 3.6101E-01 | 4.1384 E-01 | 1.4436E-34 | 4.1902E-01 |
| TRAIL | 2.4722E-02 | 1.391 8E-01 | 6.2828E-56 | 2.9185E-156 | 8.2684E-01 | 6.2797E-05 | 8.2684 E-01 | 2.4486E-17 | 1.1148E-09 |
| IL-4 | 1.1448E-02 | 3.191 1E-01 | 3.0844E-69 | 1.7484E-206 | 3.9276E-01 | 4.7672E-08 | 5.7785 E-01 | 2.1611E-12 | 1.2664E-13 |
| sPLA2 | 8.3753E-18 | 2.731 7E-01 | 1.5890E-82 | 1.2702E-09 | 1.2356E-04 | 3.7225E-01 | 4.1002 E-01 | 8.1232E-15 | 4.0213E-05 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| NGAL | 1.570 6E-01 | 2.065 0E-02 | 3.748 6E-27 | 2.284 8E-43 | 3.7129E-01 | 1.4239E-01 | 3.9957 E-01 | 1.3734E -24 | 5.3057E-03 |
| LBP | 1.656 7E-10 | 4.386 5E-01 | 2.110 7E-116 | 2.427 8E-254 | 8.2765E-03 | 5.4993E-07 | 6.1624 E-01 | 1.4861E -39 | 1.4254E-24 |
| C2 | 2.103 5E-04 | 1.459 3E-01 | 7.600 5E-28 | 2.186 5E-27 | 4.8543E-02 | 2.9326E-01 | 3.8932 E-01 | 9.8425E -03 | 1.2901E-03 |
| AGP | 2.507 6E-03 | 9.527 3E-02 | 1.987 0E-26 | 3.272 6E-28 | 9.3140E-02 | 8.9492E-01 | 9.5756 E-01 | 9.5273E -02 | 3.2225E-06 |
| HP | 5.764 0E-15 | 7.268 5E-01 | 2.837 6E-51 | 7.966 7E-51 | 7.2760E-03 | 6.9555E-01 | 6.9555 E-01 | 9.7145E -01 | 1.7228E-04 |
| C4b | 3.907 7E-15 | 9.303 7E-03 | 9.356 7E-160 | 3.444 9E-171 | 6.9926E-04 | 2.2357E-03 | 8.6228 E-01 | 2.2357E -03 | 1.0351E-29 |

Different colours based on significance: green ($p < 0.05$, slight significance); orange ($p < 0.01$, high significance); red ($p < 0.001$, strong significance). * Malnutrition status calculated based on WHO body mass index criteria.

**Supplementary Table 7: Univariate analysis – Overall (malaria-positive and malaria-negative) population**

| | Overall - Malaria negatives AUROC (CI), N | | | Overall - Malaria positives AUROC (CI), N | | |
|---|---|---|---|---|---|---|
| | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** |
| **WBC count** | 0.74, (0.7-0.79), 493 | 0.75, (0.71-0.78), 880 | 0.72, (0.68-0.75), 1127 | 0.65, (0.57-0.73), 174 | 0.65, (0.58-0.71), 481 | 0.64, (0.59-0.7), 630 |
| **RBC count** | 0.58, (0.53-0.63), 494 | 0.52, (0.48-0.56), 880 | 0.51, (0.47-0.54), 1127 | 0.58, (0.5-0.67), 175 | 0.5, (0.44-0.56), 481 | 0.51, (0.46-0.57), 630 |
| **Lymphocyte count** | 0.66, (0.61-0.71), 491 | 0.57, (0.53-0.61), 877 | 0.55, (0.51-0.58), 1123 | 0.63, (0.54-0.71), 174 | 0.57, (0.5-0.63), 480 | 0.54, (0.49-0.6), 627 |
| **Neutrophil count** | 0.71, (0.66-0.75), 480 | 0.75, (0.71-0.79), 847 | 0.73, (0.69-0.76), 1079 | 0.67, (0.59-0.75), 172 | 0.65, (0.58-0.71), 461 | 0.65, (0.59-0.71), 603 |
| **IL-4** | 0.36, (0.31-0.42), 486 | 0.4, (0.35-0.44), 868 | 0.61, (0.57-0.64), 1113 | 0.66, (0.58-0.74), 175 | 0.59, (0.53-0.65), 478 | 0.58, (0.53-0.63), 624 |
| **TRAIL** | 0.36, (0.3-0.41), 489 | 0.63, (0.59-0.67), 871 | 0.63, (0.59-0.67), 1117 | 0.68, (0.6-0.76), 175 | 0.6, (0.54-0.66), 478 | 0.58, (0.53-0.64), 625 |
| **IL-6** | 0.61, (0.55-0.66), 489 | 0.49, (0.45-0.53), 873 | 0.49, (0.45-0.53), 1120 | 0.42, (0.33-0.5), 175 | 0.57, (0.5-0.63), 478 | 0.53, (0.48-0.59), 626 |
| **CRP NycoCard** | 0.52, (0.47-0.57), 496 | 0.57, (0.53-0.61), 884 | 0.57, (0.53-0.6), 1132 | 0.52, (0.43-0.6), 175 | 0.49, (0.43-0.56), 481 | 0.5, (0.44-0.55), 630 |
| **Gal-9** | 0.52, (0.47-0.57), 490 | 0.54, (0.5-0.58), 875 | 0.56, (0.52-0.59), 1122 | 0.57, (0.48-0.65), 176 | 0.54, (0.48-0.6), 480 | 0.53, (0.48-0.59), 629 |
| **CHI3L1** | 0.56, (0.51-0.62), 489 | 0.55, (0.51-0.59), 873 | 0.55, (0.51-0.59), 1119 | 0.5, (0.41-0.59), 176 | 0.52, (0.45-0.58), 480 | 0.5, (0.44-0.55), 627 |
| **IP-10** | 0.53, (0.48-0.58), 489 | 0.52, (0.48-0.56), 874 | 0.52, (0.49-0.56), 1120 | 0.56, (0.47-0.64), 176 | 0.53, (0.47-0.59), 478 | 0.51, (0.45-0.56), 627 |
| **sPLA2** | 0.52, (0.47-0.57), 490 | 0.52, (0.48-0.56), 874 | 0.52, (0.49-0.56), 1121 | 0.49, (0.4-0.58), 176 | 0.54, (0.48-0.61), 479 | 0.54, (0.49-0.6), 628 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **NGAL** | 0.61, (0.56-0.66), 489 | 0.62, (0.57-0.66), 833 | 0.6, (0.57-0.64), 1049 | 0.61, (0.52-0.7), 157 | 0.56, (0.49-0.62), 403 | 0.56, (0.51-0.62), 527 |
| **LBP** | 0.74, (0.69-0.78), 488 | 0.69, (0.65-0.73), 832 | 0.67, (0.64-0.71), 1048 | 0.67, (0.58-0.76), 158 | 0.58, (0.52-0.64), 404 | 0.57, (0.51-0.62), 529 |
| **C2** | 0.59, (0.54-0.64), 483 | 0.56, (0.52-0.6), 866 | 0.56, (0.52-0.59), 1113 | 0.63, (0.55-0.72), 176 | 0.59, (0.53-0.66), 480 | 0.56, (0.5-0.61), 629 |
| **AGP** | 0.67, (0.62-0.72), 490 | 0.6, (0.56-0.64), 874 | 0.58, (0.55-0.62), 1120 | 0.52, (0.43-0.6), 176 | 0.52, (0.45-0.59), 480 | 0.53, (0.47-0.59), 629 |
| **HBP** | 0.67, (0.57-0.76), 179 | 0.64, (0.56-0.72), 254 | 0.61, (0.53-0.68), 280 | 0.55, (0.37-0.72), 57 | 0.52, (0.42-0.63), 141 | 0.53, (0.43-0.64), 149 |
| **HP** | 0.55, (0.49-0.6), 489 | 0.5, (0.46-0.54), 871 | 0.52, (0.48-0.56), 1116 | 0.58, (0.49-0.66), 175 | 0.55, (0.48-0.61), 473 | 0.54, (0.48-0.59), 622 |

**Supplementary Table 8: Univariate analysis – malaria-positive population**

| | **Malawi - Malaria positives AUROC (CI), N** | | | **Gabon - Malaria positives AUROC (CI), N** | | |
|---|---|---|---|---|---|---|
| | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** |
| **WBC count** | 0.67 (0.58-0.76), 132 | 0.68 (0.61 – 0.75), 369 | 0.67 (0.61-0.72), 491 | 0.67 (0.44-0.91), 42 | 0.61 (0.38-0.83), 112 | 0.61 (0.44-0.78), 139 |
| **RBC count** | 0.69 (0.6-0.79), 131 | 0.55 (0.48-0.61), 367 | 0.53 (0.47-0.59), 488 | 0.56 (0.31-0.81), 43 | 0.51 (0.3-0.71), 113 | 0.49 (0.33-0.65), 140 |
| **Lymphocyte count** | 0.7 (0.61-0.79), 131 | 0.59 (0.53-0.66), 368 | 0.57 (0.51-0.62), 488 | 0.72 (0.51-0.93), 42 | 0.66 (0.47-0.85), 112 | 0.67 (0.52-0,.82), 139 |
| **Neutrophil count** | 0.62 (0.52-0.72), 129 | 0.65 (0.57-0.72), 348 | 0.66 (0.6-0.72), 463 | 0.53 (0.31-0.76), 43 | 0.59 (0.39-0.79), 113 | 0.59 (0.43-0.75), 140 |
| **IL-4** | 0.46 (0.36-0.56), 132 | 0.47 (0.4-0.53), 369 | 0.48 (0.42-0.53), 488 | 0.44 (0.38-0.5), 40 | 0.46 (0.44-0.49), 103 | 0.5 (0.42-0.57), 127 |
| **TRAIL** | 0.6 (0.51-0.7),132 | 0.55 (0.49-0.62), 369 | 0.54 (0.48-0.59), 488 | 0.5 (0.5-0.5), 43 | 0.5 (0.5-0.5), 109 | 0.53 (0.47-0.6), 136 |
| **IL-6** | 0.6 (0.5-0.7), 131 | 0.58 (0.51-0.65), 367 | 0.54 (0.48-0.6), 485 | 0.45 (0.32 - 0.57), 42 | 0.47 (0.37-0.57), 103 | 0.45 (0.37-0.53), 127 |
| **CRP NycoCard** | 0.48 (0.38-0.58), 131 | 0.54 (0.47-0.61), 367 | 0.53 (0.47-0.59), 489 | 0.59 (0.32-0.86), 44 | 0.59 (0.36-0.82), 114 | 0.57 (0.4-0.75), 141 |
| **Gal-9** | 0.58 (0.48-0.69), 132 | 0.56 (0.49-0.62), 369 | 0.54 (0.47-0.6), 491 | 0.57 (0.34-0.8), 43 | 0.5 (0.32-0.68), 109 | 0.56 (0.42-0.71), 136 |
| **CHI3L1** | 0.56 (0.46-0.66), 132 | 0.55 (0.48-0.62), 367 | 0.55 (0.49-0.61), 487 | 0.52 (0.26-0.79), 43 | 0.53 (0.31-0.75), 106 | 0.63 (0.44-0.81), 131 |
| **IP-10** | 0.67 (0.58-0.76), 132 | 0.56 (0.49-0.63), 363 | 0.52 (0.46-0.59), 484 | 0.51 (0.33-0.69), 40 | 0.49 (0.35-0.63), 104 | 0.48 (0.35-0.61), 129 |
| **sPLA2** | 0.53 (0.43-0.64), 133 | 0.56 (0.48-0.63), 370 | 0.56 (0.5-0.62), 492 | 0.49 (0.24-0.74), 43 | 0.56 (0.34-0.77), 109 | 0.49 (0.32-0.67), 136 |
| **NGAL** | 0.5 (0.39-0.61), 114 | 0.5 (0.43-0.58), 291 | 0.49 (0.42-0.55)386 | 0.65 (0.44-0.91), 41 | 0.59 (0.41-0.77), 106 | 0.54 (0.38-0.7), 131 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **LBP** | 0.47 (0.35-0.59), 115 | 0.54 (0.46-0.61), 295 | 0.54 (0.48-0.6), 393 | 0.6 (0.34 - 0.85), 42 | 0.58 (0.37-0.8), 105 | 0.65 (0.48-0.81), 131 |
| **C2** | 0.62 (0.52-0.72), 133 | 0.57 (0.5-0.64), 369 | 0.54 (0.48-0.6), 491 | 0.72 (0.54-0.9), 43 | 0.72 (0.57-0.87), 105 | 0.64 (0.48-0.8), 131 |
| **AGP** | 0.54 (0.44 - 0.64), 133 | 0.52 (0.44-0.59), 371 | 0.48 (0.42-0.54), 493 | 0.51 (0.27-0.75), 43 | 0.53 (0.33-0.74), 109 | 0.58 (0.41-0.76), 136 |
| **HBP** | 0.55, (0.37-0.72), 57 | 0.53, (0.43-0.64), 143 | 0.54, (0.44-0.64), 151 | .. | .. | .. |
| **HP** | 0.58 (0.48-0.68), 133 | 0.54 (0.47-0.61), 365 | 0.51 (0.45-0.57), 487 | 0.57 (0.33-0.8), 42 | 0.56 (0.36-0.76), 107 | 0.61 (0.46-0.77), 134 |

*Green (AUROC ≥ 0.7), yellow (AUROC ≥ 0.65 and <7), orange (AUROC 0.6-0.65,) red (AUROC <0.6)*

## Univariate analysis – age subgroups

**Supplementary Table 9: Univariate analysis - age less than 6 years (non-malaria)**

| | Malawi - Malaria negatives AUROC (CI), N | | | Brazil - Malaria negatives AUROC (CI), N | | | Gabon - Malaria negatives AUROC (CI), N | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** |
| **WBC count** | 0.83, (0.73-0.94), 61 | 0.79, (0.71-0.87), 122 | 0.76, (0.69-0.84), 170 | 0.52, (0.25-0.78), 21 | 0.65, (0.46-0.85), 34 | 0.69, (0.51-0.86), 38 | 0.78, (0.62-0.94), 32 | 0.68, (0.52-0.83), 75 | 0.65, (0.52-0.79), 105 |
| **RBC count** | 0.65, (0.49-0.8), 62 | 0.58, (0.48-0.68), 123 | 0.58, (0.5-0.67), 172 | 0.6, (0.33-0.86), 21 | 0.56, (0.35-0.77), 33 | 0.59, (0.39-0.78), 37 | 0.6, (0.4-0.81), 32 | 0.56, (0.4-0.72), 75 | 0.53, (0.38-0.67), 105 |
| **Lymphocyte count** | 0.58, (0.43-0.72), 60 | 0.53, (0.42-0.64), 121 | 0.48, (0.38-0.57), 170 | 0.63, (0.36-0.89), 21 | 0.67, (0.44-0.91), 34 | 0.7, (0.5-0.9), 38 | 0.71, (0.53-0.89), 32 | 0.6, (0.44-0.76), 75 | 0.63, (0.49-0.76), 105 |
| **Neutrophil count** | 0.82, (0.7-0.93), 57 | 0.79, (0.7-0.88), 108 | 0.77, (0.69-0.86), 148 | 0.58, (0.32-0.85), 21 | 0.56, (0.36-0.77), 34 | 0.6, (0.41-0.79), 38 | 0.86, (0.72-0.99), 32 | 0.79, (0.67-0.92), 74 | 0.7, (0.58-0.83), 103 |
| **IL-4** | 0.54, (0.39-0.68), 63 | 0.5, (0.41-0.59), 125 | 0.48, (0.41-0.56), 174 | 0.63, (0.38-0.88), 20 | 0.66, (0.49-0.84), 31 | 0.62, (0.44-0.8), 33 | 0.43, (0.31-0.55), 30 | 0.49, (0.43-0.56), 72 | 0.51, (0.44-0.57), 103 |
| **TRAIL** | 0.57, (0.39-0.75), 63 | 0.6, (0.5-0.69), 125 | 0.59, (0.51-0.67), 174 | 0.5, (0.23-0.77), 20 | 0.63, (0.43-0.82), 31 | 0.59, (0.4-0.79), 33 | 0.5, (0.5-0.5), 28 | 0.5, (0.5-0.5), 69 | 0.49, (0.48-0.51), 99 |
| **IL-6** | 0.59, (0.44-0.73), 63 | 0.61, (0.52-0.7), 125 | 0.6, (0.52-0.68), 174 | 0.41, (0.29-0.53), 20 | 0.39, (0.29-0.49), 29 | 0.39, (0.3-0.49), 31 | 0.5, (0.5-0.5), 31 | 0.5, (0.5-0.5), 73 | 0.49, (0.47-0.5), 104 |
| **CRP NycoCard** | 0.56, (0.37-0.74), 61 | 0.61, (0.51-0.71), 121 | 0.59, (0.5-0.68), 169 | 0.49, (0.22-0.76), 21 | 0.59, (0.38-0.79), 34 | 0.6, (0.42-0.79), 38 | 0.76, (0.57-0.95), 32 | 0.62, (0.49-0.76), 75 | 0.57, (0.45-0.69), 106 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Gal-9** | 0.79, (0.66-0.92), 63 | 0.59, (0.49-0.69), 125 | 0.57, (0.48-0.66), 173 | 0.47, (0.2-0.75), 20 | 0.5, (0.28-0.72), 31 | 0.52, (0.3-0.73), 33 | 0.66, (0.45-0.87), 31 | 0.6, (0.43-0.76), 72 | 0.54, (0.4-0.69), 102 |
| **CHI3L1** | 0.56, (0.4-0.72), 62 | 0.52, (0.42-0.63), 124 | 0.54, (0.45-0.63), 173 | 0.61, (0.35-0.87), 20 | 0.66, (0.47-0.86), 31 | 0.67, (0.49-0.86), 33 | 0.68, (0.49-0.88), 31 | 0.62, (0.45-0.79), 73 | 0.61, (0.47-0.75), 102 |
| **IP-10** | 0.67, (0.51-0.83), 63 | 0.62, (0.52-0.72), 125 | 0.6, (0.51-0.68), 174 | 0.65, (0.39-0.9), 20 | 0.7, (0.51-0.89), 31 | 0.64, (0.45-0.84), 33 | 0.71, (0.53-0.9), 31 | 0.52, (0.38-0.67), 73 | 0.51, (0.38-0.63), 104 |
| **sPLA2** | 0.66, (0.5-0.82), 63 | 0.55, (0.45-0.66), 125 | 0.56, (0.47-0.65), 174 | 0.65, (0.38-0.91), 20 | 0.69, (0.48-0.9), 31 | 0.68, (0.48-0.88), 33 | 0.58, (0.37-0.78), 31 | 0.57, (0.41-0.72), 73 | 0.59, (0.45-0.73), 104 |
| **NGAL** | 0.61, (0.44-0.77), 63 | 0.68, (0.58-0.78), 109 | 0.67, (0.59-0.76), 144 | 0.67, (0.41-0.93), 20 | 0.58, (0.38-0.79), 31 | 0.52, (0.31-0.72), 33 | 0.63, (0.43-0.83), 31 | 0.6, (0.44-0.77), 73 | 0.57, (0.43-0.71), 103 |
| **LBP** | 0.47, (0.31-0.63), 63 | 0.5, (0.39-0.62), 109 | 0.53, (0.43-0.63), 144 | 0.47, (0.2-0.75), 20 | 0.46, (0.25-0.68), 30 | 0.48, (0.27-0.7), 32 | 0.73, (0.53-0.93), 30 | 0.7, (0.53-0.86), 70 | 0.59, (0.44-0.75), 101 |
| **C2** | 0.51, (0.34-0.69), 63 | 0.56, (0.45-0.66), 125 | 0.52, (0.44-0.61), 174 | 0.47, (0.18-0.76), 19 | 0.64, (0.41-0.87), 29 | 0.62, (0.4-0.83), 31 | 0.51, (0.29-0.73), 30 | 0.48, (0.32-0.64), 71 | 0.5, (0.36-0.64), 102 |
| **AGP** | 0.54, (0.38-0.7), 63 | 0.56, (0.45-0.66), 125 | 0.57, (0.48-0.66), 174 | 0.72, (0.48-0.96), 20 | 0.57, (0.34-0.81), 31 | 0.61, (0.39-0.82), 33 | 0.8, (0.63-0.98), 31 | 0.72, (0.56-0.88), 72 | 0.62, (0.48-0.76), 103 |
| **HBP** | 0.67, (0.45-0.89), 26 | 0.55, (0.37-0.73), 45 | 0.54, (0.37-0.71), 48 | .. | .. | .. | .. | .. | .. |
| **HP** | 0.64, (0.49-0.78), 62 | 0.57, (0.46-0.67), 124 | 0.57, (0.48-0.66), 173 | 0.68, (0.42-0.93), 20 | 0.61, (0.38-0.84), 31 | 0.62, (0.41-0.84), 33 | 0.78, (0.59-0.97), 28 | 0.72, (0.57-0.88), 69 | 0.63, (0.49-0.77), 100 |

*Green (AUROC ≥ 0.7), yellow (AUROC ≥ 0.65 and <7), orange (AUROC 0.6-0.65), red (AUROC <0.6)*

**Supplementary Table 10: Univariate analysis - aged between 7 and 15 years (non-malaria)**

| | Malawi - Malaria negatives AUROC (CI), N | | | Brazil - Malaria negatives AUROC (CI), N | | | Gabon - Malaria negatives AUROC (CI), N | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** |
| **WBC count** | 0.49, (0.26-0.73), 28 | 0.69, (0.54-0.84), 50 | 0.75, (0.64-0.86), 81 | 0.79, (0.61-0.96), 34 | 0.83, (0.71-0.95), 69 | 0.82, (0.71-0.94), 75 | 0.46, (0.27-0.65), 47 | 0.51, (0.34-0.67), 87 | 0.47, (0.31-0.62), 112 |
| **RBC count** | 0.62, (0.41-0.84), 28 | 0.54, (0.37-0.7), 51 | 0.57, (0.44-0.7), 82 | 0.7, (0.51-0.88), 34 | 0.61, (0.45-0.78), 69 | 0.6, (0.44-0.75), 75 | 0.56, (0.38-0.75), 47 | 0.55, (0.4-0.7), 87 | 0.48, (0.35-0.62), 112 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Lymphocyte count** | 0.76, (0.58-0.94), 28 | 0.67, (0.51-0.83), 51 | 0.62, (0.49-0.74), 82 | 0.6, (0.37-0.83), 34 | 0.69, (0.54-0.85), 69 | 0.71, (0.56-0.86), 75 | 0.59, (0.42-0.76), 47 | 0.61, (0.48-0.74), 87 | 0.55, (0.43-0.68), 112 |
| **Neutrophil count** | 0.46, (0.23-0.7), 26 | 0.7, (0.54-0.86), 45 | 0.76, (0.64-0.87), 73 | 0.73, (0.53-0.93), 34 | 0.82, (0.69-0.95), 69 | 0.8, (0.68-0.93), 75 | 0.66, (0.46-0.86), 46 | 0.61, (0.43-0.8), 86 | 0.61, (0.44-0.78), 111 |
| **IL-4** | 0.56, (0.34-0.78), 28 | 0.46, (0.31-0.6), 50 | 0.48, (0.37-0.6), 80 | 0.73, (0.53-0.92), 33 | 0.62, (0.47-0.77), 69 | 0.59, (0.45-0.74), 75 | 0.46, (0.41-0.5), 47 | 0.48, (0.46-0.5), 86 | 0.51, (0.45-0.57), 112 |
| **TRAIL** | 0.48, (0.23-0.73), 28 | 0.6, (0.45-0.76), 50 | 0.57, (0.45-0.7), 80 | 0.55, (0.34-0.77), 33 | 0.53, (0.38-0.68), 69 | 0.52, (0.38-0.66), 75 | 0.5, (0.5-0.5), 45 | 0.49, (0.48-0.51), 83 | 0.49, (0.47-0.5), 109 |
| **IL-6** | 0.45, (0.21-0.69), 28 | 0.56, (0.4-0.71), 51 | 0.55, (0.44-0.67), 82 | 0.46, (0.34-0.58), 33 | 0.44, (0.33-0.56), 69 | 0.43, (0.33-0.53), 75 | 0.53, (0.44-0.62), 47 | 0.53, (0.46-0.6), 86 | 0.54, (0.46-0.62), 112 |
| **CRP NycoCard** | 0.56, (0.34-0.78), 28 | 0.61, (0.46-0.77), 51 | 0.62, (0.5-0.74), 82 | 0.57, (0.33-0.81), 34 | 0.52, (0.35-0.68), 71 | 0.51, (0.35-0.68), 77 | 0.75, (0.59-0.92), 47 | 0.71, (0.55-0.87), 87 | 0.69, (0.56-0.83), 113 |
| **Gal-9** | 0.67, (0.43-0.9), 28 | 0.68, (0.53-0.84), 51 | 0.66, (0.54-0.78), 82 | 0.71, (0.52-0.9), 33 | 0.57, (0.41-0.73), 69 | 0.54, (0.39-0.7), 75 | 0.79, (0.62-0.95), 47 | 0.61, (0.44-0.77), 86 | 0.55, (0.39-0.71), 112 |
| **CHI3L1** | 0.53, (0.28-0.78), 28 | 0.6, (0.44-0.76), 51 | 0.61, (0.49-0.73), 82 | 0.69, (0.5-0.87), 32 | 0.66, (0.52-0.79), 67 | 0.59, (0.44-0.73), 71 | 0.53, (0.32-0.73), 46 | 0.58, (0.41-0.74), 84 | 0.62, (0.47-0.77), 110 |
| **IP-10** | 0.64, (0.42-0.86), 28 | 0.56, (0.39-0.72), 51 | 0.59, (0.46-0.72), 82 | 0.73, (0.53-0.92), 33 | 0.62, (0.46-0.78), 69 | 0.58, (0.42-0.73), 75 | 0.6, (0.41-0.78), 47 | 0.48, (0.31-0.66), 86 | 0.52, (0.37-0.67), 112 |
| **sPLA2** | 0.47, (0.21-0.72), 28 | 0.55, (0.39-0.72), 51 | 0.56, (0.43-0.68), 82 | 0.54, (0.33-0.76), 33 | 0.49, (0.35-0.64), 69 | 0.56, (0.43-0.7), 75 | 0.46, (0.28-0.64), 47 | 0.52, (0.36-0.67), 86 | 0.44, (0.29-0.59), 112 |
| **NGAL** | 0.56, (0.32-0.8), 28 | 0.68, (0.52-0.85), 46 | 0.73, (0.61-0.85), 73 | 0.71, (0.52-0.9), 33 | 0.68, (0.54-0.82), 69 | 0.64, (0.5-0.78), 75 | 0.7, (0.52-0.89), 46 | 0.6, (0.44-0.77), 85 | 0.59, (0.44-0.74), 111 |
| **LBP** | 0.54, (0.3-0.77), 28 | 0.59, (0.42-0.75), 46 | 0.58, (0.45-0.72), 73 | 0.68, (0.5-0.87), 33 | 0.66, (0.52-0.8), 69 | 0.67, (0.54-0.8), 75 | 0.71, (0.52-0.9), 46 | 0.66, (0.48-0.84), 85 | 0.63, (0.46-0.79), 111 |
| **C2** | 0.62, (0.34-0.9), 28 | 0.53, (0.36-0.7), 51 | 0.53, (0.41-0.66), 82 | 0.54, (0.31-0.76), 32 | 0.57, (0.4-0.74), 67 | 0.61, (0.45-0.77), 73 | 0.62, (0.42-0.81), 45 | 0.46, (0.27-0.65), 83 | 0.52, (0.36-0.68), 109 |
| **AGP** | 0.57, (0.3-0.83), 28 | 0.55, (0.39-0.71), 51 | 0.52, (0.39-0.65), 81 | 0.53, (0.3-0.76), 33 | 0.6, (0.44-0.75), 69 | 0.61, (0.46-0.75), 75 | 0.75, (0.56-0.94), 47 | 0.68, (0.5-0.86), 86 | 0.67, (0.52-0.83), 112 |
| **HBP** | 0.76, (0.28-1), 10 | 0.58, (0.29-0.87), 19 | 0.65, (0.39-0.91), 23 | ## Unbalanced classes | 0.92, (0.69-1), 8 | 0.72, (0.28-1), 9 | .. | .. | .. |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **HP** | 0.5, (0.25-0.76), 28 | 0.51, (0.35-0.67), 51 | 0.5, (0.37-0.63), 82 | 0.52, (0.3-0.75), 32 | 0.62, (0.46-0.78), 68 | 0.6, (0.45-0.76), 74 | 0.53, (0.33-0.73), 47 | 0.54, (0.37-0.7), 85 | 0.53, (0.38-0.67), 109 |

*Green (AUROC ≥ 0.7), yellow (AUROC ≥ 0.65 and <7), orange (AUROC 0.6-0.65), red (AUROC <0.6)*

**Supplementary Table 11: Univariate analysis - aged more than 15 years (non-malaria)**

| | Malawi - Malaria negatives AUROC (CI), N | | | Brazil - Malaria negatives AUROC (CI), N | | | Gabon - Malaria negatives AUROC (CI), N | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** |
| **WBC count** | 0.67, (0.53-0.82), 66 | 0.71, (0.62-0.8), 132 | 0.68, (0.6-0.75), 210 | 0.84, (0.77-0.91), 202 | 0.84, (0.77-0.9), 305 | 0.83, (0.77-0.89), 329 | 2 patients in total | 5 patients in total | 5 patients in total |
| **RBC count** | 0.59, (0.44-0.73), 65 | 0.53, (0.43-0.63), 131 | 0.51, (0.43-0.59), 209 | 0.56, (0.45-0.67), 203 | 0.56, (0.47-0.64), 306 | 0.55, (0.47-0.63), 330 | - | - | - |
| **Lymphocyte count** | 0.5, (0.34-0.66), 66 | 0.53, (0.43-0.63), 131 | 0.49, (0.41-0.57), 209 | 0.67, (0.58-0.76), 202 | 0.65, (0.57-0.72), 305 | 0.64, (0.57-0.71), 329 | - | - | - |
| **Neutrophil count** | 0.65, (0.49-0.81), 60 | 0.7, (0.6-0.8), 120 | 0.66, (0.59-0.74), 193 | 0.82, (0.74-0.9), 202 | 0.82, (0.76-0.89), 305 | 0.82, (0.75-0.88), 329 | - | - | - |
| **IL-4** | 0.4, (0.28-0.52), 66 | 0.47, (0.39-0.54), 131 | 0.45, (0.39-0.52), 209 | 0.56, (0.47-0.65), 196 | 0.53, (0.46-0.6), 298 | 0.54, (0.47-0.6), 321 | - | - | - |
| **TRAIL** | 0.68, (0.54-0.82), 66 | 0.65, (0.56-0.73), 131 | 0.66, (0.59-0.73), 209 | 0.57, (0.48-0.65), 199 | 0.54, (0.47-0.61), 302 | 0.54, (0.48-0.61), 326 | - | - | - |
| **IL-6** | 0.59, (0.46-0.72), 67 | 0.63, (0.54-0.72), 131 | 0.59, (0.52-0.66), 209 | 0.51, (0.44-0.58), 194 | 0.51, (0.45-0.58), 297 | 0.5, (0.44-0.56), 320 | - | - | - |
| **CRP NycoCard** | 0.53, (0.38-0.68), 67 | 0.6, (0.5-0.7), 133 | 0.57, (0.49-0.64), 211 | 0.66, (0.57-0.76), 204 | 0.65, (0.57-0.73), 307 | 0.66, (0.58-0.73), 331 | - | - | - |
| **Gal-9** | 0.72, (0.59-0.86), 67 | 0.6, (0.5-0.7), 133 | 0.63, (0.56-0.71), 211 | 0.61, (0.52-0.71), 199 | 0.56, (0.48-0.65), 301 | 0.57, (0.5-0.65), 325 | - | - | - |
| **CHI3L1** | 0.52, (0.36-0.67), 65 | 0.51, (0.41-0.61), 129 | 0.53, (0.45-0.61), 207 | 0.66, (0.58-0.75), 194 | 0.62, (0.54-0.69), 296 | 0.62, (0.55-0.69), 320 | - | - | - |
| **IP-10** | 0.64, (0.48-0.79), 67 | 0.59, (0.49-0.69), 133 | 0.61, (0.53-0.68), 210 | 0.59, (0.5-0.68), 199 | 0.52, (0.44-0.6), 302 | 0.53, (0.45-0.6), 326 | - | - | - |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **sPLA2** | 0.53, (0.37-0.69), 67 | 0.54, (0.44-0.64), 132 | 0.54, (0.46-0.62), 210 | 0.58, (0.48-0.67), 199 | 0.56, (0.48-0.64), 302 | 0.56, (0.48-0.63), 326 | - | - | - |
| **NGAL** | 0.49, (0.33-0.65), 65 | 0.62, (0.51-0.72), 110 | 0.53, (0.44-0.62), 175 | 0.55, (0.46-0.65), 196 | 0.54, (0.46-0.62), 296 | 0.53, (0.45-0.61), 320 | - | - | - |
| **LBP** | 0.56, (0.41-0.7), 66 | 0.56, (0.45-0.67), 112 | 0.53, (0.44-0.61), 177 | 0.65, (0.56-0.74), 195 | 0.6, (0.52-0.67), 298 | 0.56, (0.49-0.64), 322 | - | - | - |
| **C2** | 0.67, (0.53-0.81), 67 | 0.59, (0.49-0.69), 133 | 0.58, (0.51-0.66), 210 | 0.5, (0.4-0.6), 193 | 0.51, (0.43-0.58), 296 | 0.51, (0.44-0.59), 320 | - | - | - |
| **AGP** | 0.6, (0.45-0.75), 67 | 0.57, (0.47-0.67), 133 | 0.54, (0.46-0.62), 211 | 0.65, (0.55-0.74), 199 | 0.58, (0.5-0.66), 302 | 0.56, (0.49-0.64), 326 | - | - | - |
| **HBP** | 0.48, (0.25-0.71), 28 | 0.54, (0.36-0.72), 44 | 0.47, (0.31-0.63), 55 | 0.66, (0.51-0.81), 107 | 0.66, (0.53-0.79), 136 | 0.63, (0.5-0.76), 142 | - | - | - |
| **HP** | 0.53, (0.39-0.67), 67 | 0.58, (0.48-0.68), 132 | 0.5, (0.42-0.58), 209 | 0.56, (0.46-0.66), 196 | 0.47, (0.39-0.55), 299 | 0.48, (0.4-0.55), 323 | - | - | - |

*Green (AUROC ≥ 0.7), yellow (AUROC ≥ 0.65 and <7), orange (AUROC 0.6-0.65) red (AUROC <0.6)*

**Supplementary Table 12: Univariate analysis - age less than 6 years (malaria)**

| | Malawi - Malaria positives AUROC (CI), N | | | Gabon - Malaria positives AUROC (CI), N | | |
|---|---|---|---|---|---|---|
| | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** |
| **WBC count** | 0.64, (0.47-0.81), 50 | 0.71, (0.59-0.82), 148 | 0.7, (0.6-0.8), 178 | 0.62, (0.23-1), 11 | 0.62, (0.36-0.88), 44 | 0.62, (0.41-0.83), 56 |
| **RBC count** | 0.51, (0.33-0.68), 49 | 0.55, (0.44-0.65), 147 | 0.55, (0.44-0.65), 177 | 0.7, (0.34-1), 11 | 0.63, (0.42-0.84), 44 | 0.62, (0.45-0.8), 56 |
| **Lymphocyte count** | 0.45, (0.26-0.64), 49 | 0.58, (0.47-0.7), 147 | 0.55, (0.44-0.66), 177 | 0.57, (0.17-0.96), 11 | 0.6, (0.34-0.86), 44 | 0.63, (0.42-0.85), 56 |
| **Neutrophil count** | 0.59, (0.41-0.77), 49 | 0.65, (0.53-0.76), 140 | 0.66, (0.56-0.76), 169 | 0.7, (0.3-1), 11 | 0.49, (0.24-0.75), 44 | 0.55, (0.35-0.75), 56 |
| **IL-4** | 0.68, (0.5-0.86), 50 | 0.62, (0.52-0.71), 148 | 0.58, (0.49-0.67), 178 | 0.5, (0.5-0.5), 11 | 0.47, (0.42-0.51), 39 | 0.48, (0.44-0.51), 51 |
| **TRAIL** | 0.73, (0.56-0.89), 50 | 0.59, (0.48-0.69), 148 | 0.56, (0.47-0.66), 178 | 0.5, (0.5-0.5), 11 | 0.5, (0.5-0.5), 41 | 0.5, (0.5-0.5), 53 |
| **IL-6** | 0.6, (0.4-0.79), 49 | 0.64, (0.53-0.74), 147 | 0.63, (0.53-0.72), 175 | 0.47, (0.2-0.73), 11 | 0.48, (0.33-0.62), 37 | 0.48, (0.36-0.59), 49 |
| **CRP NycoCard** | 0.52, (0.33-0.7), 48 | 0.58, (0.48-0.69), 145 | 0.56, (0.46-0.66), 175 | 0.78, (0.47-1), 11 | 0.66, (0.41-0.91), 44 | 0.63, (0.42-0.84), 56 |
| **Gal-9** | 0.58, (0.37-0.79), 49 | 0.54, (0.43-0.65), 148 | 0.53, (0.43-0.64), 178 | 0.5, (0.05-0.95), 11 | 0.63, (0.45-0.82), 41 | 0.6, (0.44-0.76), 53 |
| **CHI3L1** | 0.53, (0.36-0.7), 50 | 0.6, (0.49-0.71), 148 | 0.57, (0.47-0.67), 178 | 0.47, (0.07-0.86), 11 | 0.54, (0.28-0.79), 40 | 0.56, (0.33-0.8), 51 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **IP-10** | 0.73, (0.57-0.9), 50 | 0.58, (0.47-0.69), 143 | 0.57, (0.47-0.67), 172 | 0.77, (0.38-1), 11 | 0.45, (0.26-0.64), 39 | 0.48, (0.32-0.64), 51 |
| **sPLA2** | 0.49, (0.3-0.69), 50 | 0.63, (0.52-0.75), 148 | 0.62, (0.52-0.72), 178 | 0.73, (0.38-1), 11 | 0.52, (0.27-0.78), 41 | 0.52, (0.31-0.73), 53 |
| **NGAL** | 0.61, (0.43-0.79), 47 | 0.56, (0.44-0.68), 118 | 0.54, (0.43-0.65), 141 | 0.87, (0.6-1), 11 | 0.62, (0.4-0.85), 40 | 0.61, (0.41-0.8), 52 |
| **LBP** | 0.55, (0.3-0.79), 48 | 0.48, (0.37-0.59), 122 | 0.52, (0.41-0.62), 147 | 0.45, (0.03-0.87), 11 | 0.58, (0.33-0.83), 41 | 0.61, (0.4-0.81), 53 |
| **C2** | 0.57, (0.38-0.76), 50 | 0.57, (0.47-0.68), 148 | 0.56, (0.46-0.67), 178 | 0.58, (0.2-0.97), 11 | 0.78, (0.6-0.96), 38 | 0.77, (0.6-0.93), 50 |
| **AGP** | 0.68, (0.52-0.84), 50 | 0.6, (0.49-0.71), 149 | 0.57, (0.47-0.68), 179 | 0.63, (0.24-1), 11 | 0.52, (0.32-0.73), 41 | 0.46, (0.27-0.65), 53 |
| **HBP** | 0.55, (0.27-0.84), 33 | 0.62, (0.49-0.76), 78 | 0.63, (0.49-0.76), 82 | .. | .. | .. |
| **HP** | 0.72, (0.58-0.87), 50 | 0.59, (0.48-0.7), 147 | 0.56, (0.46-0.67), 177 | 0.57, (0.18-0.95), 11 | 0.45, (0.21-0.69), 40 | 0.47, (0.26-0.68), 52 |

*Green (AUROC ≥ 0.7), yellow (AUROC ≥ 0.65 and <7), orange (AUROC 0.6-0.65), red (AUROC <0.6)*

**Supplementary Table 13: Univariate analysis - aged between 7 and 15 years (malaria)**

| | **Malawi - Malaria positives AUROC (CI), N** | | | **Gabon - Malaria positives AUROC (CI), N** | | |
|---|---|---|---|---|---|---|
| | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** |
| **WBC count** | 0.67, (0.51-0.82), 51 | 0.7, (0.6-0.8), 134 | 0.66, (0.57-0.75), 185 | **## unbalanced classes (24 non-bacterial, 1 bacterial) for 25 patients** | **## unbalanced classes (54 non-bacterial, 1 bacterial) for 55 patients** | 0.47, (0.03-0.91), 72 |
| **RBC count** | 0.74, (0.6-0.87), 51 | 0.55, (0.43-0.68), 134 | 0.53, (0.43-0.63), 185 | - | - | 0.67, (0.28-1), 73 |
| **Lymphocyte count** | 0.64, (0.49-0.79), 51 | 0.59, (0.47-0.7), 134 | 0.55, (0.46-0.64), 184 | - | - | 0.44, (0.14-0.75), 72 |
| **Neutrophil count** | 0.63, (0.47-0.79), 50 | 0.67, (0.56-0.78), 127 | 0.67, (0.58-0.76), 174 | - | - | 0.51, (0.17-0.86), 73 |
| **IL-4** | 0.53, (0.36-0.7), 51 | 0.54, (0.44-0.64), 134 | 0.53, (0.45-0.61), 184 | - | - | 0.62, (0.27-0.96), 65 |
| **TRAIL** | 0.51, (0.35-0.68), 51 | 0.52, (0.41-0.63), 134 | 0.54, (0.45-0.63), 184 | - | - | 0.62, (0.38-0.87), 72 |
| **IL-6** | 0.62, (0.46-0.78), 50 | 0.57, (0.46-0.68), 132 | 0.51, (0.41-0.6), 181 | - | - | 0.41, (0.37-0.46), 67 |
| **CRP NycoCard** | 0.55, (0.39-0.71), 51 | 0.52, (0.4-0.64), 134 | 0.51, (0.41-0.61), 185 | - | - | 0.59, (0.21-0.97), 73 |
| **Gal-9** | 0.6, (0.44-0.76), 51 | 0.53, (0.42-0.65), 134 | 0.55, (0.45-0.65), 185 | - | - | 0.64, (0.23-1), 72 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **CHI3L1** | 0.53, (0.36-0.69), 51 | 0.49, (0.38-0.6), 133 | 0.54, (0.45-0.64), 183 | - | - | 0.61, (0.08-1), 69 |
| **IP-10** | 0.63, (0.47-0.79), 50 | 0.56, (0.45-0.68), 133 | 0.53, (0.43-0.63), 184 | - | - | 0.55, (0.11-0.99), 67 |
| **NGAL** | 0.55, (0.38-0.71), 51 | 0.52, (0.41-0.64), 134 | 0.53, (0.44-0.63), 185 | - | - | 0.56, (0.13-0.99), 72 |
| **HNL** | 0.67, (0.48-0.85), 42 | 0.47, (0.35-0.59), 108 | 0.57, (0.48-0.67), 150 | - | - | 0.66, (0.33-1), 69 |
| **LBP** | 0.61, (0.44-0.78), 42 | 0.59, (0.47-0.71), 108 | 0.56, (0.46-0.66), 151 | - | - | 0.9, (0.77-1), 67 |
| **C2** | 0.62, (0.46-0.78), 51 | 0.57, (0.46-0.68), 133 | 0.54, (0.45-0.64), 184 | - | - | 0.73, (0.47-0.98), 70 |
| **AGP** | 0.6, (0.44-0.76), 51 | 0.55, (0.43-0.67), 134 | 0.52, (0.42-0.62), 185 | - | - | 0.53, (0.07-0.99), 72 |
| **HBP** | 0.64, (0.39-0.9), 21 | 0.46, (0.28-0.65), 50 | 0.49, (0.31-0.67), 55 | - | - | - |
| **HP** | 0.54, (0.37-0.7), 51 | 0.49, (0.38-0.59), 132 | 0.49, (0.4-0.59), 183 | - | - | 0.79, (0.6-0.98), 71 |

*Green (AUROC ≥ 0.7), yellow (AUROC ≥ 0.65 and <7), orange (AUROC 0.6-0.65) red (AUROC <0.6)*

**Supplementary Table 14: Univariate analysis - aged more than 15 years (malaria)**

| | Malawi - Malaria positives AUROC (CI), N | | | Gabon - Malaria positives AUROC (CI), N | | |
|---|---|---|---|---|---|---|
| | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** |
| **WBC count** | 0.54, (0.32-0.76), 31 | 0.56, (0.37-0.75), 87 | 0.65, (0.51-0.78), 128 | 2 patients in total | 11 patients in total | 11 patients in total |
| **RBC count** | 0.42, (0.2-0.63), 31 | 0.58, (0.42-0.73), 86 | 0.57, (0.44-0.7), 126 | - | - | - |
| **Lymphocyte count** | 0.77, (0.61-0.94), 31 | 0.64, (0.5-0.78), 87 | 0.66, (0.55-0.77), 127 | - | - | - |
| **Neutrophil count** | 0.5, (0.28-0.73), 30 | 0.55, (0.35-0.74), 81 | 0.62, (0.48-0.77), 120 | - | - | - |
| **IL-4** | 0.53, (0.33-0.73), 31 | 0.5, (0.34-0.66), 87 | 0.48, (0.37-0.59), 126 | - | - | - |
| **TRAIL** | 0.62, (0.42-0.82), 31 | 0.6, (0.44-0.76), 87 | 0.63, (0.51-0.75), 126 | - | - | - |
| **IL-6** | 0.67, (0.47-0.87), 32 | 0.52, (0.35-0.69), 88 | 0.54, (0.41-0.66), 129 | - | - | - |
| **CRP NycoCard** | 0.57, (0.36-0.78), 32 | 0.52, (0.37-0.68), 88 | 0.52, (0.4-0.64), 129 | - | - | - |
| **Gal-9** | 0.61, (0.4-0.82), 32 | 0.59, (0.44-0.73), 87 | 0.52, (0.39-0.65), 128 | - | - | - |

| | | | | | | |
|---|---|---|---|---|---|---|
| **CHI3L1** | 0.64, (0.43-0.85), 31 | 0.53, (0.37-0.69), 86 | 0.52, (0.4-0.65), 126 | - | - | - |
| **IP-10** | 0.66, (0.45-0.87), 32 | 0.52, (0.35-0.69), 87 | 0.58, (0.44-0.71), 128 | - | - | - |
| **sPLA2** | 0.62, (0.42-0.82), 32 | 0.53, (0.37-0.69), 88 | 0.56, (0.44-0.69), 129 | - | - | - |
| **NGAL** | 0.7, (0.48-0.92), 25 | 0.55, (0.35-0.75), 65 | 0.56, (0.41-0.7), 95 | - | - | - |
| **LBP** | 0.37, (0.14-0.6), 25 | 0.47, (0.29-0.66), 65 | 0.59, (0.46-0.73), 95 | - | - | - |
| **C2** | 0.64, (0.43-0.85), 32 | 0.59, (0.42-0.76), 88 | 0.47, (0.33-0.6), 129 | - | - | - |
| **AGP** | 0.68, (0.49-0.87), 32 | 0.47, (0.31-0.63), 88 | 0.52, (0.39-0.64), 129 | - | - | - |
| **HBP** | 0.8, (0.34-1), 7 | 0.62, (0.29-0.95), 23 | 0.62, (0.29-0.95), 24 | - | - | - |
| **HP** | 0.52, (0.31-0.73), 32 | 0.51, (0.35-0.67), 86 | 0.53, (0.41-0.64), 127 | - | - | - |

*Green (AUROC ≥ 0.7), yellow (AUROC ≥ 0.65 and <7), orange (AUROC 0.6-0.65) red (AUROC <0.6)*

**Supplementary Table 15: Multivariate analysis – non-malaria population; haematological biomarkers**

| **Haematological biomarkers** | | | | | | |
|---|---|---|---|---|---|---|
| **Overall** | | | | | | |
| **Multivariate models' variables** | | | **Classification group** | **Best multivariate model/models: mean (SD) AUROC** | **Best host-biomarker: mean (SD) AUROC** | **Multivariate AUROC gain/loss (%)** |
| **Rulefit** | **Logistic - RFA** | **Logistic - SW** | | | | |
| country , neutrophil count WBC count, lymphocyte count, fever duration, temperature, pulse rate, respiratory rate | country neutrophil count, fever duration | country neutrophil count fever duration respiratory rate | L | RF/SW/RFA: 0.75 (0.03) | WBC count : 0.7 (0.03) | +7% |
| | | | S | SW: 0.83 (0.04) | WBC count: 0.78 (0.03) | +6% |
| | | | E | SW/RFA: 0.83 (0.02) | WBC count: 0.77 (0.03) | +8% |
| **Gabon*** | | | | | | |
| Gabon performance evaluation using the Overall model and Gabon data extracted from the Overall test sets | | | L | SW:0.7 (0.12) | WBC count : 0.7 (0.03) | |
| | | | S | SW: 0.77 (0.12) | WBC count: 0.73 (0.03) | +5% |
| | | | E | RFA: 0.77 (0.08) | WBC count: 0.75 (0.03) | +3% |
| **Malawi** | | | | | | |
| diastolic blood pressure, HAEMATO_C lymphocyte count, neutrophil count, pulse rate, temperature, fever duration | fever duration neutrophil count | fever duration neutrophil count | L | RFA: 0.74(.05) | neutrophil count: 0.72(.06) | +3% |
| | | | S | SW: 0.73(.06) | neutrophil count: 0.72(.07) | +1% |
| | | | E | RFA: 0.66(.16) | WBC count: 0.7 (0.05) | -6% |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Brazil** | | | | | | |
| diastolic blood pressure, haematocrit lymphocyte count, neutrophil count, pulse rate, temperature, fever duration, respiratory rate, WBC count | WBC count respiratory rate neutrophil count | WBC count respiratory rate | L | RFA: 0.82 (0.08) | WBC count: 0.81 (0.08) | +1% |
| | | | S | RFA: 0.82 (0.08) | WBC count: 0.81 (0.08) | +1% |
| | | | E | RFA: 0.84 (0.07) | WBC count: 0.83 (0.07) | +1% |

E, electronic classification group; S, strict classification group; L, loose classification group; RF, Rulefit; RFA, logistic recursive feature addition; SW, stepwise logistic regression. Green (gain, i.e. multivariate models have better performances than univariate models); red (loss, i.e. univariate models have better performances than multivariate models).
*Multivariate performances for Gabon were computed using the Overall population-trained model as a predictor model and tested with Gabon data due to the limited data.

**Supplementary Table 16: Multivariate analysis – non-malaria population; protein biomarkers**

| **Protein biomarkers** | | | | | | |
|---|---|---|---|---|---|---|
| **Overall** | | | | | | |
| **Multivariate models' variables** | | | **Classification group** | **Best multivariate model/models: mean (SD) AUROC** | **Best host-biomarker: mean (SD) AUROC** | **Multivariate AUROC gain/loss (%)** |
| **Rulefit** | **Logistic - RFA** | **Logistic - SW** | | | | |
| CRP AGP LBP NGAL pulse rate respiratory rate diastolic blood pressure temperature country | CRP country LBP NGAL pulse rate | CRP country NGAL pulse rate respiratory rate temperature | L | RF/RFA/SW: 0.66 (0.05) | LBP: 0.62 (0.04) | +6% |
| | | | S | RF: 0.74 (0.04) | LBP: 0.66 (0.05) | +12% |
| | | | E | RFA: 0.76 (0.04) | LBP: 0.75 (0.04) | +1% |
| **Gabon*** | | | | | | |
| Gabon performance evaluation using the Overall model and Gabon data extracted from the Overall test sets | | | L | SW: 0.64 (0.12) | LBP: 0.62 (0.04) | +3% |
| | | | S | RFA: 0.7 (0.11) | LBP: 0.66 (0.05) | +6% |
| | | | E | RFA: 0.7 (0.09) | LBP: 0.75 (0.04) | -7% |
| **Malawi** | | | | | | |
| IP-10 Gal-9 NGAL temperature CRP respiratory rate fever duration pulse rate diastolic blood pressure | Gal-9 NGAL temperature | Gal-9 NGAL temperature pulse rate fever duration | L | SW: 0.7 (0.06) | Lipocalin. 2: 0.65 (0.06) | +8% |
| | | | S | RF/ SW: 0.67 (0.06) | Lipocalin. 2: 0.64 (0.06) | +5% |
| | | | E | RF: 0.71 (0.12) | IP-10: 0.69 (0.08) | +3% |
| **Brazil** | | | | | | |
| CRP, Gal-9, AGP | Gal-9, TRAIL, | Gal-9, pulse rate, fever duration, | L | RF: 0.67 (0.04) | CRP: 0.65 (0.06) | +3% |

| | | | | | | |
|---|---|---|---|---|---|---|
| pulse rate, diastolic blood pressure respiratory rate, temperature | NGAL | NGAL, temperature | S | SW/RFA: 0.66(.04) | CRP: 0.65 (0.05) | +1% |
| | | | E | SW/RFA: 0.65(.05) | CRP: 0.63 (0.08) | +3% |

E, electronic classification group; S, strict classification group; L, loose classification group; RF, Rulefit; RFA, logistic recursive feature addition; SW, stepwise logistic regression. Green (gain, i.e. multivariate models have better performances than univariate models); red (loss, i.e. univariate models have better performances than multivariate models).

* Multivariate performances for Gabon were computed using the Overall population-trained model as a predictor model and tested with Gabon data.

**Supplementary Table 17: Multivariate analysis – non-malaria population; haematological and protein biomarkers**

| **Haematology + protein biomarkers** | | | | | | |
|---|---|---|---|---|---|---|
| **Overall** | | | | | | |
| **Multivariate models' variables** | | | **Classification group** | **Best multivariate model/models: mean (SD) AUROC** | **Best host-biomarker: mean (SD) AUROC** | **Multivariate AUROC gain/loss (%) ** multivariate and single host-biomarkers ratio** |
| **Rulefit** | **Logistic - RFA** | **Logistic - SW** | | | | |
| AGP<br>LBP<br>NGAL<br>neutrophil count<br>WBC count<br>Country<br>temperature<br>fever duration<br>pulse rate<br>respiratory rate | Country<br>neutrophil count<br>fever duration<br>LBP | Country<br>neutrophil count<br>fever duration<br>respiratory rate | L | SW/RFA/RF:0.75(.03) | WBC count: 0.7 (.03) | +7% |
| | | | S | SW:0.83(.04) | WBC count: 0.78(.03) | +6% |
| | | | E | SW/RFA:0.83 (.03) | WBC count: 0.77 (0.04) | +8% |
| **Brazil** | | | | | | |
| Gal-9, neutrophil count, WBC count, CRP, sPLA, respiratory rate, temperature, diastolic blood pressure, fever duration, pulse rate | neutrophil count, WBC count, respiratory rate, Gal-9 | WBC count, Gal-9 respiratory rate | L | SW: 0.82 (0.06) | WBC count: 0.8 (0.06) | +2.5% |
| | | | S | RFA: 0.82 (0.06) | WBC count: 0.8 (0.06) | +2.5% |
| | | | E | SW: 0.85 (0.06) | WBC count: 0.83 (0.07) | +2% |
| **Gabon*** | | | | | | |
| Gabon performance evaluation using the overall model and Gabon data extracted from the Overall test sets | | | L | SW/RFA: 0.7 (0.12) | WBC count: 0.7 (.03) | - |
| | | | S | SW/RFA: 0.76 (0.12) | WBC count: 0.78(.03) | -3% |
| | | | E | RFA: 0.77 (0.07) | WBC count: 0.77 (0.04) | - |
| **Malawi** | | | | | | |
| IP-10<br>Gal-9<br>LBP<br>neutrophil count | neutrophil count, WBC count<br>fever | neutrophil count<br>WBC count, fever duration, | L | SW/RFA: 0.74 (0.06) | neutrophil count: 0.72 (0.03) | +3% |

| | | | | | | |
|---|---|---|---|---|---|---|
| WBC count<br>NGAL<br>pulse rate<br>respiratory rate<br>temperature<br>diastolic blood pressure<br>fever duration | duration, IP-10 | IP-10, temperature | S | SW: 0.73 (0.06) | neutrophil count: 0.72 (0.07) | +1% |
| | | | E | RFA: 0.72 (0.6) | WBC count: 0.7 (0.) | +2% |

E, electronic classification group; S, strict classification group; L, loose classification group; RF, Rulefit; RFA, logistic recursive feature addition; SW, stepwise logistic regression. Green (gain, i.e. multivariate models have better performances than univariate models); red (loss, i.e. univariate models have better performances than multivariate models).

* Multivariate performances for Gabon were computed using the Overall population-trained model as a predictor model and tested with Gabon data.

**Supplementary Table 18: Multivariate analysis – malaria population; haematological biomarkers**

| **Haematological biomarkers** | | | | | | |
|---|---|---|---|---|---|---|
| **Overall** | | | | | | |
| **Multivariate models' variables** | | | **Classification group** | **Best multivariate model/models: mean (SD) AUROC** | **Best host-biomarker: mean (SD) AUROC** | **Multivariate AUROC gain/loss (%)** |
| **Rulefit** | **Logistic - RFA** | **Logistic - SW** | | | | |
| haematocrit<br>lymphocyte count<br>neutrophil count<br>diastolic blood pressure<br>fever duration<br>pulse rate<br>respiratory rate<br>country<br>temperature | neutrophil count<br>WBC count<br>country | lymphocyte count<br>neutrophil count<br>country | L | RFA: 0.68 (0.04) | neutrophil count: 0.65 (0.05) | +5% |
| | | | S | SW: 0.66 (0.05) | neutrophil count: 0.6 (0.08) | +10% |
| | | | E | RF: 0.69 (0.07) | neutrophil count: 0.61 (0.08) | +13% |
| **Gabon*** | | | | | | |
| Gabon performance evaluation using the Overall model and Gabon data extracted from the Overall test sets | | | L | SW: 0.67 (0.18) | neutrophil count: 0.65 (0.05) | +3% |
| | | | S | SW: 0.75 (0.2) | neutrophil count: 0.6 (0.08) | +25% |
| | | | E | Not sufficient data | | |
| **Malawi** | | | | | | |
| diastolic blood pressure<br>lymphocyte count<br>neutrophil count<br>temperature<br>WBC count<br>haematocrit<br>pulse rate<br>respiratory rate<br>fever duration | neutrophil count,<br>WBC count,<br>temperature | WBC count, | L | RFA: 0.7 (0.06) | WBC count: 0.69 (0.05) | +1% |
| | | | **S** | SW: 0.69 (0.07) | WBC count: 0.69 (0.07) | - |
| | | | **E** | RFA: 0.6 (0.14) | lymphocyte count: 0.67 (0.05) | -10% |

E, electronic classification group; S, strict classification group; L, loose classification group; RF, Rulefit; RFA, logistic recursive feature addition; SW, stepwise logistic regression. Green (gain, i.e. multivariate models have better performances than univariate models); red (loss, i.e. univariate models have better performances than multivariate models).

* Multivariate performances for Gabon were computed using the Overall population-trained model as a predictor model and tested with Gabon data.

**Supplementary Table 19: Multivariate analysis – malaria population; protein biomarkers**

| Protein biomarkers | | | | | | |
|---|---|---|---|---|---|---|
| **Overall** | | | | | | |
| **Multivariate models' variables** | | | **Classification group** | **Best multivariate model/models: mean (SD) AUROC** | **Best host-biomarker: mean (SD) AUROC** | **Multivariate AUROC gain/loss (%)** |
| **Rulefit** | **Logistic - RFA** | **Logistic - SW** | | | | |
| AGP<br>diastolic blood pressure<br>Gal-9<br>C2<br>LBP<br>pulse rate<br>respiratory rate<br>temperature<br>fever duration | C2 | country<br>respiratory rate<br>temperature<br>AGP | L | SW: 0.62 (0.07) | CHI3L1: 0.57 (0.03) | + 9% |
| | | | S | SW: 0.64 (0.04) | _NGAL: 0.6 (0.06) | + 7% |
| | | | E | SW: 0.67 (0.08) | C2: 0.63 (01) | + 6% |
| **Gabon*** | | | | | | |
| Gabon performance evaluation using the Overall model and Gabon data extracted from the Overall test sets | | | L | SW: 0.67 (0.17) | CHI3L1: 0.57 (0.03) | + 18% |
| | | | S | RFA: 0.81 (0.12) | NGAL: 0.6 (0.06) | +35%[$] |
| | | | E | Not sufficient data | | |
| **Malawi** | | | | | | |
| diastolic blood pressure<br>CHI3L1<br>IP-10<br>fever duration<br>Gal-9<br>C2<br>pulse rate<br>respiratory rate<br>temperature | respiratory rate, sPLA | respiratory rate, sPLA | L | RFA/SW: 0.57 (0.06) | IP-10: 0.57 (0.05) | - |
| | | | S | SW/RFA: 0.62 (0.09) | HCC2_PL: 0.62 (0.06) | - |
| | | | E | SW/RFA: 0.61 (0.06) | IP-10: 0.66 (0.09) | -7% |

E, electronic classification group; S, strict classification group; L, loose classification group; RF, Rulefit; RFA, logistic recursive feature addition; SW, stepwise logistic regression. Green (gain, i.e. multivariate models have better performances than univariate models); red (loss, i.e. univariate models have better performances than multivariate models).

*Multivariate performances for Gabon are computed using the Overall population-trained model as a predictor model and tested with Gabon data. [$]This output has to be considered an outlier due to biomarker data imbalance between pipeline data and the available Gabon data set.

**Supplementary Table 20: Multivariate analysis – malaria population; haematological and protein biomarkers**

| Protein + haematological biomarkers | | | | | | |
|---|---|---|---|---|---|---|
| **Overall** | | | | | | |
| **Multivariate models' variables** | | | **Classification group** | **Best multivariate model/models: mean (SD) AUROC** | **Best host-biomarker: mean (SD) AUROC** | **Multivariate AUROC gain/loss (%)** |
| **Rulefit** | **Logistic - RFA** | **Logistic - SW** | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| AGP_Pl<br>diastolic blood pressure<br>Gal-9<br>C2<br>LBP.<br>NGAL<br>neutrophil count<br>respiratory rate<br>temperature<br>pulse rate<br>fever duration | country<br>WBC count | country,<br>Wbc_c, | L | SW/RFA: 0.68 (0.04) | neutrophil count: 0.65 (0.05) | +5% |
| | | | **S** | RFA/SW: 0.66 (0.05) | neutrophil count: 0.6 (0.08) | +10% |
| | | | **E** | RFA/SW: 0.66 (0.11) | HCC2_PL: 0.63 (0.1) | +5% |
| **Gabon*** | | | | | | |
| Gabon performance evaluation using the Overall model and Gabon data extracted from the Overall test sets | | | **L** | **RFA/SW: 0.66 (0.18)** | neutrophil count: 0.65 (0.05) | +1% |
| | | | **S** | RFA/SW: 0.7 (0.2) | neutrophil count: 0.6 (0.08) | +17% |
| | | | E | Not sufficient data | | |
| **Malawi** | | | | | | |
| CHI3L1<br>IP-10<br>Gal-9<br>C2<br>neutrophil count<br>respiratory rate<br>temperature<br>diastolic blood pressure<br>pulse rate<br>fever duration | C2<br>neutrophil count<br>WBC count | WBC count | **L** | **SW: 0.69 (0.05)** | **WBC count: 0.69 (0.05)** | - |
| | | | **S** | RFA: 0.73 (0.07) | WBC count: 0.69 (0.07) | +6% |
| | | | **E** | RFA: 0.72. (0.1) | lymphocyte count: 0.67 (0.05) | +7% |

E, electronic classification group; S, strict classification group; L, loose classification group; RF, Rulefit; RFA, logistic recursive feature addition; SW, stepwise logistic regression. Green (gain, i.e. multivariate models have better performances than univariate models); red (loss, i.e. univariate models have better performances than multivariate models).

*Multivariate performances for Gabon are computed using the Overall population-trained model as a predictor model and tested with Gabon data.

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# Cross-Sectional Evaluation of Host Biomarkers for Guiding Antibiotic Use in Bacterial and Non-Bacterial Acute Febrile Illness in Low- and Middle-Income Tropical Settings



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| | |

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# Cross-Sectional Evaluation of Host Biomarkers for Guiding Antibiotic Use in Bacterial and Non-Bacterial Acute Febrile Illness in Low- and Middle-Income Tropical Settings

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## STRENGTHS AND LIMITATIONS OF THIS STUDY

- This study is the most diverse evaluations of host biomarkers across three settings in low- and middle-income countries (LMICs) to differentiate bacterial from non-bacterial infections.
- The study protocol aligns with FDA-approved classifications for distinguishing between bacterial and non-bacterial infections, enhancing methodological rigor.
- The absence of a control group limits the ability to establish baseline biomarker performance or to assess asymptomatic carriers.
- The two-step clinical classification process may introduce subjectivity, particularly as clinicians had access to hematology biomarker results during classification, potentially biasing results.

# ABSTRACT

## Objectives

To evaluate the effectiveness of 18 different host biomarkers in differentiating bacterial from non-bacterial acute febrile illness (AFI) in resource-limited settings, specifically in Brazil, Malawi, and Gabon.

## Design

Multinational, cross-sectional study

## Setting

The study was carried out across multiple primary healthcare facilities, including urban and rural settings, with a total of three participating centers. Recruitment took place from October 2018 to July 2019 in Brazil, May to November 2019 in Gabon, and April 2017 to April 2018 in Malawi.

## Participants

A total of 1,915 participants, including children and adults aged 21 to 65 years with a fever of ≤7 days, were recruited through convenience sampling from outpatient clinics in Brazil, Gabon, and Malawi. Individuals with signs of severe illness were excluded. Written consent was obtained from all participants or their guardians.

## Intervention

Not applicable as the study primarily focused on biomarker evaluation without specific therapeutic interventions.

## Primary and Secondary Outcome Measures

The primary outcome measure was the ability of each host biomarker to differentiate between bacterial and non-bacterial AFI, as evaluated by area under the receiver operating characteristic (AUROC) curves. Secondary outcomes included the performance of individual biomarkers across the different study sites and in a multivariable setting.

**Results**

A Kruskal-Wallis test, adjusted by Benjamini-Hochberg, was performed for each biomarker to identify covariates significantly affecting biomarker values. The analysis revealed that country of origin (Brazil, Gabon, Malawi), age, sex, and malaria status significantly impacted biomarker distribution ($p \leq 0.001$). The most widely known biomarkers, such as white blood cell count and C-reactive protein (CRP), demonstrated the best performance in distinguishing between bacterial and non-bacterial infections, with AUROCs reaching up to 0.83 [0.77 - 0.88] for white blood cell count and 0.71 [0.59 - 0.82] for CRP. However, none of the evaluated novel host biomarkers exhibited high performance (AUROC < 0.70 in most cases), and variations in biomarker performance were observed across the three settings. Multivariable analyses demonstrated that while the best combination of biomarkers achieved higher AUROCs, the increase was modest (1–13%), suggesting that the interaction of biomarkers contributed minimally to predictive accuracy.

**Conclusions**

There is a continued need for innovation in the host-biomarker space as the available markers do not meet the needs of diverse populations around the globe. This highlights the importance of targeted evaluations in non-severe patients in multiple settings to understand true potentials for real-life use. The findings highlight that not one-marker fits all settings and novel innovations remain urgently needed.

**Trial Registration**

Clinical trial number: NCT03047642

**Keywords**

Antimicrobial Resistance, AMR, CRP, Host Biomarkers, Prospective study, biomarker, non-malaria fever, primary health care, Malawi, Brazil, Gabon

## INTRODUCTION

Globally, acute febrile illness (AFI) is one of the leading reasons individuals, particularly children aged less than 5 years, present to primary healthcare facilities [1]. AFI has various causes, both infectious and non-infectious, that vary according to geography, age group, and season [1]. In malaria-endemic settings, malaria was long considered the primary cause of all fevers; however, the introduction of rapid diagnostic tests (RDTs) for malaria in the past decade has disproved this. Modelling estimates suggest that approximately 70% of all fevers can be attributed to non-malarial causes, even in malaria-endemic settings [2]. In the Integrated Management of Childhood Illness (IMCI), introduced by the World Health Organization (WHO) and UNICEF in the mid-1990s and subsequently implemented in more than 100 countries, the standard "fever" algorithm currently includes a malaria RDT but no diagnostic test for other infections [3]. Hence, at primary care level, the only evidence-based treatment decision that can be made relies on the malaria RDT, resulting in extremely high levels of antibiotic use in malaria-negative patients [4]. In this context of limited knowledge about the causes of AFI and limited diagnostic and human capacity, it is unsurprising that healthcare providers prescribe antibiotics to avoid negative outcomes in their patients.

To assist healthcare providers with clinical decision-making, a simple diagnostic tool is required to differentiate patients with AFI of bacterial and non-bacterial aetiology and provide appropriate care. In well-resourced settings, in both high-income countries (HICs) and low- and middle-income countries (LMICs), some nonspecific host-biomarkers are used for this purpose, most frequently C-reactive protein (CRP) and procalcitonin (PCT), although these biomarkers are less useful in settings with a higher frequency of comorbidities [5]. Thus, in 2015, an international group of experts was convened to define the target product profile (TPP) of such a tool, specifically for low-resource settings, to guide product development and implementation as part of integrated treatment management guidelines [6]. Since then, the

ongoing viral pandemic (SARS-CoV-2) has further highlighted the challenge of differential diagnosis and shows yet again that better antimicrobial stewardship interventions are needed to counter the overprescribing of antibiotics in patients with viral infections [7].

Host biomarkers other than CRP and PCT have been evaluated for distinguishing bacterial from non-bacterial infections, including human neutrophil lipocalin (HNL), heparin-binding protein (HBP), and chitinase 3-like protein 1 (CHI3L1) [8]. There are also some commercially available tests. ImmunoXpert™, from MeMed, uses a biomarker combination comprising CRP, interferon gamma-inducible protein 10 (IP-10), and TNF-related apoptosis-inducing ligand (TRAIL), while FebriDx®, from Lumos Diagnostics, uses an MxA and CRP biomarker combination. While these biomarker signatures show promise, they have only been evaluated in limited settings. Any potential impact of co-infections or comorbidities, common in LMICs, on their effectiveness is unknown. Other characteristics of host-biomarker studies that hamper direct comparisons include: (i) just one/a few biomarkers in the study; (ii) small sample sizes, increasing the probability of recruiting unrepresentative study populations; (iii) narrow population subgroups (e.g. children only, hospitalised only, respiratory infections only, etc), limiting the generalisability of study results to the broader AFI population; (iv) studies conducted in one country, so co-infections/comorbidities may not be comparable with those of other countries; (v) retrospective studies that used convenience sampling and case-control study designs, increasing the risk of bias; and (vi) the lack of a standard definitions for classifying bacterial versus non-bacterial infections [9].

Here, we describe the Biomarker for Fever Diagnostic (BFF-Dx) study, specifically designed to evaluate host biomarkers to distinguish bacterial from non-bacterial infections in line with the published TPP and the final use case of such diagnostic tests. To our knowledge, this is the only study to evaluate host biomarkers in the intended target population (non-severe patients), prospectively, in multiple settings with a large sample set. We evaluated 18 host-biomarkers in

three distinct settings, in Brazil, Gabon, and Malawi with the main objective to provide a performance comparison of host biomarkers in the non-severe AFI population from resource-limited settings, with the goal to overcome many of the previously described limitations (eg. sample size, retrospective vs prospective, focused populations, biased analysis) [10]. The described comparison was conducted within the pragmatic context of diagnostic product development and aimed to identify host biomarkers or biomarker combinations for utilisation in next-generation rapid diagnostic tests.

# METHODOLOGY

## Study settings

This multinational, cross-sectional study was conducted in Brazil, Gabon, and Malawi; Gabon and Malawi were selected as high-malaria endemicity settings, while Brazil was selected as a low-malaria endemic setting. The study sites were UPA Manguinhos and Family Health Clinics Armando Palhares in Rio de Janeiro, Brazil; the Clinical Trials Unit Center of Medical Research Lambaréné (CERMEL), Lambaréné, Gabon; and Malawi Epidemiology and Intervention Research Unit (MEIRU), Chilumba campus, Malawi. The enrollment sites were an urban primary healthcare facility, a hospital in a semi-rural setting, and a rural primary healthcare facility in Brazil, Gabon, and Malawi, respectively. Participants were recruited from October 2018 to July 2019, May to November 2019, and April 2017 to April 2018, in Brazil, Gabon, and Malawi, respectively. The study protocol was submitted to clinicaltrial.gov (NCT03047642) and ethical approval was obtained from all relevant institutional committees in Brazil (Research Ethics Committee of INI-FIOCRUZ and Comissão Nacional de Ética em Pesquisa [Ref:2.235.565] ; National Research Ethics Committee), Gabon (Comité National d'Ethique pour la Recherche [RefNr:N°0078/2019PR/SG/CNER]) and Malawi (National Health Science Research Committee [ApprovalNr: 16/9/1668] ; Observational and Intervention Research Ethics Committee of the London School of Hygiene and Tropical Medicine , UK [LSTMH Ref: 11974]) and all details of the design have been previously published [10]. Reporting complies with the STARD-15 checklist.

## Study population and study procedure

Participants were obtained through convenience sampling and included both children and adults, aged between 2 and 65 years, who presented at the outpatient clinics with a history of fever of ≤7 days duration (Brazil and Gabon) or fever at presentation (Malawi). Patients with

signs of severe illness were not included in the study. The overarching study protocol was slightly adapted to each site due to local requirements (logistical or ethical). Detailed criteria for inclusion by study sites have been published previously [10]. Outcomes were based on the TPP criteria and while no patient input was used, external expert input was used to define target population and criteria. Only patients who met the eligibility criteria and who provided written consent (patient or guardian for children) were enrolled in the study. Data and samples were systematically collected and analysed as previously described. To ensure consistent quality and comparability of data, the same standard operating procedures were used at all sites (for data collection and laboratory testing) [10].

**Patient and Public Involvement statement**

None

**Bacterial/non-bacterial classification and biomarker selection and testing**

A two-step process was used to classify the patients into "bacterial" and "non-bacterial" groups. First, the cause of fever (bacterial/non-bacterial) was classified according to laboratory-determined parameters ("electronic group"). The electronic group was based on predefined and widely accepted laboratory parameters, including direct pathogen detection, a fourfold increase in anti- body titre, or a positive PCR or antigen RDT result. The list of tests performed is described in detail in by Escadafal et al. [10]. Next, cases that could not be classified by laboratory-determined parameters were assessed by a panel of three independent clinical experts. Patient's history and clinical and laboratory data was provided to the experts. Clinical expert's assessments were then compared.If the three panel members unanimously assigned a diagnostic label, patients were considered to have "bacterial" or "non-bacterial" infections; if two out of three panel members reported a classification of "bacterial" or "non-bacterial", these

patients were considered to have “probable bacterial infection” or “probable non-bacterial infection”, respectively.

Data were analysed based on three groups of patients: 1) the “electronic group”, i.e. subjects with a cause of fever defined based on laboratory parameters; 2) the “strict group”, which comprised the electronic group and the patients that were unanimously classified by the clinical panel of three experts; and 3) the “loose group”, which comprised the electronic and strict groups as well as those patients for whom two of the clinical experts agreed they had either probable bacterial or probable non-bacterial infection. Subjects with undetermined cause of fever according to the three classification criteria considered (“electronic group”, “strict group”, “loose group”) were excluded from the statistical analysis. This outcome-oriented approach, based on methods previously developed for host-biomarker studies and described previously, was used to ensure the total intended-use population of any future test was represented in the final analysis [10, 11].

The evaluated biomarkers were selected based on previously reported performances, and haematological markers as well as CRP were included as comparators (Table 1 and Supplementary Table 1 and 2) [8, 12].

At the end of data collection, all biomarker data were analysed to assess the percentage of missing values and the percentage of values below the lower limit or above the upper limit of detection of the used tests. Biomarkers with more than 50% of missing data or more than 95% of saturated values below the lower limit of quantification of the used test, were excluded from the following statistical analysis.

**Table 1**. Novel biomarkers identified in the literature and evaluated in the BFF-Dx study, including sample type used, evaluation method, and sample origin.

| Abbreviation | Biomarker name | Sample type | Evaluation method | Sample origin |
|---|---|---|---|---|
| AGP | A-1-acid glycoprotein | EDTA-plasma | Luminex | B, G, M |
| C2 | Complement 2 | EDTA-plasma | Luminex | B, G, M |
| C4b | Complement C4b | EDTA-plasma | Luminex | B, G, M |
| CHI3L1 | Chitinase-3-like protein 1 | EDTA-plasma | Luminex | B, G, M |
| CRP | C-reactive protein | EDTA-plasma | CRP Nycocard/ NycoCardReader II, ELISA | B, G, M |
| Gal-9 | Galectin-9 | EDTA-plasma | Luminex | B, G, M |
| HBP | Heparin-binding protein | EDTA-plasma | ELISA | B, M |
| HNL | Human neutrophil lipocalin | Heparin-activated plasma time-controlled activation# | ELISA | M |
| | | EDTA-plasma | ELISA | B, G, M |
| HP | Haptoglobin | EDTA-plasma | Luminex | B, G, M |
| IFN-gamma | Interferon gamma | EDTA-plasma | Luminex | B, G, M |
| IL-4 | Interleukin-4 | EDTA-plasma | Luminex | B, G, M |
| IL-6 | Interleukin-6 | EDTA-plasma | Luminex | B, G, M |
| IP-10 | Gamma-induced protein 10 | EDTA-plasma | Luminex | B, G, M |
| LBP | Lipopolysaccharide binding protein | EDTA-plasma | Luminex | B, G, M |
| NGAL | Neutrophil gelatinase-associated lipocalin | Frozen heparin-activated plasma | Luminex | M |
| | | EDTA-plasma | Luminex | B, G, M |
| PCT | Procalcitonin | EDTA-plasma | Luminex; ELISA | B, G, M |
| sPLA2 | Secretory phospholipase 2 | EDTA-plasma | Luminex | B, G, M |
| sTREM-1 | Soluble triggering receptor expressed on myeloid cells 1 | EDTA-plasma | Luminex | B, G, M |
| TRAIL | TNF-related apoptosis-inducing ligand | EDTA-plasma | Luminex | B, G, M |

B, Brazil; G, Gabon; M, Malawi

# Whole blood samples were collected in lithium heparin tubes and activation was performed within 60 min prior to freezing and subsequent ELISA testing [13]. All biomarkers were tested using the same standard operating procedures (SOPs) and all sites were trained on the SOPSs. For CRP and PCT different devices were used at different sites, repeat testing was performed at the central facility (NMI).

## Statistical analysis

a. Kruskal-Wallis Analysis and Definition of Covariates Influence on Biomarkers

A Kruskal-Wallis test, adjusted by Benjamini-Hochberg, was performed for each biomarker to identify which covariates significantly affect the biomarker value. The covariates studied were country (i.e., the country of origin of the patients), age, sex, malaria status, comorbidities (i.e., presence of one or more diseases among cardiovascular, neurological, respiratory, renal, genitourinary, connective tissue, cancer, or infectious diseases), malnutrition status calculated based on WHO body mass index criteria, self-reported use of antibiotics prior to visiting the health facility, axillary temperature ≥38°C, and positive result to Chikungunya test. The Kruskal-Wallis test was performed for each of the three patient groups defined in the previous section ("electronic", "strict", "loose"). The results of the Kruskal-Wallis test allowed the identification of covariates that most significantly impacted the biomarker distribution ($p \leq 0.001$, adjusted by Benjamini-Hochberg). The most significant covariates were considered for defining subgroups of patients in which the following univariate analyses were performed, or included as covariates in the multivariable analyses.

b. Univariate analysis

As an exploratory step, the ability of each biomarker to discriminate between bacterial and non-bacterial infections was assessed by the area under the receiver operating characteristic curve (AUROC). In particular, subjects were ranked based on the values of the single variable of interest (i.e. based on ordered values) and, using this as score, calculated the ROC curve and the corresponding area under the curve. Such univariate analysis was conducted for each patient group ("electronic", "strict", "loose") and specific patient subgroup (Malaria status, Country and Age).

However, since the univariate analyses did not yield satisfactory results, we also explored multivariable models to potentially improve the predictive capabilities by incorporating a broader range of information.

c. Multivariable analysis

Multivariable classification models were developed to assess the discrimination ability of combinations of biomarkers and covariates. For the multivariable analysis, both linear (logistic regression) and non-linear classification models (RuleFit) were explored [14]. The candidate features for each model included a group of host-biomarkers and some additional covariates (age, temperature, fever duration, diastolic blood pressure, respiration rate, and pulse rate). Regarding host-biomarkers, three different groups of biomarkers were considered: haematology biomarkers only (i.e. white blood cell, neutrophil, red blood cell, lymphocyte counts), protein biomarkers only (i.e. novel biomarkers + CRP), and haematology plus protein biomarkers (i.e. all biomarkers).

For each patient subgroup and each candidate feature set, three multivariable models were developed: i) a logistic regression model with stepwise (SW) feature selection; ii) a logistic regression model with features selected based on recursive feature addition (RFA; a variant of the method proposed in [15]); iii) RuleFit, a non-linear model in which a set of rules from an ensemble of decision trees (typically from a tree-based model like a Random Forest or Gradient Boosted Trees) is generated and then fit a sparse linear regression model (regularized with LASSO), where the features are the rules generated from the trees [14, 15]. To further tackle the number of biomarkers and variables included in the best models, we introduced an additional selection step, employing a plateau seeking approach. The primary objective of this approach was to pinpoint a concise set of variables capable of attaining an AUROC score similar to that of our comprehensive model, which already incorporated the

most impactful and previously selected variables. This was to ensure that our model is not only effective in terms of performance but also efficient in its variable inclusion.

Each model was trained and tested using the following pipeline. The data were randomly split into training and test sets (80% and 20% of the data, respectively) stratifying by the outcome variable. Missing data in the training and test sets were imputed using the MICE (multiple imputation by chained equation) algorithm. The n_imp parameter for MICE imputation was set to 1, resulting in a single imputed dataset; however, the imputation process was integrated in a robust bootstrapping pipeline, generating ten independent datasets. This approach ensured variability in our results, stemming not only from the MICE imputation but also from the bootstrapping process. This dual approach guarantees that each imputed dataset is distinct [16]. All quantitative variables were scaled into the range [0,1] by subtracting their minimum value and dividing by the difference between the maximum and minimum values in the training set. The categorical variables with n categories were encoded using n-1 binary "dummy" variables. The model was then trained on the imputed and scaled training set, and its performance was assessed on the imputed and scaled test set by computing the AUROC. The AUROC on the test set was also calculated for single host biomarkers, to allow a fair comparison of the performance of the multivariable classification models vs. single host biomarkers.

To assess the robustness and variability in the results of the developed models, the entire pipeline were bootstrapped, i.e. it was run ten times with different random training-test set splits. Finally, the mean and the standard deviation (SD) or the minimum and maximum reached of the AUROC across the ten training-test splits were calculated for each multivariable model and each single host biomarker.

a. Software

All statistical analyses and model development were performed using the R programming language (version 4.1.2). Specifically, the *mice* package was used for data imputation, while

the *pre* and *stats* packages were used for RuleFit and logistic regression model development, respectively.

# RESULTS

## Study population

In total, 1915 patients with AFI were included in the study (Brazil: n=500; Gabon: n=415; Malawi: n=1000). Just under half (862/1915, 45%) of participants at each study site were male. Children aged <5 years comprised 45/500 (9%), 182/415 (43·9%), and 367/1000 (36·7%) participants in Brazil, Gabon, and Malawi, respectively; the median (range) age was 3 (2–4) years (Table 2). Detailed baseline characteristics of patients and analyses of differences will be described in a separate manuscript (Alabi et al in preparation).

328 **Table 2: Baseline characteristics of patients.**

| | Brazil | Gabon | Malawi | All |
|---|---|---|---|---|
| 0–5 years (median, IQR, n) | 3, [2-4], 45 | 3, [2-5],182 | 3, [2-5], 367 | 3, [2-4], 594 |
| 5–15 years (median, IQR, n) | 11, [8-14], 85 | 9, [7-12], 214 | 9 [7-12], 276 | 9, [7-12], 575 |
| >15 years (median, IQR, n) | 34, [24-45], 370 | 16, [16-16·5], 19 | 28, [21-38], 357 | 30, [21-42], 746 |
| Male (%, n) | 49·6%, 248 | 45·1%, 187 | 42·7%, 427 | 45·0%, 862 |
| Temperature, °C (median, IQR, n) | 37·7, [36·7-38·4], 500 | 36·8, [36·4-37·4], 415 | 38·1, [37·1-38·8], 999 | 37·8, [37·3-38·5], 1914 |
| WBC count, $10^9$/L (median, IQR, n) | 7·28, [5·47-10·39], 494 | 7·7, [5·7-10], 411 | 6·7, [5·1-9·1], 985 | 7·1, [5·3-9·8], 1890 |
| Neutrophil count, $10^9$/L (median, IQR, n) | 4·97, [3·63-7·4], 494 | 2·77, [1.96-3·9], 408 | 4·3, [3·1-6·8], 906 | 4·1, [2·8-6], 1812 |
| RBC count, $10^9$/L (median, IQR, n) | 40·1, [36·5-43·2], 494 | 33·2, [29·4-35·8], 412 | 36·2, [33·1-39·5], 984 | 36·3, [33-40·2], 1892 |
| Lymphocyte count, $10^9$/L (median, IQR, n) | 1·15, [0·7-1·99], 493 | 2·73, [1·8-4·16], 411 | 1·5, [1·1-2·2], 982 | 1·63, [1-2.6], 1883 |
| CRP NycoCard# – mg/L (median, IQR, n) | 70·5, [35-98·75], 498 | 28, [5-73], 415 | 47, [12-106·5], 987 | 49, [13-98], 1900 |
| Malaria-positive by RDT on-site (% all, n) | 0·2%, 1 | 56·4%, 234 | 45·9%, 458 | 36·2%,693 |
| Malaria-positive by qPCR or microscopy (% all, n) | - | - | 50·5%, 505 | - |
| HIV-positive by RDT (% all, n) | 1·4%, 7 | 1·2%, 5 | 4·2%, 42 | 2·8%,54 |
| History of antibiotic-use pre-presentation (% all, n) | 8·8%, 44 | 2·41%, 10 | 7·2%, 72 | 6·5%,124 |
| History of antipyretic-use pre-presentation (% all, n) | 83·2%, 416 | 79·76%, 331 | 55·1%, 551 | 62·2%,1298 |
| Cough (%, n) | 35·8%, 179 | 30·1%, 125 | 48·2%, 482 | 41%, 786 |

| | | | | |
|---|---|---|---|---|
| Diarrhea or vomiting (%, n) | 31·8%, 159 | 28·9%, 120 | 27·5%, 225 | 28·9%, 554 |
| Dysuria or urinary urgency (%, n) | 0·9%, 45 | 5·12%, 21 | 7·6%, 73 | 7·4%, 142 |
| Headache (%, n) | 76·4%, 382 | 46·5%, 193 | 71·1%, 1151 | 67·2%, 1286 |
| Sore throat or swallow pain (%, n) | 39%, 195 | 8·92%, 37 | 15·8%, 128 | 20%, 390 |
| Rash (%, n) | 24·4%, 122 | 4·1%, 17 | 2·5%, 20 | 8·6%, 164 |

# NycoCard was found to be equivalent to reference testing in the relevant range (Supplementary Figure 1). CRP, C-reactive protein; IQR, interquartile range; qPCR, quantitative PCR; RBC, red blood cell; RDT, rapid diagnostic test; WBC, white blood cell; -: data not available

**Bacterial and non-bacterial outcomes by classification groups**

Using the electronic classification grouping, 15·1% (290/1915) of cases were bacterial infections, 20·2% (387/1915) were non-bacterial infections, and 64.5% (1238/1915) had an undetermined cause of fever (Figure 1). Under the strict classification grouping, 24·3% (366/1509), 66.9% (1010/1509), and 9·0% (133/1509) were classified as bacterial, non-bacterial, and undetermined infections, respectively, while using the loose classification grouping 25·7% (491/1915), 67·3% (1286/1915), and 7·0% (133/1915) were classified as bacterial, non-bacterial, and undetermined infections, respectively (Figure 1). Subjects with undetermined cause of fever/infections were excluded from the following univariate and multivariable analyses.

**Exclusion of biomarkers with too many missing or saturated values**

The biomarkers C4b, HNL and PCT had more than 50% missing values and were therefore excluded. The high number of missing values is due to fact that biomarkers were analysed in groups based on the required dilution using Luminex platform. For some biomarkers the dilution was not optimal, and it was only possible to re-measure biomarkers with a different dilution a limited number of times. IFN-gamma and sTREM-1 were excluded due to more than 95% of values saturated to the minimum/maximum level detectable by the measurement instrument. All the biomarkers retained in the analysis had less than 12% missing values (Supplementary Table 3).

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**Identification of relevant subgroups for analyses**

According to the Kruskal-Wallis analysis on the "electronic group", the variables "country", "malaria status" and "age" had a strong ($p \leq 0{\cdot}001$) or high ($0{\cdot}001 \leq p < 0{\cdot}01$) effect on many of the host biomarkers (Supplementary Table 4). The variables "sex", "comorbidities", "history of antibiotic use" showed no ($p > 0{\cdot}05$) or slight ($p \leq 0{\cdot}05$) associations with all the host biomarkers. The effects of "chikungunya status" and "fever above 38°C" were generally significant ($p \leq 0.01$), but the sample sizes for these groups were either too small or exhibited an imbalance. Additionally, while we conducted subgroup analyses by clinical syndromes (i.e. cough, diarrhea or vomiting, dysuria or urinary urgency, headache, sore throat or swallow pain, rash), the resulting datasets were similarly limited in size, restricting our ability to make robust interpretations from these analyses. The primary focus remained centered on populations grouped by study country and malaria status variables - both of which were strongly associated with the biomarker value in the "strict" and "loose" groups (Supplementary Table 5, 6) - other significant covariates were also included in the multivariable analysis. This inclusion was due to their influence, and factors like the study country were considered as variables in the overall scenario.

**Individual host-biomarker performance – univariate analysis**

The performance of 18 host biomarkers was consistent across the three patient classification groups in each of the settings (Table 3). White blood cell (WBC) and neutrophil counts were the most effective biomarkers for differentiating bacterial and non-bacterial infections. For the malaria-negative population, the mean (95% confidence interval) of AUROC for WBCs was between 0·60 (0·48–0·72) and 0·83 (0·77–0·88) and for neutrophils it was between 0·67 (0·57–0·77) and 0·80 (0·74–0·86) across the three countries and the three groups ("electronic",

"strict", "loose"). Neutrophil and WBC counts showed the highest AUROCs in the Brazilian population, between 0·80 (0·74–0·86) and 0·83 (0·77–0·88), respectively. All protein biomarkers showed relatively poor performances (<0·7 in most cases, Table 4) in all three settings. Galactin-9, CRP, IP-10, and NGAL were the best-performing protein biomarkers across the three settings and criteria. Protein biomarkers showed better performances in Malawi and Gabon, as in Brazil most protein biomarkers showed performances of <0·6. When the biomarker results were stratified by age, the AUROCs were slightly higher for children (≤15 years) compared with those seen for adults in the malaria-negative population (Supplementary Tables 9-11). Among the malaria-positive population, WBC, lymphocyte, and neutrophil counts were the best-performing biomarkers in both Gabon and Malawi (in most cases between 0·6 and 0·7).

**Table 3: Univariate analysis of 18 individual biomarkers# among malaria-negative patients for all three countries (a-c).**

Common biomarkers such as CRP and haematological biomarkers were included for reference. In this context we defined performance as follows: green (AUROC ≥0·7), yellow (AUROC > 0·65 and <0.7), orange (AUROC 0·6–0·65), and red (AUROC <0·6).

**a) Brazil**

| | Brazil AUROC** (CI), N | | |
|---|---|---|---|
| | Electronic | Strict | Loose |
| **Haematological biomarkers** | | | |
| Lymphocyte count | 0·67 (0·59-0·74), 257 | 0·66 (0·59-0·72), 408 | 0·66 (0·6-0·72), 442 |
| Neutrophil count | 0·77 (0·7-0·84), 257 | 0·8 (0·74-0·86), 408 | 0·79 (0·73-0·84), 442 |
| RBC count | 0·61 (0·52-0·69), 258 | 0·58 (0·51-0·65), 408 | 0·58 (0·51-0·64), 442 |
| WBC count | 0·81 (0·75-0·87), 257 | 0·83 (0·77-0·88), 408 | 0·82 (0·77-0·87), 442 |
| **Protein biomarkers** | | | |
| AGP | 0·59 (0·51-0·68), 252 | 0·54 (0·47-0·61), 402 | 0·52 (0·46-0·59), 434 |
| Chitinase 3-like 1 | 0·58 (0·5-0·66), 246 | 0·54 (0·47-0·6), 394 | 0·55 (0·49-0·61), 424 |
| CRP* | 0·61 (0·52-0·69), 259 | 0·61 (0·54-0·68), 412 | 0·62 (0·55-0·68), 446 |
| IP-10/IP-10/CRG-2 | 0·6 (0·52-0·68), 252 | 0·53 (0·46-0·59), 402 | 0·53 (0·47-0·59), 434 |
| Galectin-9 | 0·63 (0·55-0·71), 252 | 0·56 (0·49-0·63), 401 | 0·57 (0·5-0·63), 433 |
| hCC2 | 0·51 (0·43-0·6), 244 | 0·51 (0·44-0·58), 392 | 0·52 (0·46-0·59), 424 |
| HBP*** | 0·67 (0·52-0·81), 113 | 0·68 (0·55-0·8), 144 | 0·64 (0·51-0·76), 151 |

| | | | |
|---|---|---|---|
| **HPTGN** | 0·48 (0·4-0·57), 248 | 0·51 (0·44-0·58), 398 | 0·51 (0·45-0·58), 430 |
| **IL-4** | 0·58 (0·5-0·65), 249 | 0·53 (0·47-0·59), 398 | 0·54 (0·48-0·59), 429 |
| **IL-6** | 0·49 (0·43-0·54), 247 | 0·49 (0·44-0·54), 395 | 0·48 (0·43-0·52), 426 |
| **LBP** | 0·58 (0·5-0·66), 248 | 0·54 (0·48-0·61), 397 | 0·52 (0·46-0·58), 429 |
| **Lipocalin-2/NGAL** | 0·49 (0·41-0·57), 249 | 0·51 (0·44-0·57), 396 | 0·51 (0·44-0·57), 428 |
| **sPLA/Lp-PLA2** | 0·54 (0·46-0.62), 252 | 0·53 (0·46-0·59), 402 | 0·52 (0·45-0·58), 434 |
| **TRAIL** | 0·56 (0·49-0·64), 252 | 0·53 (0·47-0·59), 402 | 0·53 (0·48-0·59), 434 |

**b) Gabon**

| | Gabon AUROC** (CI), N | | |
|---|---|---|---|
| | **Electronic** | **Strict** | **Loose** |
| **Haematological biomarkers** | | | |
| **Lymphocyte count** | 0·58 (0·45-0·71), 81 | 0·52 (0·4-0·63), 167 | 0·55 (0·45-0·65), 222 |
| **Neutrophil count** | 0·78 (0·66-0·89), 80 | 0·72 (0·62-0·83), 165 | 0·67 (0·57-0·77), 219 |
| **RBC count** | 0·55 (0·41-0·68), 81 | 0·52 (0·41-0·63), 167 | 0·53 (0·43-0·63), 222 |
| **WBC count** | 0·67 (0·54-0·79), 81 | 0·6 (0·48-0·72), 167 | 0·61 (0·5-0·71), 222 |
| **Protein biomarkers** | | | |
| **AGP** | 0·77 (0·65-0·9), 80 | 0·7 (0·59-0·82), 163 | 0·65 (0·55-0·75), 220 |
| **Chitinase 3-like 1** | 0·6 (0·46-0·74), 79 | 0·6 (0·48-0·72), 162 | 0·62 (0·52-0·72), 217 |
| **CRP*** | 0·71 (0·59-0·82), 81 | 0·65 (0·55-0·75), 167 | 0·63 (0·53-0·72), 224 |
| **IP-10/IP-10/CRG-2** | 0·6 (0·48-0·73), 80 | 0·51 (0·4-0·62), 164 | 0·52 (0·43-0·62), 221 |
| **Galectin-9** | 0·7 (0·58-0·83), 80 | 0·6 (0·48-0·71), 163 | 0·54 (0·43-0·64), 219 |
| **hCC2** | 0·55 (0·41-0·69), 77 | 0·52 (0·4-0·64), 159 | 0·51 (0·41-0·61), 216 |
| **HBP***** | .. | .. | .. |
| **HPTGN** | 0·64 (0·5-0·78), 77 | 0·62 (0·51-0·74), 159 | 0·55 (0·45-0·66), 214 |
| **IL-4** | 0·46 (0·4-0·52), 79 | 0·49 (0·45-0·53), 163 | 0·51 (0·47-0·55), 220 |
| **IL-6** | 0·51 (0·47-0·55), 80 | 0·51 (0·48-0·55), 164 | 0·51 (0·47-0·55), 221 |
| **LBP** | 0·69 (0·56-0·83), 78 | 0·67 (0·55-0·78), 160 | 0·6 (0·5-0·71), 217 |
| **Lipocalin-2/NGAL** | 0·67 (0·54-0·8), 79 | 0·6 (0·49-0·72), 163 | 0·58 (0·48-0·68), 219 |
| **sPLA/Lp-PLA2** | 0·58 (0·44-0·71), 80 | 0·54 (0·43-0·65), 164 | 0·58 (0·48-0·68), 221 |
| **TRAIL** | 0·5 (0·5-0·5), 74 | 0·5 (0·49-0·5), 156 | 0·49 (0·48-0·5), 212 |

**c) Malawi**

| | Malawi AUROC** (CI), N | | |
|---|---|---|---|
| | **Electronic** | **Strict** | **Loose** |
| **Haematological biomarkers** | | | |
| **Lymphocyte count** | 0·56 (0·47-0·66), 154 | 0·51 (0·45-0·58), 303 | 0·52 (0·47-0·58), 461 |
| **Neutrophil count** | 0·67 (0·58-0·77), 143 | 0·73 (0·67-0·79), 273 | 0·7 (0·65-0·76), 414 |
| **RBC count** | 0·46 (0·36-0·56), 155 | 0·53 (0·46-0·59), 305 | 0·56 (0·5-0·61), 463 |
| **WBC count** | 0·69 (0·6-0·78), 155 | 0·72 (0·66-0·78), 304 | 0·68 (0·63-0·73), 461 |
| **Protein biomarkers** | | | |
| **AGP** | 0·56 (0·46-0·66), 158 | 0·54 (0·48-0·6), 309 | 0·54 (0·49-0·59), 466 |
| **Chitinase 3-like 1** | 0·49 (0·39-0·59), 155 | 0·5 (0·43-0·56), 304 | 0·5 (0·44-0·55), 462 |
| **CRP*** | 0·55 (0·45-0·65), 156 | 0·6 (0·54-0·67), 305 | 0·58 (0·53-0·63), 462 |
| **IP-10/IP-10/CRG-2** | 0·66 (0·56-0·75), 158 | 0·6 (0·53-0·66), 309 | 0·61 (0·56-0·66), 466 |

| | | | |
|---|---|---|---|
| **Galectin-9** | 0·71 (0·62-0·8), 158 | 0·61 (0·55-0·67), 309 | 0·63 (0·57-0·68), 466 |
| **hCC2** | 0·59 (0·49-0·69), 158 | 0·55 (0·49-0·62), 309 | 0·55 (0·5-0·6), 466 |
| **HBP*** ** | 0·53 (0·39-0·68), 63 | 0.55 (0.44-0·66), 106 | 0·52 (0·41-0·63), 124 |
| **HPTGN** | 0·54 (0·45-0·64), 157 | 0·51 (0·45-0·58), 307 | 0·51 (0·46-0·57), 464 |
| **IL-4** | 0·48 (0·4-0·57), 157 | 0·48 (0·42-0·53), 306 | 0·47 (0·42-0·51), 463 |
| **IL-6** | 0·56 (0·47-0·65), 158 | 0·61 (0·55-0·67), 307 | 0·59 (0·54-0·64), 465 |
| **LBP** | 0·52 (0·42-0·61), 157 | 0·54 (0·47-0·61), 267 | 0·53 (0·47-0·59), 394 |
| **Lipocalin-2/NGAL** | 0·56 (0·46-0·66), 156 | 0·65 (0·59-0·72), 265 | 0·61 (0·56-0·67), 392 |
| **sPLA/Lp-PLA2** | 0·58 (0·47-0·68), 158 | 0·55 (0·49-0·61), 308 | 0·56 (0·51-0·61), 466 |
| **TRAIL** | 0·61 (0·51-0·71), 157 | 0·62 (0·56-0·68), 306 | 0·62 (0·57-0·67), 463 |

*CRP was measured with a NycoCard device. **AUROC has a value between 0 and 1, where 1 corresponds to an effect classifier, 0·5 to one that assigns classes randomly. #Freeze–thaw experiments to evaluate the stability of the biomarkers after five cycles (referred to as "treated") were performed with Luminex 9- and 2-plexes. Three samples each were freeze–thawed up to six times and compared with samples after the first thawing (referred to as "untreated"; biomarkers were considered stable with 80–120% recovery). Samples were analysed in triplicate and showed good stability up to five freeze–thaw cycles for all analytes showing acceptable results, except for the C2 and C4b biomarkers (C2: 2/3 [66·7%] samples were stable; C4b: two samples failed the sixth freeze–thaw cycle). As a result, these biomarkers were excluded as they would never be suitable as the basis of a diagnostic test. ***HBP was evaluated in a small group of patients in Malawi and Brazil; however, HBP did not show promise and was not evaluated further.

**Combinations of host-biomarkers and additional covariates – multivariable analysis**

The best-performing biomarkers in the univariate analysis were compared with the best performances from the multivariable analyses, which several feature-selected biomarkers and covariates (Table 4 and Supplementary Tables 15-20). In most cases the best combination of biomarkers showed higher AUROCs than the top-performing individual biomarkers, with a low/moderate "gain" (range 1–13%). The best-performing AUROCs were very similar, irrespective of the multivariable model used, especially for the "strict" and "loose" groups (difference in AUROC range 0·02–0·03 for Malawi and Brazil). Biomarkers identified as top performing by the multivariable analyses differed depending on the model used. While SW and RFA selected three to five biomarkers or combinations, RuleFit selected more biomarkers (ten variables on average) to be part of the signature. The relatively low increase in AUROC when comparing the top-performing single biomarker with multivariable models indicates that biomarkers in addition to the single best-performing biomarker do not make a major contribution.

**Table 4: Multivariable analysis of biomarkers among malaria-negative patients, including the gain/loss of performance when comparing multivariable analysis and single host-biomarkers comprising both haematological and protein host-biomarkers.**

| Classification group | Best multivariable model/models: mean (min-max) AUROC | Best host-biomarker: mean (min-max) AUROC | Multivariable AUROC gain/loss (%) *** multivariable and single host-biomarkers ratio |
|---|---|---|---|
| **Overall (Brazil + Gabon + Malawi)*** | | | |
| L | SW/RFA/RF:0·75 (0.69-0.81) | WBC count: 0·7 (0.64, 0.76) | +7% |
| S | SW:0.83 (0.75 - 0.91) | WBC count: 0·78 (0.72 - 0.84) | +6% |
| E | SW/RFA:0.83 (0.77 - 0.89) | WBC count: 0·77 (0.69 - 0.85) | +8% |
| **Brazil** | | | |
| L | SW: 0·82 (0.70 - 0.94) | WBC count: 0·8 (0.68 - 0.92) | +2·5% |
| S | RFA: 0·82 (0.70 - 0.94) | WBC count: 0·8 (0.68 - 0.92) | +2·5% |
| E | SW: 0·85 (0.73 - 0.97) | WBC count: 0·83 (0.69 - 0.97) | +2% |
| **Gabon**** | | | |
| L | SW/RFA: 0·7 (0.46 - 0.94) | WBC count: 0·7 (0.64 - 0.76) | .. |
| S | SW/RFA: 0·76 (0.52 – 0.96) | WBC count: 0·78 (0.72 - 0.84) | -3% |
| E | RFA: 0·77 (0.63 - 0.91) | WBC count: 0·77 (0.69 - 0.85) | .. |
| **Malawi** | | | |
| L | SW/RFA: 0·74 (0.62 - 0.86) | neutrophil count: 0·72 (0.66 - 0.78) | +3% |
| S | SW: 0·73 (0.61 - 0.85) | neutrophil count: 0·72 (0.58 - 0.86) | + 1% |
| E | RFA: 0·72 (0.60 - 0.84) | WBC count: 0·7 (0.56, 0.84) | + 2% |

E, electronic classification group; S, strict classification group; L, loose classification group; RF, RuleFit; RFA, logistic recursive feature addition; SW, stepwise logistic regression.

* In the "Overall" scenario, the model was developed using the data of all countries and the variable indicating the country was used as a covariate in the model.

**Multivariable performances for Gabon were computed using as a predictor model the model trained in the "Overall" scenario (all participants from the three analysed countries) then evaluated using Gabon data only. Indeed, the sample size of Gabon data was not sufficient to allow the development of a reliable model specific for this country.

*** Performance comparison was computed as: [ (multivariable AUROC – univariate AUROC) / univariate AUROC ] * 100 Green (gain, i.e. the multivariable models show better performances than univariate models); red (loss, i.e. the univariate models show better performances than multivariable models).

## DISCUSSION

We present the most extensive and diverse host-biomarker evaluation study to differentiate bacterial from non-bacterial infections in LMICs. The study aimed to identify if next-generation host-biomarkers for distinguishing bacterial from non-bacterial cases of AFI, which could replace existing biomarkers such as CRP, PCT, and WBC/neutrophil assessments. The data show that none of the promising host-biomarkers exhibited high AUROCs in our non-severe AFI population in either low malaria prevalence (Brazil) or high malaria prevalence (Gabon, Malawi) settings. Haematology biomarkers and CRP were included a baseline to identify better-performing markers; however, they remain those with the highest AUROC values (approximately 0·60–0·70 AUROC) in our population.

Overall, the performance of all markers was underwhelming, yet not surprising. It aligns with previous data where a marked reduction in performance was observed when shifting the population from in- to outpatients [17-19]. Previously, it was hypothesised that the decrease in performance in host biomarkers between HIC and LMIC settings, or even between Africa and Asia, was due to the untreated comorbidities (e.g. diabetes, malaria, neglected tropical diseases) which contribute to inflammation and the nonspecific triggering of host biomarkers, unrelated to the current acute presentation [19, 20]. In our data the performance was indeed poorer in malaria-positive patients (AUROC <0·6); however, even in the malaria-negative population, biomarkers showed low performances (~0·6–0·7) in our cohort. Similarly, sex and arboviral status appeared to have no major effect on biomarker performance. Our data notably indicated that combining biomarkers can enhance performance. However, this improvement was not consistently observed. When combining several biomarkers and additional covariates, the "gain" in AUROC values was low/moderate (range 1–13%) compared to the top-performing individual biomarkers. From a diagnostic development perspective, a low gain in performance would not justify the additional complexity and cost of developing a simple multiplex test.

Adding to the challenges of host-biomarker studies is the lack of consistent reference standards and that most studies have focused their analyses solely on the subpopulation of patients with a microbiologically confirmed diagnosis. This approach ignores the largest group (>70%) of patients and intended-use population of any future test [21]. The group with laboratory confirmed diagnosis will decrease further in the non-severe AFI population; presenting at primary care level. Going forward more clarity will likely follow as a recent host-biomarker test (BVtest, MeMed, Israel) was approved by the FDA and subsequent guidance will prescribe more clearly how studies have to be designed to standardize the classification of "bacterial" vs "non-bacterial" evaluated to guide prescribing for bacterial or non-bacterial infections [9, 22]. Our protocol is aligned with the FDA approved classification hence we are confident our methodology is robust.

While our study aimed to mitigate the challenges described, it still had several limitations. The study did not include a control group, so no baseline information was available for biomarker performance or asymptomatic carrier populations. The enrolment period in Brazil and Gabon lasted for less than one year and given the heterogeneity of causes of AFI across time a the performance of the biomarkers may not be generalisable to different times of the year and geographical settings, particularly in Asia. The study utilised a two-step process to classify outcomes, and the clinical classification based on recorded clinical information may have introduced subjectivity. Notably, clinicians had access to the haematology biomarker results (WBCs, neutrophils) during outcome classification, which might have introduced a bias in favour of these biomarkers. However, comparing AUROCs between all classification groups (E, L, S) suggests this potential bias had no major impact as the results are similar across groups. There were some heterogeneities in the inclusion criteria across the various study sites, including age groups and fever criteria. In Brazil and Gabon, the inclusion criterion was a history of fever in the past 7 days, while it was fever at presentation in Malawi. Studies have

found that acute fever at presentation has implications for the interpretation of host biomarkers [23]; however, our sub-analysis by acute fever showed no differences, so we do not consider that these different inclusion criteria impacted interpretation. Despite best efforts to standardise procedures, there was a level of adaptability required in the choice of testing methods by the clinical teams in each country, for arbovirus and respiratory pathogen detection. Further, the choice to follow the TPP and focus on non-severe patients in the recruitment was based on the need's definition by the WHO and others, while this still holds as a major priority, in hindsight this focus did not allow us to stratify by severity (eg. SOFA score).

Overall, the results of this diverse study highlight the difficulties in identifying single host-biomarkers or simple host-biomarker combinations that can help solve the problem of undifferentiated prescribing at primary healthcare, particularly to be used across diverse global settings. On the 8th birthday of the original TPP for a diagnostic assay to distinguish bacterial and non-bacterial infections in resource-limited settings, a more recent consultation confirmed that the need for such an assay remains and is in fact increasingly urgent [6, 24]. Yet again, the consultation concluded primary healthcare clinics and their equivalents must have the ability to perform tests other than just malaria RDTs [24]. The lack of diagnostics infrastructure at the lower levels of health systems is well documented and requires urgent improvement to support medical staff in their decision making.. While no novel host-biomarker assay meets these needs, evidence for existing biomarkers, e.g. CRP, and various haematology biomarkers, should be utilised to drive such improvements, albeit utilizing slightly different approaches and cut-offs across settings. In addition to utilising existing tools, increased investment into lower level health infrastructures are critical and the first step to improved care. Recent studies have shown that even simple host-biomarkers, such as CRP, can have a major impact on how clinical staff use antibiotics [25, 26, 27]. The current study confirms that the existing biomarkers are imperfect and hence should only be used as guidance, in conjunction with expanded clinical

algorithms [28, 29]. Such guidelines, alongside adopted policies, strengthened infrastructues and accessible haematology/biochemisty data could enable healthcare workers to use simple tools to gain additional data points to help form a more evidence-based diagnosis that has to be guided by the local epidemiology. Optimising existing haematology or biochemistry tools and their maintenance requirements to meet the needs of low resourced settings could be one step towards more expanded use of these well-known markers. In conclusion, our study reinforces the continued need for innovation in the host-biomarker space and highlights the importance of targeted evaluations of such innovations, in diverse intended-use settings, to fully understand their true value.

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**Competing Interests**

SD, BLFC, CE, VH, SO, CH, AM, SL are or were employed by FIND, the global alliance for diagnostic during the study period. All other authors do not declare any competing interests.

**Author contribution**

SD, CE, SO, AM, AMS, SG, STA, MML, ATA conceptualised the study and study design; CE, AS, SG, STA, AMS, JKM, VH, JM, ALK, AA, JCBO, MML, PNE, JAM, PB, LB, AdRM, BCC, MAMS, AMBdF, EAdS, RdS, MCSL, JH, AG, MJ, NSM, CH, SJL, implemented the

study and data collection; MA, MV, SL, SO, BDC, BLFC, SD, SP, SG, AMS, STA conducted data analysis and interpretation. BLFC, SD wrote the first draft of the manuscript and all authors contributed to the final version of the manuscript. Guarantor is SD.

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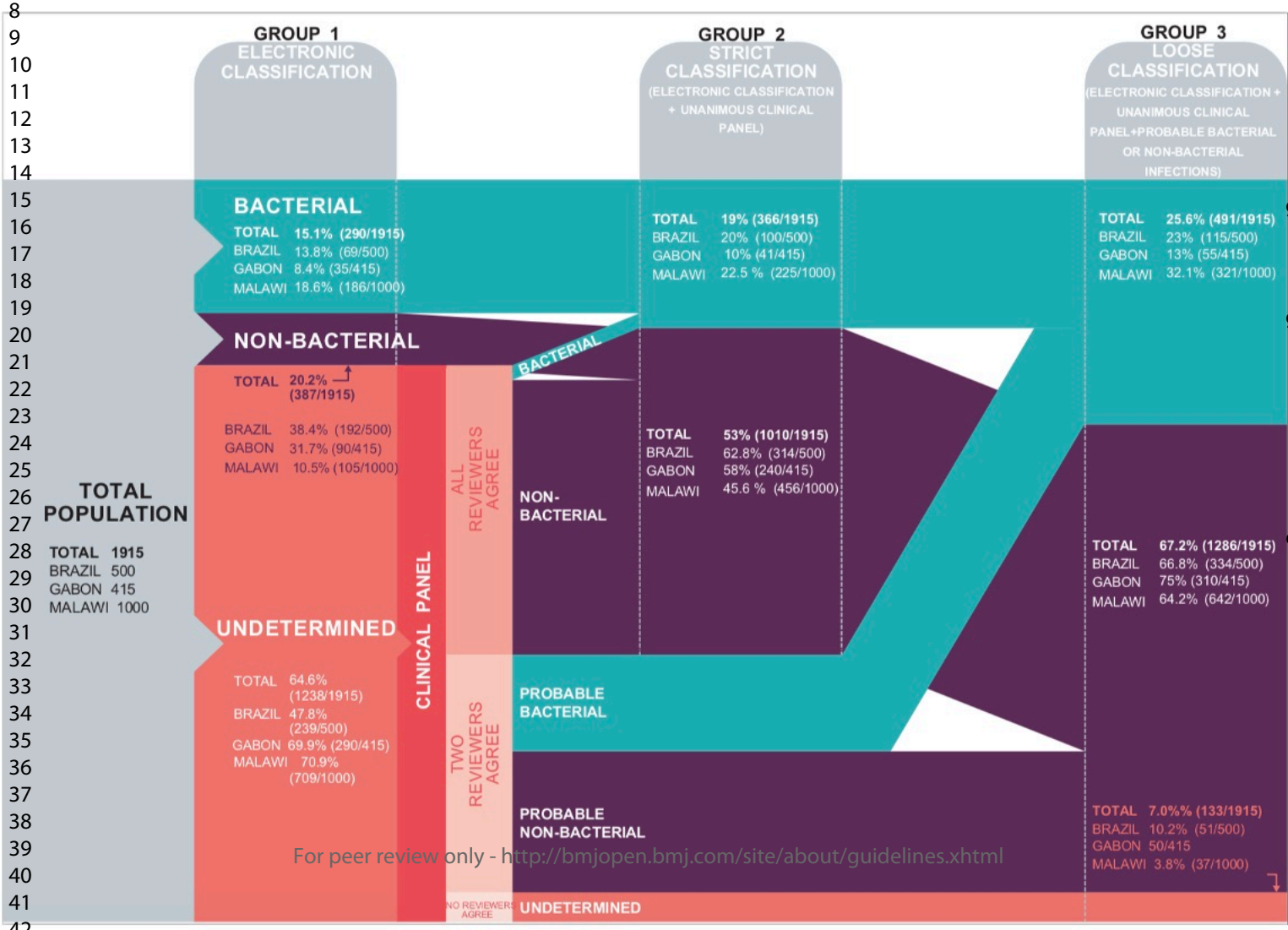
**Figure 1: Classification criteria to assign bacterial versus non-bacterial infection categories for the analysis.** The flows in different colours (turquoise=bacteria, purple=non-bacterial, red=undetermined) represent the proportion of patients that were assigned into the respective group (bacteria/non-bacteria/undetermined) after each classification step. Group 1 representing only patients assigned using laboratory data; group 2 representing patients with a unanimous decision after review by the clinical panel; group 3 after clinical panel review and group 3 including all patients, even if only 2 panel members agreed on the probable cause. The study follows the STARD-15 checklist and reporting guidelines.

**Figure 1: Classification criteria to assign bacterial versus non-bacterial infection categories for the analysis.** The flows in different colours (turquoise=bacteria, purple=non-bacterial, red=undetermined) represent the proportion of patients that were assigned into the respective group (bacteria/non-bacteria/undetermined) after each classification step. Group 1 representing only patients assigned using laboratory data; group 2 representing patients with a unanimous decision after review by the clinical panel; group 3 after clinical panel review and group 3 including all patients, even if only 2 panel members agreed on the probable cause. The study follows the STARD-15 checklist and reporting guidelines.



# Supplementary Material

**Evaluation of host biomarkers to support the development of a point-of-care diagnostic test to guide antibiotic use in bacterial/non-bacterial acute febrile illness cases**

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*authors contributed equally

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# Biomarker selection

Biomarkers evaluated were selected based on reported performances for distinguishing bacterial versus non-bacterial infections in prior publications, which were systematically reviewed in 2016 by Kapasi et al.[1] and other key publications (Supplementary Table 1). Biomarker performances reported in the 2016 systematic review were compared with reported performances in a later systematic review conducted in 2020.[2]

**Supplementary Table 1. Biomarkers included based on Kapasi et al.'s (2016) systematic review and other key publications.**

| **Biomarker** | **Performance, 2016 systematic review** |
|---|---|
| C-reactive protein (CRP) | 1 |
| FebriDx (MxA+CRP) | 2 |
| Galectin-9 | *2* |
| Gamma-induced protein 10 (IP-10) | 2* |
| Haptoglobin | 2[#] |
| Heparin-binding protein (HBP) | 3 |
| Human neutrophil lipocalin (HNL) | 2 |
| Interferon gamma (IFN-gamma) | 3 |
| Interleukin-4 (IL-4) | 2 |
| Interleukin-6 (IL-6) | 3 |
| Lipopolysaccharide binding protein (LBP) | 3[$] |
| Procalcitonin (PCT) | 1 |
| Secretory phospholipase 2 (sPLA2) | 2 |
| Soluble triggering receptor expressed on myeloid cells 1 (sTREM-1) | 3[§] |
| TNF-related apoptosis-inducing ligand (TRAIL) | 2* |
| | |
| *Included based on key publications in the field* | |
| **Biomarker** | **Publication** |
| A-1-acid glycoprotein | Struck et al.[3] |
| Chitinase-3-like protein 1 (CHI3L1) | Erdman et al.[4] |
| Complement 2 | Struck et al.[3] |
| Complement C4b | Struck et al.[3] |
| Neutrophil gelatinase-associated lipocalin (NGAL) | Huang et al.[5] |

Performances were scored as: 1, high-performing biomarker (meets the current TPP minimum diagnostic performance criteria, i.e. ≥0.90 and 0.80 sensitivity/specificity); 2, moderately performing biomarker (≥0.65 and 0.65 and <0.90 and 0.80 sensitivity/specificity); 3, AUROC >0.8; 4, low-performing biomarker; 5, not evaluated. *As part of the signature CRP+IP-10+TRAIL; # as part of the signature Haptoglobin+IL-10+TIMP1; $ in respiratory tract infections as part of the signature CRP+LBP; § as part of the signature sTREM+CRP; 1 only in the context of meningitis, otherwise low performance.

# Reference laboratory methodology

## Materials, equipment, and software

All assay reagents used were delivered with the commercial kits and were used as described in the corresponding kit manuals. Supplementary Table 2 shows the commercial human multi-analyte kits and ELISA kits used.

**Supplementary Table 2:** Commercial human multi-analyte kits and ELISA kits used.

| Analytes | Assay type | Provider | Reference laboratory that performed the analysis |
|---|---|---|---|
| CHI3L1, Gal-9, IL-4, IL-6, IP-10, IFN-gamma, sPLA2, sTREM-1, TRAIL | Luminex, 9-plex | Biotechne/ R&D Systems | NMI |
| NGAL, LBP | Luminex, 2-plex | Biotechne/ R&D Systems | NMI |
| C2, C4b | Luminex, 2-plex | Merck | NMI |
| HP, AGP | Luminex, 2-plex | Merck | NMI |
| PCT | Luminex, 1-plex | Biotechne/ R&D Systems | NMI |
| | Immunoassay | Elecsys BRAHMS, Roche | MVZ Limbach |
| HNL | ELISA | Diagnostics Development | NMI |

| | | | |
|---|---|---|---|
| CRP | ELISA | Biotechne/ R&D Systems | NMI |
| | Immunoassay | Elecsys BRAHMS, Roche | MVZ Limbach |
| HBP | ELISA | Axis-Shield | on-site |

NMI, The Natural and Medical Sciences Institute (NMI) at the University of Tübingen, Reutlingen, Germany; MVZ Labor, Dr. Limbach & Kollegen, Heidelberg, Germany

For data generation, the Luminex FLEXMAP 3D instrument, operated with xPONENT Software V4.2, was used for the bead-based Luminex assays. The data evaluation was performed using Bio-Rad Bio-Plex Manager Software 6.1.1. To generate the data for the ELISAs at NMI a BioTek ELx 808 absorption reader was used. The embedded software Gen5 (BioTek) was used for data evaluation. At MVZ Limbach, a Cobas 8000 immunoanalyzer (Roche Diagnostics) was used for data generation.

## Methods

All assays were processed according to the manufacturer's protocol. Standard curves, quality control (QC) samples, and blanks were analysed in duplicate; samples were assayed singly. Two or three QC samples were measured on each assay plate. QC samples were taken to cover the range of the standard curve (low, mid, and high level). All QC samples were prepared and aliquoted in larger quantities at the beginning of sample screening so that a fresh aliquot could be used for each measurement, and all QC samples underwent the same freeze–thaw cycle. The performance of the standard curves was controlled over the entire measurement period based on %CVs of the standard point duplicates (<20% and <25% for the last standard point) and percentage recovery on the basis of the nominal concentrations. If permitted by the dilution factor, samples out of the dynamic range were re-analysed with a lower or higher dilution factor.

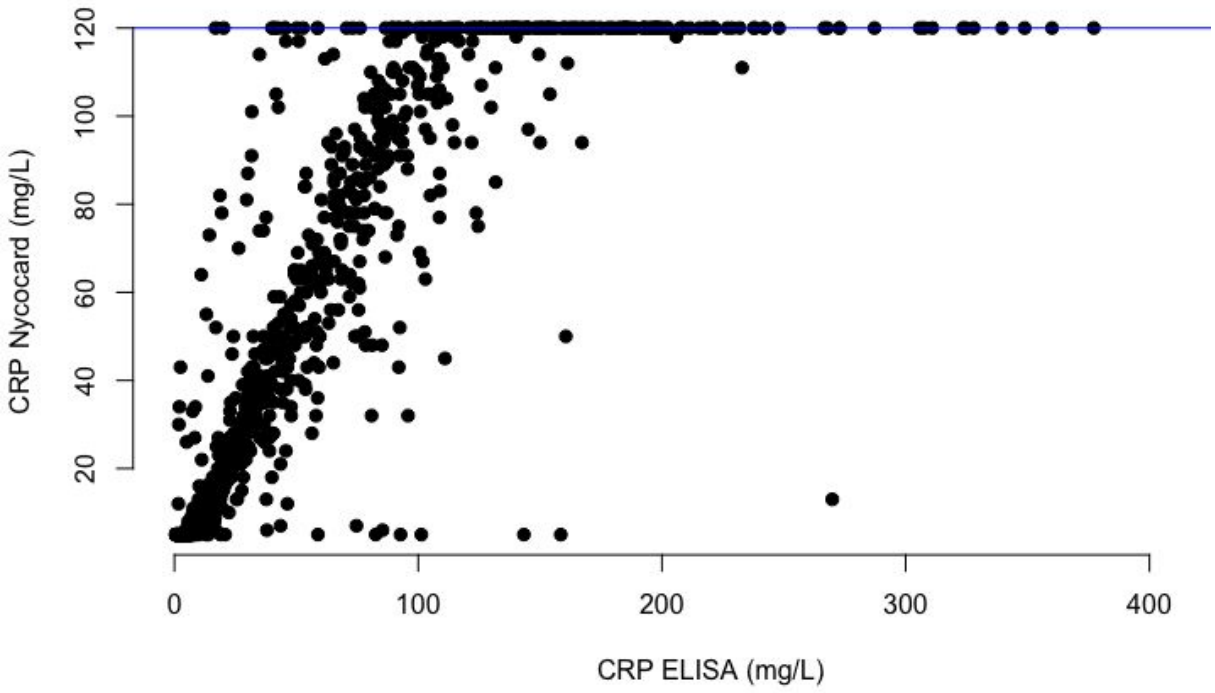
**Heparin-binding protein (HBP) assay**

The commercially available Axis-Shield heparin-binding protein ELISA for citrated plasma was validated for human EDTA plasma. Calibration curve, limit of detection (LOD), assay range, precision, parallelism, and spike-in recovery experiments were performed.

The ELISA was processed according to the assay protocol provided with the kit. Validation was performed using a fit-for-purpose approach and under consideration of the recommendations for assay validation given in guidelines from health authorities (European Medicine Agency (2011); Food and Drug Administration (2018)). This was a short validation with a limited number of samples.

Except for the percentage recovery, all analysed parameters met the criteria during the validation of the HBP ELISA using human EDTA plasma instead of the recommended citrated plasma matrix. The assay performance seemed to be stable for the sample evaluation using the kit.

**Supplementary Figure 1: Analytical assessment of CRP Nycocard vs CRP ELISA**



# Statistical analysis

This section contains additional figures and tables related to the statistical analysis.

**Supplementary Table 3: Number and percentage of missing values for the biomarkers included in the statistical analysis**

| | Electronic group¶ [n (%)] | Strict group§ [n (%)] | Loose group# [n (%)] |
|---|---|---|---|
| White blood cells | 6 (0.8%) | 11 (0.8%) | 15 (0.8%) |
| HAEMATO COUNT | 6 (0.8%) | 11 (0.8%) | 15 (0.8%) |
| Lymphocytes | 6 (0.8%) | 12 (0.9%) | 17 (1%) |
| Neutrophils | 22 (3%) | 64 (5%) | 90 (5%) |
| CRP NYCOCARD | 5 (0.7%) | 10 (0.7%) | 14 (0.8%) |
| IL-6 | 10 (1.5%) | 20 (1%) | 24 (1%) |
| Gal-9 | 10 (1.5%) | 20 (1%) | 24 (1%) |
| CHI3L1 | 10 (1.5%) | 20 (1%) | 25 (1%) |
| IP-10 | 10 (1.5%) | 20 (1%) | 24 (1%) |
| TRAIL | 10 (1.5%) | 20 (1%) | 24 (1%) |
| IL-4 | 13 (2%) | 24 (2%) | 29 (2%) |
| sPLA2 | 10 (1.5%) | 20 (1%) | 24 (1%) |
| NGAL | 29 (4%) | 138 (10%) | 197 (11%) |
| LBP | 30 (4%) | 139 (10%) | 198 (11%) |
| C2 | 10 (1.5%) | 21 (1.5%) | 25 (1%) |
| AGP | 10 (1.5%) | 21(1.5%) | 25 (1%) |
| HP | 11(1.6%) | 24 (2%) | 29 (2%) |

¶ Total number of subjects in the Electronic group: 677
§ Total number of subjects in the Strict group: 1376
# Total number of subjects in the Loose group: 1777

## Kruskal-Wallis tables

**Supplementary Table 4: Kruskal-Wallis table results for the electronic classification**

| | Age | Sex | Malaria | Country | Comorbidities | Malnutrition* | Prior antibiotics | Temperature ≥38°C | Chikungunya |
|---|---|---|---|---|---|---|---|---|---|
| White blood cells | 1.2145E-13 | 1.9808E-01 | 1.0985E-02 | 3.4408E-01 | 8.4018E-01 | 2.7154E-01 | 4.3535E-01 | 3.4408E-01 | 5.4183E-09 |
| HAEMATO COUNT | 2.8040E-45 | 1.0446E-09 | 4.3461E-28 | 1.3185E-36 | 6.8045E-02 | 9.1321E-01 | 6.9000E-01 | 9.9455E-01 | 3.6951E-08 |
| Lymphocytes | 1.3850E-45 | 8.0680E-03 | 3.1562E-29 | 4.5414E-32 | 1.0022E-05 | 4.4874E-01 | 4.5900E-01 | 5.4198E-08 | 1.9910E-11 |
| Neutrophils | 5.6495E-03 | 3.9147E-01 | 1.1337E-04 | 1.8674E-17 | 1.5980E-02 | 4.2719E-01 | 4.3608E-01 | 3.0003E-08 | 6.5439E-04 |
| CRP NYCOCARD | 1.4485E-03 | 4.2297E-01 | 1.3861E-15 | 3.0332E-07 | 2.1171E-01 | 4.6667E-01 | 8.4615E-01 | 3.0231E-03 | 2.1171E-01 |
| IL-6 | 9.2626E-06 | 2.5277E-01 | 4.6686E-34 | 4.2810E-21 | 6.1106E-03 | 7.1615E-01 | 5.8674E-02 | 2.0177E-10 | 9.2626E-06 |
| Gal-9 | 7.8084E-11 | 3.3296E-01 | 1.2731E-07 | 2.2471E-07 | 4.3173E-01 | 5.3845E-01 | 9.9020E-02 | 3.6659E-01 | 8.5282E-04 |
| CHI3L1 | 3.6874E-01 | 1.5427E-01 | 2.2593E-04 | 3.5942E-05 | 9.0961E-01 | 8.0977E-01 | 7.9973E-01 | 2.5264E-02 | 2.5264E-02 |
| IP-10 | 7.0235E-01 | 7.0235E-01 | 4.0429E-09 | 7.0486E-10 | 4.9729E-01 | 7.0235E-01 | 4.0169E-01 | 3.6086E-08 | 3.3476E-01 |
| TRAIL | 1.4108E-03 | 1.5429E-02 | 6.7710E-19 | 6.9473E-56 | 9.2177E-01 | 2.2485E-02 | 9.5591E-01 | 9.7926E-04 | 1.8702E-06 |
| IL-4 | 1.4190E-03 | 8.9566E-02 | 1.7896E-25 | 1.1179E-73 | 4.2256E-01 | 8.9341E-03 | 8.9692E-01 | 3.0403E-03 | 2.2958E-09 |
| sPLA2 | 9.5993E-05 | 9.2127E-01 | 2.8477E-20 | 5.6810E-03 | 1.5011E-01 | 9.2127E-01 | 6.1633E-01 | 7.4323E-03 | 7.4323E-03 |
| NGAL | 2.6841E-02 | 7.1924E-01 | 1.2498E-05 | 6.4604E-21 | 7.1924E-01 | 2.6841E-02 | 5.1387E-01 | 1.2498E-05 | 9.6273E-03 |
| LBP | 2.2658E-11 | 5.1481E-02 | 1.8527E-54 | 2.1544E-101 | 8.2974E-02 | 5.3837E-03 | 1.1745E-01 | 3.5938E-09 | 6.0583E-19 |
| C2 | 1.7219E-02 | 3.0063E-01 | 6.8628E-13 | 6.8628E-13 | 6.2951E-02 | 8.5874E-01 | 5.6324E-01 | 4.4637E-01 | 6.2045E-03 |
| AGP | 5.1888E-03 | 2.0274E-01 | 3.6747E-16 | 1.3445E-16 | 1.5176E-01 | 9.8963E-01 | 6.3154E-01 | 2.3325E-01 | 3.1922E-05 |
| HP | 2.9420E-07 | 2.7390E-01 | 1.8393E-25 | 2.4997E-25 | 2.7390E-01 | 2.7390E-01 | 4.0178E-01 | 7.2077E-01 | 2.9140E-03 |
| C4b | 5.6159E-19 | 6.7010E-02 | 4.5041E-81 | 1.9491E-84 | 6.7179E-03 | 6.7179E-03 | 3.3168E-01 | 1.8052E-01 | 8.0363E-18 |

Different colours based on significance: green ($p < 0.05$, slight significance); orange ($p < 0.01$, high significance); red ($p < 0.001$, strong significance). * Malnutrition status calculated based on WHO body mass index criteria.

## Kruskal-Wallis tables

**Supplementary Table 5: Kruskal-Wallis table results for the strict classification**

| | Age | Sex | Malaria | Country | Comorbidities | Malnutrition* | Prior antibiotics | Temperature ≥38°C | Chikungunya |
|---|---|---|---|---|---|---|---|---|---|
| White blood cells | 3.1149E-20 | 2.4091E-01 | 3.6749E-09 | 9.3997E-03 | 3.1632E-01 | 6.3502E-02 | 6.3502E-02 | 9.1443E-01 | 1.7973E-08 |
| HAEMATO COUNT | 6.1835E-100 | 1.9994E-04 | 5.6304E-55 | 3.7852E-68 | 1.6199E-04 | 8.0189E-01 | 7.1282E-01 | 2.9137E-01 | 1.7149E-10 |
| Lymphocytes | 8.4778E-84 | 1.5291E-01 | 2.6779E-44 | 2.7404E-58 | 6.3047E-07 | 6.1980E-03 | 4.5554E-01 | 7.1024E-22 | 8.6226E-15 |
| Neutrophils | 8.9513E-04 | 1.7152E-01 | 7.9838E-14 | 1.9134E-37 | 4.5549E-02 | 5.2789E-01 | 4.5549E-02 | 3.0001E-19 | 4.1217E-02 |
| CRP NYCOCARD | 1.6547E-02 | 5.7656E-02 | 2.4570E-38 | 6.2991E-11 | 7.4370E-01 | 3.0220E-01 | 7.4370E-01 | 9.7289E-15 | 3.0220E-01 |
| IL-6 | 2.5704E-02 | 1.2888E-01 | 2.5131E-68 | 3.4758E-27 | 1.4641E-01 | 8.1220E-01 | 6.6933E-02 | 4.3924E-26 | 2.5371E-04 |
| Gal-9 | 7.4424E-19 | 3.5455E-03 | 1.3432E-11 | 1.3757E-08 | 1.1615E-01 | 3.9116E-01 | 1.3397E-01 | 2.2573E-01 | 2.4249E-03 |
| CHI3L1 | 2.8335E-01 | 1.5433E-01 | 3.6787E-11 | 7.4319E-16 | 2.8335E-01 | 2.8335E-01 | 2.8335E-01 | 8.7744E-06 | 1.5017E-03 |
| IP-10 | 2.4521E-01 | 6.8716E-01 | 8.5656E-31 | 1.5503E-36 | 2.1157E-01 | 3.0336E-01 | 3.2906E-01 | 4.1236E-22 | 3.2906E-01 |
| TRAIL | 6.4358E-04 | 2.4206E-01 | 3.7467E-46 | 4.5806E-127 | 7.7652E-01 | 8.3869E-04 | 7.7652E-01 | 2.8337E-17 | 1.7642E-08 |
| IL-4 | 4.2108E-04 | 5.9858E-01 | 2.5949E-55 | 2.7083E-159 | 3.3368E-01 | 8.0705E-05 | 6.5563E-01 | 2.2888E-11 | 2.2888E-11 |
| sPLA2 | 3.0005E-14 | 1.1264E-01 | 4.1355E-60 | 4.7055E-09 | 6.7473E-04 | 2.2676E-01 | 3.6531E-01 | 1.0844E-09 | 4.7059E-05 |
| NGAL | 7.7462E-02 | 1.1300E-01 | 6.0927E-16 | 1.3720E-35 | 5.9955E-01 | 4.9221E-02 | 4.4419E-01 | 1.4382E-19 | 8.8808E-03 |
| LBP | 1.3509E-14 | 3.4123E-01 | 6.0660E-94 | 1.9360E-197 | 2.1248E-02 | 3.6673E-05 | 3.0644E-01 | 2.3473E-28 | 7.4289E-21 |
| C2 | 7.2674E-07 | 4.3157E-01 | 2.3145E-26 | 4.5324E-25 | 6.8236E-03 | 4.3157E-01 | 4.3157E-01 | 8.8206E-03 | 2.1062E-03 |
| AGP | 4.8513E-04 | 1.7379E-01 | 5.0587E-21 | 7.1496E-23 | 1.5900E-01 | 7.9521E-01 | 9.7767E-01 | 1.1305E-01 | 1.4880E-05 |
| HP | 1.2127E-13 | 6.3311E-01 | 1.6366E-46 | 3.0053E-46 | 2.9299E-03 | 5.6523E-01 | 5.6523E-01 | 9.0316E-01 | 4.8596E-04 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| C4b | 6.3193E-21 | 1.923 1E-02 | 1.6664E-139 | 3.1999E-147 | 1.9749E-04 | 2.6638E-04 | 9.3349 E-01 | 8.0678E-03 | 3.0903E-25 |

Different colours based on significance: green ($p < 0.05$, slight significance); orange ($p < 0.01$, high significance); red ($p < 0.001$, strong significance). * Malnutrition status calculated based on WHO body mass index criteria.

## Kruskal-Wallis tables

**Supplementary Table 6: Kruskal-Wallis table results for the loose classification**

| | Age | Sex | Malaria | Country | Comorbidities | Malnutrition* | Prior antibiotics | Temperature ≥38°C | Chikungunya |
|---|---|---|---|---|---|---|---|---|---|
| White blood cells | 2.0574E-28 | 9.875 9E-01 | 1.8484E-08 | 4.5260E-03 | 9.0171E-02 | 4.8259E-02 | 1.0890 E-01 | 7.4007E-01 | 1.8484E-08 |
| HAEMATO COUNT | 1.3083E-126 | 1.861 9E-04 | 6.2835E-56 | 7.7962E-76 | 1.1102E-06 | 7.8862E-01 | 7.9391 E-01 | 2.9434E-01 | 1.2853E-10 |
| Lymphocytes | 4.9651E-101 | 2.946 1E-01 | 4.6796E-45 | 1.6372E-67 | 4.8743E-07 | 6.6823E-04 | 2.9461 E-01 | 2.4236E-29 | 4.3110E-15 |
| Neutrophils | 1.1310E-04 | 7.267 7E-01 | 7.2742E-15 | 1.6127E-46 | 2.0313E-01 | 4.6743E-01 | 2.0038 E-01 | 1.2920E-24 | 2.9723E-02 |
| CRP NYCOCARD | 1.3614E-01 | 4.4123E-03 | 1.0347E-57 | 2.4703E-15 | 4.0226E-01 | 5.2068E-01 | 5.9738 E-01 | 6.7648E-18 | 1.3614E-01 |
| IL-6 | 9.5250E-02 | 4.873 6E-02 | 8.6303E-95 | 1.9688E-31 | 1.5356E-01 | 8.2374E-01 | 9.3076 E-02 | 6.1774E-34 | 2.1766E-05 |
| Gal-9 | 2.0463E-27 | 1.4431E-03 | 1.9318E-13 | 6.8273E-10 | 2.3586E-01 | 2.3586E-01 | 3.6447 E-02 | 2.3586E-01 | 3.0166E-03 |
| CHI3L1 | 2.7483E-01 | 5.354 1E-02 | 3.6128E-14 | 3.6128E-14 | 2.8535E-01 | 7.9359E-01 | 3.0946 E-01 | 1.4718E-04 | 7.1655E-04 |
| IP-10 | 4.1384E-01 | 7.867 4E-01 | 6.5193E-43 | 4.2202E-47 | 7.9605E-02 | 3.6101E-01 | 4.1384 E-01 | 1.4436E-34 | 4.1902E-01 |
| TRAIL | 2.4722E-02 | 1.391 8E-01 | 6.2828E-56 | 2.9185E-156 | 8.2684E-01 | 6.2797E-05 | 8.2684 E-01 | 2.4486E-17 | 1.1148E-09 |
| IL-4 | 1.1448E-02 | 3.191 1E-01 | 3.0844E-69 | 1.7484E-206 | 3.9276E-01 | 4.7672E-08 | 5.7785 E-01 | 2.1611E-12 | 1.2664E-13 |
| sPLA2 | 8.3753E-18 | 2.731 7E-01 | 1.5890E-82 | 1.2702E-09 | 1.2356E-04 | 3.7225E-01 | 4.1002 E-01 | 8.1232E-15 | 4.0213E-05 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| NGAL | 1.5706E-01 | 2.065 0E-02 | 3.748 6E-27 | 2.284 8E-43 | 3.7129E-01 | 1.4239E-01 | 3.9957 E-01 | 1.3734E -24 | 5.3057E-03 |
| LBP | 1.656 7E-10 | 4.386 5E-01 | 2.110 7E-116 | 2.427 8E-254 | 8.2765E-03 | 5.4993E-07 | 6.1624 E-01 | 1.4861E -39 | 1.4254E-24 |
| C2 | 2.103 5E-04 | 1.459 3E-01 | 7.600 5E-28 | 2.186 5E-27 | 4.8543E-02 | 2.9326E-01 | 3.8932 E-01 | 9.8425E -03 | 1.2901E-03 |
| AGP | 2.507 6E-03 | 9.527 3E-02 | 1.987 0E-26 | 3.272 6E-28 | 9.3140E-02 | 8.9492E-01 | 9.5756 E-01 | 9.5273E -02 | 3.2225E-06 |
| HP | 5.764 0E-15 | 7.268 5E-01 | 2.837 6E-51 | 7.966 7E-51 | 7.2760E-03 | 6.9555E-01 | 6.9555 E-01 | 9.7145E -01 | 1.7228E-04 |
| C4b | 3.907 7E-15 | 9.303 7E-03 | 9.356 7E-160 | 3.444 9E-171 | 6.9926E-04 | 2.2357E-03 | 8.6228 E-01 | 2.2357E -03 | 1.0351E-29 |

Different colours based on significance: green ($p < 0.05$, slight significance); orange ($p < 0.01$, high significance); red ($p < 0.001$, strong significance). * Malnutrition status calculated based on WHO body mass index criteria.

**Supplementary Table 7: Univariate analysis – Overall (malaria-positive and malaria-negative) population**

| | Overall - Malaria negatives AUROC (CI), N | | | Overall - Malaria positives AUROC (CI), N | | |
|---|---|---|---|---|---|---|
| | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** |
| **WBC count** | 0.74, (0.7-0.79), 493 | 0.75, (0.71-0.78), 880 | 0.72, (0.68-0.75), 1127 | 0.65, (0.57-0.73), 174 | 0.65, (0.58-0.71), 481 | 0.64, (0.59-0.7), 630 |
| **RBC count** | 0.58, (0.53-0.63), 494 | 0.52, (0.48-0.56), 880 | 0.51, (0.47-0.54), 1127 | 0.58, (0.5-0.67), 175 | 0.5, (0.44-0.56), 481 | 0.51, (0.46-0.57), 630 |
| **Lymphocyte count** | 0.66, (0.61-0.71), 491 | 0.57, (0.53-0.61), 877 | 0.55, (0.51-0.58), 1123 | 0.63, (0.54-0.71), 174 | 0.57, (0.5-0.63), 480 | 0.54, (0.49-0.6), 627 |
| **Neutrophil count** | 0.71, (0.66-0.75), 480 | 0.75, (0.71-0.79), 847 | 0.73, (0.69-0.76), 1079 | 0.67, (0.59-0.75), 172 | 0.65, (0.58-0.71), 461 | 0.65, (0.59-0.71), 603 |
| **IL-4** | 0.36, (0.31-0.42), 486 | 0.4, (0.35-0.44), 868 | 0.61, (0.57-0.64), 1113 | 0.66, (0.58-0.74), 175 | 0.59, (0.53-0.65), 478 | 0.58, (0.53-0.63), 624 |
| **TRAIL** | 0.36, (0.3-0.41), 489 | 0.63, (0.59-0.67), 871 | 0.63, (0.59-0.67), 1117 | 0.68, (0.6-0.76), 175 | 0.6, (0.54-0.66), 478 | 0.58, (0.53-0.64), 625 |
| **IL-6** | 0.61, (0.55-0.66), 489 | 0.49, (0.45-0.53), 873 | 0.49, (0.45-0.53), 1120 | 0.42, (0.33-0.5), 175 | 0.57, (0.5-0.63), 478 | 0.53, (0.48-0.59), 626 |
| **CRP NycoCard** | 0.52, (0.47-0.57), 496 | 0.57, (0.53-0.61), 884 | 0.57, (0.53-0.6), 1132 | 0.52, (0.43-0.6), 175 | 0.49, (0.43-0.56), 481 | 0.5, (0.44-0.55), 630 |
| **Gal-9** | 0.52, (0.47-0.57), 490 | 0.54, (0.5-0.58), 875 | 0.56, (0.52-0.59), 1122 | 0.57, (0.48-0.65), 176 | 0.54, (0.48-0.6), 480 | 0.53, (0.48-0.59), 629 |
| **CHI3L1** | 0.56, (0.51-0.62), 489 | 0.55, (0.51-0.59), 873 | 0.55, (0.51-0.59), 1119 | 0.5, (0.41-0.59), 176 | 0.52, (0.45-0.58), 480 | 0.5, (0.44-0.55), 627 |
| **IP-10** | 0.53, (0.48-0.58), 489 | 0.52, (0.48-0.56), 874 | 0.52, (0.49-0.56), 1120 | 0.56, (0.47-0.64), 176 | 0.53, (0.47-0.59), 478 | 0.51, (0.45-0.56), 627 |
| **sPLA2** | 0.52, (0.47-0.57), 490 | 0.52, (0.48-0.56), 874 | 0.52, (0.49-0.56), 1121 | 0.49, (0.4-0.58), 176 | 0.54, (0.48-0.61), 479 | 0.54, (0.49-0.6), 628 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **NGAL** | 0.61, (0.56-0.66), 489 | 0.62, (0.57-0.66), 833 | 0.6, (0.57-0.64), 1049 | 0.61, (0.52-0.7), 157 | 0.56, (0.49-0.62), 403 | 0.56, (0.51-0.62), 527 |
| **LBP** | 0.74, (0.69-0.78), 488 | 0.69, (0.65-0.73), 832 | 0.67, (0.64-0.71), 1048 | 0.67, (0.58-0.76), 158 | 0.58, (0.52-0.64), 404 | 0.57, (0.51-0.62), 529 |
| **C2** | 0.59, (0.54-0.64), 483 | 0.56, (0.52-0.6), 866 | 0.56, (0.52-0.59), 1113 | 0.63, (0.55-0.72), 176 | 0.59, (0.53-0.66), 480 | 0.56, (0.5-0.61), 629 |
| **AGP** | 0.67, (0.62-0.72), 490 | 0.6, (0.56-0.64), 874 | 0.58, (0.55-0.62), 1120 | 0.52, (0.43-0.6), 176 | 0.52, (0.45-0.59), 480 | 0.53, (0.47-0.59), 629 |
| **HBP** | 0.67, (0.57-0.76), 179 | 0.64, (0.56-0.72), 254 | 0.61, (0.53-0.68), 280 | 0.55, (0.37-0.72), 57 | 0.52, (0.42-0.63), 141 | 0.53, (0.43-0.64), 149 |
| **HP** | 0.55, (0.49-0.6), 489 | 0.5, (0.46-0.54), 871 | 0.52, (0.48-0.56), 1116 | 0.58, (0.49-0.66), 175 | 0.55, (0.48-0.61), 473 | 0.54, (0.48-0.59), 622 |

**Supplementary Table 8: Univariate analysis – malaria-positive population**

| | **Malawi - Malaria positives AUROC (CI), N** | | | **Gabon - Malaria positives AUROC (CI), N** | | |
|---|---|---|---|---|---|---|
| | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** |
| **WBC count** | 0.67 (0.58-0.76), 132 | 0.68 (0.61 – 0.75), 369 | 0.67 (0.61-0.72), 491 | 0.67 (0.44-0.91), 42 | 0.61 (0.38-0.83), 112 | 0.61 (0.44-0.78), 139 |
| **RBC count** | 0.69 (0.6-0.79), 131 | 0.55 (0.48-0.61), 367 | 0.53 (0.47-0.59), 488 | 0.56 (0.31-0.81), 43 | 0.51 (0.3-0.71), 113 | 0.49 (0.33-0.65), 140 |
| **Lymphocyte count** | 0.7 (0.61-0.79), 131 | 0.59 (0.53-0.66), 368 | 0.57 (0.51-0.62), 488 | 0.72 (0.51-0.93), 42 | 0.66 (0.47-0.85), 112 | 0.67 (0.52-0,.82), 139 |
| **Neutrophil count** | 0.62 (0.52-0.72), 129 | 0.65 (0.57-0.72), 348 | 0.66 (0.6-0.72), 463 | 0.53 (0.31-0.76), 43 | 0.59 (0.39-0.79), 113 | 0.59 (0.43-0.75), 140 |
| **IL-4** | 0.46 (0.36-0.56), 132 | 0.47 (0.4-0.53), 369 | 0.48 (0.42-0.53), 488 | 0.44 (0.38-0.5), 40 | 0.46 (0.44-0.49), 103 | 0.5 (0.42-0.57), 127 |
| **TRAIL** | 0.6 (0.51-0.7),132 | 0.55 (0.49-0.62), 369 | 0.54 (0.48-0.59), 488 | 0.5 (0.5-0.5), 43 | 0.5 (0.5-0.5), 109 | 0.53 (0.47-0.6), 136 |
| **IL-6** | 0.6 (0.5-0.7), 131 | 0.58 (0.51-0.65), 367 | 0.54 (0.48-0.6), 485 | 0.45 (0.32 - 0.57), 42 | 0.47 (0.37-0.57), 103 | 0.45 (0.37-0.53), 127 |
| **CRP NycoCard** | 0.48 (0.38-0.58), 131 | 0.54 (0.47-0.61), 367 | 0.53 (0.47-0.59), 489 | 0.59 (0.32-0.86), 44 | 0.59 (0.36-0.82), 114 | 0.57 (0.4-0.75), 141 |
| **Gal-9** | 0.58 (0.48-0.69), 132 | 0.56 (0.49-0.62), 369 | 0.54 (0.47-0.6), 491 | 0.57 (0.34-0.8), 43 | 0.5 (0.32-0.68), 109 | 0.56 (0.42-0.71), 136 |
| **CHI3L1** | 0.56 (0.46-0.66), 132 | 0.55 (0.48-0.62), 367 | 0.55 (0.49-0.61), 487 | 0.52 (0.26-0.79), 43 | 0.53 (0.31-0.75), 106 | 0.63 (0.44-0.81), 131 |
| **IP-10** | 0.67 (0.58-0.76), 132 | 0.56 (0.49-0.63), 363 | 0.52 (0.46-0.59), 484 | 0.51 (0.33-0.69), 40 | 0.49 (0.35-0.63), 104 | 0.48 (0.35-0.61), 129 |
| **sPLA2** | 0.53 (0.43-0.64), 133 | 0.56 (0.48-0.63), 370 | 0.56 (0.5-0.62), 492 | 0.49 (0.24-0.74), 43 | 0.56 (0.34-0.77), 109 | 0.49 (0.32-0.67), 136 |
| **NGAL** | 0.5 (0.39-0.61), 114 | 0.5 (0.43-0.58), 291 | 0.49 (0.42-0.55)386 | 0.65 (0.44-0.91), 41 | 0.59 (0.41-0.77), 106 | 0.54 (0.38-0.7), 131 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **LBP** | 0.47 (0.35-0.59), 115 | 0.54 (0.46-0.61), 295 | 0.54 (0.48-0.6), 393 | 0.6 (0.34 - 0.85), 42 | 0.58 (0.37-0.8), 105 | 0.65 (0.48-0.81), 131 |
| **C2** | 0.62 (0.52-0.72), 133 | 0.57 (0.5-0.64), 369 | 0.54 (0.48-0.6), 491 | 0.72 (0.54-0.9), 43 | 0.72 (0.57-0.87), 105 | 0.64 (0.48-0.8), 131 |
| **AGP** | 0.54 (0.44 - 0.64), 133 | 0.52 (0.44-0.59), 371 | 0.48 (0.42-0.54), 493 | 0.51 (0.27-0.75), 43 | 0.53 (0.33-0.74), 109 | 0.58 (0.41-0.76), 136 |
| **HBP** | 0.55, (0.37-0.72), 57 | 0.53, (0.43-0.64), 143 | 0.54, (0.44-0.64), 151 | .. | .. | .. |
| **HP** | 0.58 (0.48-0.68), 133 | 0.54 (0.47-0.61), 365 | 0.51 (0.45-0.57), 487 | 0.57 (0.33-0.8), 42 | 0.56 (0.36-0.76), 107 | 0.61 (0.46-0.77), 134 |

*Green (AUROC ≥ 0.7), yellow (AUROC ≥ 0.65 and <7), orange (AUROC 0.6-0.65,) red (AUROC <0.6)*

## Univariate analysis – age subgroups

**Supplementary Table 9: Univariate analysis - age less than 6 years (non-malaria)**

| | Malawi - Malaria negatives AUROC (CI), N | | | Brazil - Malaria negatives AUROC (CI), N | | | Gabon - Malaria negatives AUROC (CI), N | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** |
| **WBC count** | 0.83, (0.73-0.94), 61 | 0.79, (0.71-0.87), 122 | 0.76, (0.69-0.84), 170 | 0.52, (0.25-0.78), 21 | 0.65, (0.46-0.85), 34 | 0.69, (0.51-0.86), 38 | 0.78, (0.62-0.94), 32 | 0.68, (0.52-0.83), 75 | 0.65, (0.52-0.79), 105 |
| **RBC count** | 0.65, (0.49-0.8), 62 | 0.58, (0.48-0.68), 123 | 0.58, (0.5-0.67), 172 | 0.6, (0.33-0.86), 21 | 0.56, (0.35-0.77), 33 | 0.59, (0.39-0.78), 37 | 0.6, (0.4-0.81), 32 | 0.56, (0.4-0.72), 75 | 0.53, (0.38-0.67), 105 |
| **Lymphocyte count** | 0.58, (0.43-0.72), 60 | 0.53, (0.42-0.64), 121 | 0.48, (0.38-0.57), 170 | 0.63, (0.36-0.89), 21 | 0.67, (0.44-0.91), 34 | 0.7, (0.5-0.9), 38 | 0.71, (0.53-0.89), 32 | 0.6, (0.44-0.76), 75 | 0.63, (0.49-0.76), 105 |
| **Neutrophil count** | 0.82, (0.7-0.93), 57 | 0.79, (0.7-0.88), 108 | 0.77, (0.69-0.86), 148 | 0.58, (0.32-0.85), 21 | 0.56, (0.36-0.77), 34 | 0.6, (0.41-0.79), 38 | 0.86, (0.72-0.99), 32 | 0.79, (0.67-0.92), 74 | 0.7, (0.58-0.83), 103 |
| **IL-4** | 0.54, (0.39-0.68), 63 | 0.5, (0.41-0.59), 125 | 0.48, (0.41-0.56), 174 | 0.63, (0.38-0.88), 20 | 0.66, (0.49-0.84), 31 | 0.62, (0.44-0.8), 33 | 0.43, (0.31-0.55), 30 | 0.49, (0.43-0.56), 72 | 0.51, (0.44-0.57), 103 |
| **TRAIL** | 0.57, (0.39-0.75), 63 | 0.6, (0.5-0.69), 125 | 0.59, (0.51-0.67), 174 | 0.5, (0.23-0.77), 20 | 0.63, (0.43-0.82), 31 | 0.59, (0.4-0.79), 33 | 0.5, (0.5-0.5), 28 | 0.5, (0.5-0.5), 69 | 0.49, (0.48-0.51), 99 |
| **IL-6** | 0.59, (0.44-0.73), 63 | 0.61, (0.52-0.7), 125 | 0.6, (0.52-0.68), 174 | 0.41, (0.29-0.53), 20 | 0.39, (0.29-0.49), 29 | 0.39, (0.3-0.49), 31 | 0.5, (0.5-0.5), 31 | 0.5, (0.5-0.5), 73 | 0.49, (0.47-0.5), 104 |
| **CRP NycoCard** | 0.56, (0.37-0.74), 61 | 0.61, (0.51-0.71), 121 | 0.59, (0.5-0.68), 169 | 0.49, (0.22-0.76), 21 | 0.59, (0.38-0.79), 34 | 0.6, (0.42-0.79), 38 | 0.76, (0.57-0.95), 32 | 0.62, (0.49-0.76), 75 | 0.57, (0.45-0.69), 106 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Gal-9** | 0.79, (0.66-0.92), 63 | 0.59, (0.49-0.69), 125 | 0.57, (0.48-0.66), 173 | 0.47, (0.2-0.75), 20 | 0.5, (0.28-0.72), 31 | 0.52, (0.3-0.73), 33 | 0.66, (0.45-0.87), 31 | 0.6, (0.43-0.76), 72 | 0.54, (0.4-0.69), 102 |
| **CHI3L1** | 0.56, (0.4-0.72), 62 | 0.52, (0.42-0.63), 124 | 0.54, (0.45-0.63), 173 | 0.61, (0.35-0.87), 20 | 0.66, (0.47-0.86), 31 | 0.67, (0.49-0.86), 33 | 0.68, (0.49-0.88), 31 | 0.62, (0.45-0.79), 73 | 0.61, (0.47-0.75), 102 |
| **IP-10** | 0.67, (0.51-0.83), 63 | 0.62, (0.52-0.72), 125 | 0.6, (0.51-0.68), 174 | 0.65, (0.39-0.9), 20 | 0.7, (0.51-0.89), 31 | 0.64, (0.45-0.84), 33 | 0.71, (0.53-0.9), 31 | 0.52, (0.38-0.67), 73 | 0.51, (0.38-0.63), 104 |
| **sPLA2** | 0.66, (0.5-0.82), 63 | 0.55, (0.45-0.66), 125 | 0.56, (0.47-0.65), 174 | 0.65, (0.38-0.91), 20 | 0.69, (0.48-0.9), 31 | 0.68, (0.48-0.88), 33 | 0.58, (0.37-0.78), 31 | 0.57, (0.41-0.72), 73 | 0.59, (0.45-0.73), 104 |
| **NGAL** | 0.61, (0.44-0.77), 63 | 0.68, (0.58-0.78), 109 | 0.67, (0.59-0.76), 144 | 0.67, (0.41-0.93), 20 | 0.58, (0.38-0.79), 31 | 0.52, (0.31-0.72), 33 | 0.63, (0.43-0.83), 31 | 0.6, (0.44-0.77), 73 | 0.57, (0.43-0.71), 103 |
| **LBP** | 0.47, (0.31-0.63), 63 | 0.5, (0.39-0.62), 109 | 0.53, (0.43-0.63), 144 | 0.47, (0.2-0.75), 20 | 0.46, (0.25-0.68), 30 | 0.48, (0.27-0.7), 32 | 0.73, (0.53-0.93), 30 | 0.7, (0.53-0.86), 70 | 0.59, (0.44-0.75), 101 |
| **C2** | 0.51, (0.34-0.69), 63 | 0.56, (0.45-0.66), 125 | 0.52, (0.44-0.61), 174 | 0.47, (0.18-0.76), 19 | 0.64, (0.41-0.87), 29 | 0.62, (0.4-0.83), 31 | 0.51, (0.29-0.73), 30 | 0.48, (0.32-0.64), 71 | 0.5, (0.36-0.64), 102 |
| **AGP** | 0.54, (0.38-0.7), 63 | 0.56, (0.45-0.66), 125 | 0.57, (0.48-0.66), 174 | 0.72, (0.48-0.96), 20 | 0.57, (0.34-0.81), 31 | 0.61, (0.39-0.82), 33 | 0.8, (0.63-0.98), 31 | 0.72, (0.56-0.88), 72 | 0.62, (0.48-0.76), 103 |
| **HBP** | 0.67, (0.45-0.89), 26 | 0.55, (0.37-0.73), 45 | 0.54, (0.37-0.71), 48 | .. | .. | .. | .. | .. | .. |
| **HP** | 0.64, (0.49-0.78), 62 | 0.57, (0.46-0.67), 124 | 0.57, (0.48-0.66), 173 | 0.68, (0.42-0.93), 20 | 0.61, (0.38-0.84), 31 | 0.62, (0.41-0.84), 33 | 0.78, (0.59-0.97), 28 | 0.72, (0.57-0.88), 69 | 0.63, (0.49-0.77), 100 |

*Green (AUROC ≥ 0.7), yellow (AUROC ≥ 0.65 and <7), orange (AUROC 0.6-0.65), red (AUROC <0.6)*

**Supplementary Table 10: Univariate analysis - aged between 7 and 15 years (non-malaria)**

| | Malawi - Malaria negatives AUROC (CI), N | | | Brazil - Malaria negatives AUROC (CI), N | | | Gabon - Malaria negatives AUROC (CI), N | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** |
| **WBC count** | 0.49, (0.26-0.73), 28 | 0.69, (0.54-0.84), 50 | 0.75, (0.64-0.86), 81 | 0.79, (0.61-0.96), 34 | 0.83, (0.71-0.95), 69 | 0.82, (0.71-0.94), 75 | 0.46, (0.27-0.65), 47 | 0.51, (0.34-0.67), 87 | 0.47, (0.31-0.62), 112 |
| **RBC count** | 0.62, (0.41-0.84), 28 | 0.54, (0.37-0.7), 51 | 0.57, (0.44-0.7), 82 | 0.7, (0.51-0.88), 34 | 0.61, (0.45-0.78), 69 | 0.6, (0.44-0.75), 75 | 0.56, (0.38-0.75), 47 | 0.55, (0.4-0.7), 87 | 0.48, (0.35-0.62), 112 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Lymphocyte count** | 0.76, (0.58-0.94), 28 | 0.67, (0.51-0.83), 51 | 0.62, (0.49-0.74), 82 | 0.6, (0.37-0.83), 34 | 0.69, (0.54-0.85), 69 | 0.71, (0.56-0.86), 75 | 0.59, (0.42-0.76), 47 | 0.61, (0.48-0.74), 87 | 0.55, (0.43-0.68), 112 |
| **Neutrophil count** | 0.46, (0.23-0.7), 26 | 0.7, (0.54-0.86), 45 | 0.76, (0.64-0.87), 73 | 0.73, (0.53-0.93), 34 | 0.82, (0.69-0.95), 69 | 0.8, (0.68-0.93), 75 | 0.66, (0.46-0.86), 46 | 0.61, (0.43-0.8), 86 | 0.61, (0.44-0.78), 111 |
| **IL-4** | 0.56, (0.34-0.78), 28 | 0.46, (0.31-0.6), 50 | 0.48, (0.37-0.6), 80 | 0.73, (0.53-0.92), 33 | 0.62, (0.47-0.77), 69 | 0.59, (0.45-0.74), 75 | 0.46, (0.41-0.5), 47 | 0.48, (0.46-0.5), 86 | 0.51, (0.45-0.57), 112 |
| **TRAIL** | 0.48, (0.23-0.73), 28 | 0.6, (0.45-0.76), 50 | 0.57, (0.45-0.7), 80 | 0.55, (0.34-0.77), 33 | 0.53, (0.38-0.68), 69 | 0.52, (0.38-0.66), 75 | 0.5, (0.5-0.5), 45 | 0.49, (0.48-0.51), 83 | 0.49, (0.47-0.5), 109 |
| **IL-6** | 0.45, (0.21-0.69), 28 | 0.56, (0.4-0.71), 51 | 0.55, (0.44-0.67), 82 | 0.46, (0.34-0.58), 33 | 0.44, (0.33-0.56), 69 | 0.43, (0.33-0.53), 75 | 0.53, (0.44-0.62), 47 | 0.53, (0.46-0.6), 86 | 0.54, (0.46-0.62), 112 |
| **CRP NycoCard** | 0.56, (0.34-0.78), 28 | 0.61, (0.46-0.77), 51 | 0.62, (0.5-0.74), 82 | 0.57, (0.33-0.81), 34 | 0.52, (0.35-0.68), 71 | 0.51, (0.35-0.68), 77 | 0.75, (0.59-0.92), 47 | 0.71, (0.55-0.87), 87 | 0.69, (0.56-0.83), 113 |
| **Gal-9** | 0.67, (0.43-0.9), 28 | 0.68, (0.53-0.84), 51 | 0.66, (0.54-0.78), 82 | 0.71, (0.52-0.9), 33 | 0.57, (0.41-0.73), 69 | 0.54, (0.39-0.7), 75 | 0.79, (0.62-0.95), 47 | 0.61, (0.44-0.77), 86 | 0.55, (0.39-0.71), 112 |
| **CHI3L1** | 0.53, (0.28-0.78), 28 | 0.6, (0.44-0.76), 51 | 0.61, (0.49-0.73), 82 | 0.69, (0.5-0.87), 32 | 0.66, (0.52-0.79), 67 | 0.59, (0.44-0.73), 71 | 0.53, (0.32-0.73), 46 | 0.58, (0.41-0.74), 84 | 0.62, (0.47-0.77), 110 |
| **IP-10** | 0.64, (0.42-0.86), 28 | 0.56, (0.39-0.72), 51 | 0.59, (0.46-0.72), 82 | 0.73, (0.53-0.92), 33 | 0.62, (0.46-0.78), 69 | 0.58, (0.42-0.73), 75 | 0.6, (0.41-0.78), 47 | 0.48, (0.31-0.66), 86 | 0.52, (0.37-0.67), 112 |
| **sPLA2** | 0.47, (0.21-0.72), 28 | 0.55, (0.39-0.72), 51 | 0.56, (0.43-0.68), 82 | 0.54, (0.33-0.76), 33 | 0.49, (0.35-0.64), 69 | 0.56, (0.43-0.7), 75 | 0.46, (0.28-0.64), 47 | 0.52, (0.36-0.67), 86 | 0.44, (0.29-0.59), 112 |
| **NGAL** | 0.56, (0.32-0.8), 28 | 0.68, (0.52-0.85), 46 | 0.73, (0.61-0.85), 73 | 0.71, (0.52-0.9), 33 | 0.68, (0.54-0.82), 69 | 0.64, (0.5-0.78), 75 | 0.7, (0.52-0.89), 46 | 0.6, (0.44-0.77), 85 | 0.59, (0.44-0.74), 111 |
| **LBP** | 0.54, (0.3-0.77), 28 | 0.59, (0.42-0.75), 46 | 0.58, (0.45-0.72), 73 | 0.68, (0.5-0.87), 33 | 0.66, (0.52-0.8), 69 | 0.67, (0.54-0.8), 75 | 0.71, (0.52-0.9), 46 | 0.66, (0.48-0.84), 85 | 0.63, (0.46-0.79), 111 |
| **C2** | 0.62, (0.34-0.9), 28 | 0.53, (0.36-0.7), 51 | 0.53, (0.41-0.66), 82 | 0.54, (0.31-0.76), 32 | 0.57, (0.4-0.74), 67 | 0.61, (0.45-0.77), 73 | 0.62, (0.42-0.81), 45 | 0.46, (0.27-0.65), 83 | 0.52, (0.36-0.68), 109 |
| **AGP** | 0.57, (0.3-0.83), 28 | 0.55, (0.39-0.71), 51 | 0.52, (0.39-0.65), 81 | 0.53, (0.3-0.76), 33 | 0.6, (0.44-0.75), 69 | 0.61, (0.46-0.75), 75 | 0.75, (0.56-0.94), 47 | 0.68, (0.5-0.86), 86 | 0.67, (0.52-0.83), 112 |
| **HBP** | 0.76, (0.28-1), 10 | 0.58, (0.29-0.87), 19 | 0.65, (0.39-0.91), 23 | ## Unbalanced classes | 0.92, (0.69-1), 8 | 0.72, (0.28-1), 9 | .. | .. | .. |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **HP** | 0.5, (0.25-0.76), 28 | 0.51, (0.35-0.67), 51 | 0.5, (0.37-0.63), 82 | 0.52, (0.3-0.75), 32 | 0.62, (0.46-0.78), 68 | 0.6, (0.45-0.76), 74 | 0.53, (0.33-0.73), 47 | 0.54, (0.37-0.7), 85 | 0.53, (0.38-0.67), 109 |

*Green (AUROC ≥ 0.7), yellow (AUROC ≥ 0.65 and <7), orange (AUROC 0.6-0.65), red (AUROC <0.6)*

**Supplementary Table 11: Univariate analysis - aged more than 15 years (non-malaria)**

| | Malawi - Malaria negatives AUROC (CI), N | | | Brazil - Malaria negatives AUROC (CI), N | | | Gabon - Malaria negatives AUROC (CI), N | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** |
| **WBC count** | 0.67, (0.53-0.82), 66 | 0.71, (0.62-0.8), 132 | 0.68, (0.6-0.75), 210 | 0.84, (0.77-0.91), 202 | 0.84, (0.77-0.9), 305 | 0.83, (0.77-0.89), 329 | 2 patients in total | 5 patients in total | 5 patients in total |
| **RBC count** | 0.59, (0.44-0.73), 65 | 0.53, (0.43-0.63), 131 | 0.51, (0.43-0.59), 209 | 0.56, (0.45-0.67), 203 | 0.56, (0.47-0.64), 306 | 0.55, (0.47-0.63), 330 | - | - | - |
| **Lymphocyte count** | 0.5, (0.34-0.66), 66 | 0.53, (0.43-0.63), 131 | 0.49, (0.41-0.57), 209 | 0.67, (0.58-0.76), 202 | 0.65, (0.57-0.72), 305 | 0.64, (0.57-0.71), 329 | - | - | - |
| **Neutrophil count** | 0.65, (0.49-0.81), 60 | 0.7, (0.6-0.8), 120 | 0.66, (0.59-0.74), 193 | 0.82, (0.74-0.9), 202 | 0.82, (0.76-0.89), 305 | 0.82, (0.75-0.88), 329 | - | - | - |
| **IL-4** | 0.4, (0.28-0.52), 66 | 0.47, (0.39-0.54), 131 | 0.45, (0.39-0.52), 209 | 0.56, (0.47-0.65), 196 | 0.53, (0.46-0.6), 298 | 0.54, (0.47-0.6), 321 | - | - | - |
| **TRAIL** | 0.68, (0.54-0.82), 66 | 0.65, (0.56-0.73), 131 | 0.66, (0.59-0.73), 209 | 0.57, (0.48-0.65), 199 | 0.54, (0.47-0.61), 302 | 0.54, (0.48-0.61), 326 | - | - | - |
| **IL-6** | 0.59, (0.46-0.72), 67 | 0.63, (0.54-0.72), 131 | 0.59, (0.52-0.66), 209 | 0.51, (0.44-0.58), 194 | 0.51, (0.45-0.58), 297 | 0.5, (0.44-0.56), 320 | - | - | - |
| **CRP NycoCard** | 0.53, (0.38-0.68), 67 | 0.6, (0.5-0.7), 133 | 0.57, (0.49-0.64), 211 | 0.66, (0.57-0.76), 204 | 0.65, (0.57-0.73), 307 | 0.66, (0.58-0.73), 331 | - | - | - |
| **Gal-9** | 0.72, (0.59-0.86), 67 | 0.6, (0.5-0.7), 133 | 0.63, (0.56-0.71), 211 | 0.61, (0.52-0.71), 199 | 0.56, (0.48-0.65), 301 | 0.57, (0.5-0.65), 325 | - | - | - |
| **CHI3L1** | 0.52, (0.36-0.67), 65 | 0.51, (0.41-0.61), 129 | 0.53, (0.45-0.61), 207 | 0.66, (0.58-0.75), 194 | 0.62, (0.54-0.69), 296 | 0.62, (0.55-0.69), 320 | - | - | - |
| **IP-10** | 0.64, (0.48-0.79), 67 | 0.59, (0.49-0.69), 133 | 0.61, (0.53-0.68), 210 | 0.59, (0.5-0.68), 199 | 0.52, (0.44-0.6), 302 | 0.53, (0.45-0.6), 326 | - | - | - |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **sPLA2** | 0.53, (0.37-0.69), 67 | 0.54, (0.44-0.64), 132 | 0.54, (0.46-0.62), 210 | 0.58, (0.48-0.67), 199 | 0.56, (0.48-0.64), 302 | 0.56, (0.48-0.63), 326 | - | - | - |
| **NGAL** | 0.49, (0.33-0.65), 65 | 0.62, (0.51-0.72), 110 | 0.53, (0.44-0.62), 175 | 0.55, (0.46-0.65), 196 | 0.54, (0.46-0.62), 296 | 0.53, (0.45-0.61), 320 | - | - | - |
| **LBP** | 0.56, (0.41-0.7), 66 | 0.56, (0.45-0.67), 112 | 0.53, (0.44-0.61), 177 | 0.65, (0.56-0.74), 195 | 0.6, (0.52-0.67), 298 | 0.56, (0.49-0.64), 322 | - | - | - |
| **C2** | 0.67, (0.53-0.81), 67 | 0.59, (0.49-0.69), 133 | 0.58, (0.51-0.66), 210 | 0.5, (0.4-0.6), 193 | 0.51, (0.43-0.58), 296 | 0.51, (0.44-0.59), 320 | - | - | - |
| **AGP** | 0.6, (0.45-0.75), 67 | 0.57, (0.47-0.67), 133 | 0.54, (0.46-0.62), 211 | 0.65, (0.55-0.74), 199 | 0.58, (0.5-0.66), 302 | 0.56, (0.49-0.64), 326 | - | - | - |
| **HBP** | 0.48, (0.25-0.71), 28 | 0.54, (0.36-0.72), 44 | 0.47, (0.31-0.63), 55 | 0.66, (0.51-0.81), 107 | 0.66, (0.53-0.79), 136 | 0.63, (0.5-0.76), 142 | - | - | - |
| **HP** | 0.53, (0.39-0.67), 67 | 0.58, (0.48-0.68), 132 | 0.5, (0.42-0.58), 209 | 0.56, (0.46-0.66), 196 | 0.47, (0.39-0.55), 299 | 0.48, (0.4-0.55), 323 | - | - | - |

*Green (AUROC ≥ 0.7), yellow (AUROC ≥ 0.65 and <7), orange (AUROC 0.6-0.65) red (AUROC <0.6)*

**Supplementary Table 12: Univariate analysis - age less than 6 years (malaria)**

| | Malawi - Malaria positives AUROC (CI), N | | | Gabon - Malaria positives AUROC (CI), N | | |
|---|---|---|---|---|---|---|
| | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** |
| **WBC count** | 0.64, (0.47-0.81), 50 | 0.71, (0.59-0.82), 148 | 0.7, (0.6-0.8), 178 | 0.62, (0.23-1), 11 | 0.62, (0.36-0.88), 44 | 0.62, (0.41-0.83), 56 |
| **RBC count** | 0.51, (0.33-0.68), 49 | 0.55, (0.44-0.65), 147 | 0.55, (0.44-0.65), 177 | 0.7, (0.34-1), 11 | 0.63, (0.42-0.84), 44 | 0.62, (0.45-0.8), 56 |
| **Lymphocyte count** | 0.45, (0.26-0.64), 49 | 0.58, (0.47-0.7), 147 | 0.55, (0.44-0.66), 177 | 0.57, (0.17-0.96), 11 | 0.6, (0.34-0.86), 44 | 0.63, (0.42-0.85), 56 |
| **Neutrophil count** | 0.59, (0.41-0.77), 49 | 0.65, (0.53-0.76), 140 | 0.66, (0.56-0.76), 169 | 0.7, (0.3-1), 11 | 0.49, (0.24-0.75), 44 | 0.55, (0.35-0.75), 56 |
| **IL-4** | 0.68, (0.5-0.86), 50 | 0.62, (0.52-0.71), 148 | 0.58, (0.49-0.67), 178 | 0.5, (0.5-0.5), 11 | 0.47, (0.42-0.51), 39 | 0.48, (0.44-0.51), 51 |
| **TRAIL** | 0.73, (0.56-0.89), 50 | 0.59, (0.48-0.69), 148 | 0.56, (0.47-0.66), 178 | 0.5, (0.5-0.5), 11 | 0.5, (0.5-0.5), 41 | 0.5, (0.5-0.5), 53 |
| **IL-6** | 0.6, (0.4-0.79), 49 | 0.64, (0.53-0.74), 147 | 0.63, (0.53-0.72), 175 | 0.47, (0.2-0.73), 11 | 0.48, (0.33-0.62), 37 | 0.48, (0.36-0.59), 49 |
| **CRP NycoCard** | 0.52, (0.33-0.7), 48 | 0.58, (0.48-0.69), 145 | 0.56, (0.46-0.66), 175 | 0.78, (0.47-1), 11 | 0.66, (0.41-0.91), 44 | 0.63, (0.42-0.84), 56 |
| **Gal-9** | 0.58, (0.37-0.79), 49 | 0.54, (0.43-0.65), 148 | 0.53, (0.43-0.64), 178 | 0.5, (0.05-0.95), 11 | 0.63, (0.45-0.82), 41 | 0.6, (0.44-0.76), 53 |
| **CHI3L1** | 0.53, (0.36-0.7), 50 | 0.6, (0.49-0.71), 148 | 0.57, (0.47-0.67), 178 | 0.47, (0.07-0.86), 11 | 0.54, (0.28-0.79), 40 | 0.56, (0.33-0.8), 51 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **IP-10** | 0.73, (0.57-0.9), 50 | 0.58, (0.47-0.69), 143 | 0.57, (0.47-0.67), 172 | 0.77, (0.38-1), 11 | 0.45, (0.26-0.64), 39 | 0.48, (0.32-0.64), 51 |
| **sPLA2** | 0.49, (0.3-0.69), 50 | 0.63, (0.52-0.75), 148 | 0.62, (0.52-0.72), 178 | 0.73, (0.38-1), 11 | 0.52, (0.27-0.78), 41 | 0.52, (0.31-0.73), 53 |
| **NGAL** | 0.61, (0.43-0.79), 47 | 0.56, (0.44-0.68), 118 | 0.54, (0.43-0.65), 141 | 0.87, (0.6-1), 11 | 0.62, (0.4-0.85), 40 | 0.61, (0.41-0.8), 52 |
| **LBP** | 0.55, (0.3-0.79), 48 | 0.48, (0.37-0.59), 122 | 0.52, (0.41-0.62), 147 | 0.45, (0.03-0.87), 11 | 0.58, (0.33-0.83), 41 | 0.61, (0.4-0.81), 53 |
| **C2** | 0.57, (0.38-0.76), 50 | 0.57, (0.47-0.68), 148 | 0.56, (0.46-0.67), 178 | 0.58, (0.2-0.97), 11 | 0.78, (0.6-0.96), 38 | 0.77, (0.6-0.93), 50 |
| **AGP** | 0.68, (0.52-0.84), 50 | 0.6, (0.49-0.71), 149 | 0.57, (0.47-0.68), 179 | 0.63, (0.24-1), 11 | 0.52, (0.32-0.73), 41 | 0.46, (0.27-0.65), 53 |
| **HBP** | 0.55, (0.27-0.84), 33 | 0.62, (0.49-0.76), 78 | 0.63, (0.49-0.76), 82 | .. | .. | .. |
| **HP** | 0.72, (0.58-0.87), 50 | 0.59, (0.48-0.7), 147 | 0.56, (0.46-0.67), 177 | 0.57, (0.18-0.95), 11 | 0.45, (0.21-0.69), 40 | 0.47, (0.26-0.68), 52 |

*Green (AUROC ≥ 0.7), yellow (AUROC ≥ 0.65 and <7), orange (AUROC 0.6-0.65), red (AUROC <0.6)*

**Supplementary Table 13: Univariate analysis - aged between 7 and 15 years (malaria)**

| | **Malawi - Malaria positives AUROC (CI), N** | | | **Gabon - Malaria positives AUROC (CI), N** | | |
|---|---|---|---|---|---|---|
| | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** |
| **WBC count** | 0.67, (0.51-0.82), 51 | 0.7, (0.6-0.8), 134 | 0.66, (0.57-0.75), 185 | **## unbalanced classes (24 non-bacterial, 1 bacterial) for 25 patients** | **## unbalanced classes (54 non-bacterial, 1 bacterial) for 55 patients** | 0.47, (0.03-0.91), 72 |
| **RBC count** | 0.74, (0.6-0.87), 51 | 0.55, (0.43-0.68), 134 | 0.53, (0.43-0.63), 185 | - | - | 0.67, (0.28-1), 73 |
| **Lymphocyte count** | 0.64, (0.49-0.79), 51 | 0.59, (0.47-0.7), 134 | 0.55, (0.46-0.64), 184 | - | - | 0.44, (0.14-0.75), 72 |
| **Neutrophil count** | 0.63, (0.47-0.79), 50 | 0.67, (0.56-0.78), 127 | 0.67, (0.58-0.76), 174 | - | - | 0.51, (0.17-0.86), 73 |
| **IL-4** | 0.53, (0.36-0.7), 51 | 0.54, (0.44-0.64), 134 | 0.53, (0.45-0.61), 184 | - | - | 0.62, (0.27-0.96), 65 |
| **TRAIL** | 0.51, (0.35-0.68), 51 | 0.52, (0.41-0.63), 134 | 0.54, (0.45-0.63), 184 | - | - | 0.62, (0.38-0.87), 72 |
| **IL-6** | 0.62, (0.46-0.78), 50 | 0.57, (0.46-0.68), 132 | 0.51, (0.41-0.6), 181 | - | - | 0.41, (0.37-0.46), 67 |
| **CRP NycoCard** | 0.55, (0.39-0.71), 51 | 0.52, (0.4-0.64), 134 | 0.51, (0.41-0.61), 185 | - | - | 0.59, (0.21-0.97), 73 |
| **Gal-9** | 0.6, (0.44-0.76), 51 | 0.53, (0.42-0.65), 134 | 0.55, (0.45-0.65), 185 | - | - | 0.64, (0.23-1), 72 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **CHI3L1** | 0.53, (0.36-0.69), 51 | 0.49, (0.38-0.6), 133 | 0.54, (0.45-0.64), 183 | - | - | 0.61, (0.08-1), 69 |
| **IP-10** | 0.63, (0.47-0.79), 50 | 0.56, (0.45-0.68), 133 | 0.53, (0.43-0.63), 184 | - | - | 0.55, (0.11-0.99), 67 |
| **NGAL** | 0.55, (0.38-0.71), 51 | 0.52, (0.41-0.64), 134 | 0.53, (0.44-0.63), 185 | - | - | 0.56, (0.13-0.99), 72 |
| **HNL** | 0.67, (0.48-0.85), 42 | 0.47, (0.35-0.59), 108 | 0.57, (0.48-0.67), 150 | - | - | 0.66, (0.33-1), 69 |
| **LBP** | 0.61, (0.44-0.78), 42 | 0.59, (0.47-0.71), 108 | 0.56, (0.46-0.66), 151 | - | - | 0.9, (0.77-1), 67 |
| **C2** | 0.62, (0.46-0.78), 51 | 0.57, (0.46-0.68), 133 | 0.54, (0.45-0.64), 184 | - | - | 0.73, (0.47-0.98), 70 |
| **AGP** | 0.6, (0.44-0.76), 51 | 0.55, (0.43-0.67), 134 | 0.52, (0.42-0.62), 185 | - | - | 0.53, (0.07-0.99), 72 |
| **HBP** | 0.64, (0.39-0.9), 21 | 0.46, (0.28-0.65), 50 | 0.49, (0.31-0.67), 55 | - | - | - |
| **HP** | 0.54, (0.37-0.7), 51 | 0.49, (0.38-0.59), 132 | 0.49, (0.4-0.59), 183 | - | - | 0.79, (0.6-0.98), 71 |

*Green (AUROC ≥ 0.7), yellow (AUROC ≥ 0.65 and <7), orange (AUROC 0.6-0.65) red (AUROC <0.6)*

**Supplementary Table 14: Univariate analysis - aged more than 15 years (malaria)**

| | Malawi - Malaria positives AUROC (CI), N | | | Gabon - Malaria positives AUROC (CI), N | | |
|---|---|---|---|---|---|---|
| | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** |
| **WBC count** | 0.54, (0.32-0.76), 31 | 0.56, (0.37-0.75), 87 | 0.65, (0.51-0.78), 128 | 2 patients in total | 11 patients in total | 11 patients in total |
| **RBC count** | 0.42, (0.2-0.63), 31 | 0.58, (0.42-0.73), 86 | 0.57, (0.44-0.7), 126 | - | - | - |
| **Lymphocyte count** | 0.77, (0.61-0.94), 31 | 0.64, (0.5-0.78), 87 | 0.66, (0.55-0.77), 127 | - | - | - |
| **Neutrophil count** | 0.5, (0.28-0.73), 30 | 0.55, (0.35-0.74), 81 | 0.62, (0.48-0.77), 120 | - | - | - |
| **IL-4** | 0.53, (0.33-0.73), 31 | 0.5, (0.34-0.66), 87 | 0.48, (0.37-0.59), 126 | - | - | - |
| **TRAIL** | 0.62, (0.42-0.82), 31 | 0.6, (0.44-0.76), 87 | 0.63, (0.51-0.75), 126 | - | - | - |
| **IL-6** | 0.67, (0.47-0.87), 32 | 0.52, (0.35-0.69), 88 | 0.54, (0.41-0.66), 129 | - | - | - |
| **CRP NycoCard** | 0.57, (0.36-0.78), 32 | 0.52, (0.37-0.68), 88 | 0.52, (0.4-0.64), 129 | - | - | - |
| **Gal-9** | 0.61, (0.4-0.82), 32 | 0.59, (0.44-0.73), 87 | 0.52, (0.39-0.65), 128 | - | - | - |

| | | | | | | |
|---|---|---|---|---|---|---|
| **CHI3L1** | 0.64, (0.43-0.85), 31 | 0.53, (0.37-0.69), 86 | 0.52, (0.4-0.65), 126 | - | - | - |
| **IP-10** | 0.66, (0.45-0.87), 32 | 0.52, (0.35-0.69), 87 | 0.58, (0.44-0.71), 128 | - | - | - |
| **sPLA2** | 0.62, (0.42-0.82), 32 | 0.53, (0.37-0.69), 88 | 0.56, (0.44-0.69), 129 | - | - | - |
| **NGAL** | 0.7, (0.48-0.92), 25 | 0.55, (0.35-0.75), 65 | 0.56, (0.41-0.7), 95 | - | - | - |
| **LBP** | 0.37, (0.14-0.6), 25 | 0.47, (0.29-0.66), 65 | 0.59, (0.46-0.73), 95 | - | - | - |
| **C2** | 0.64, (0.43-0.85), 32 | 0.59, (0.42-0.76), 88 | 0.47, (0.33-0.6), 129 | - | - | - |
| **AGP** | 0.68, (0.49-0.87), 32 | 0.47, (0.31-0.63), 88 | 0.52, (0.39-0.64), 129 | - | - | - |
| **HBP** | 0.8, (0.34-1), 7 | 0.62, (0.29-0.95), 23 | 0.62, (0.29-0.95), 24 | - | - | - |
| **HP** | 0.52, (0.31-0.73), 32 | 0.51, (0.35-0.67), 86 | 0.53, (0.41-0.64), 127 | - | - | - |

*Green (AUROC ≥ 0.7), yellow (AUROC ≥ 0.65 and <7), orange (AUROC 0.6-0.65) red (AUROC <0.6)*

**Supplementary Table 15: Multivariate analysis – non-malaria population; haematological biomarkers**

| **Haematological biomarkers** | | | | | | |
|---|---|---|---|---|---|---|
| **Overall** | | | | | | |
| **Multivariate models' variables** | | | **Classification group** | **Best multivariate model/models: mean (SD) AUROC** | **Best host-biomarker: mean (SD) AUROC** | **Multivariate AUROC gain/loss (%)** |
| **Rulefit** | **Logistic - RFA** | **Logistic - SW** | | | | |
| country , neutrophil count WBC count, lymphocyte count, fever duration, temperature, pulse rate, respiratory rate | country neutrophil count, fever duration | country neutrophil count fever duration respiratory rate | L | RF/SW/RFA: 0.75 (0.03) | WBC count : 0.7 (0.03) | +7% |
| | | | S | SW: 0.83 (0.04) | WBC count: 0.78 (0.03) | +6% |
| | | | E | SW/RFA: 0.83 (0.02) | WBC count: 0.77 (0.03) | +8% |
| **Gabon*** | | | | | | |
| Gabon performance evaluation using the Overall model and Gabon data extracted from the Overall test sets | | | L | SW:0.7 (0.12) | WBC count : 0.7 (0.03) | |
| | | | S | SW: 0.77 (0.12) | WBC count: 0.73 (0.03) | +5% |
| | | | E | RFA: 0.77 (0.08) | WBC count: 0.75 (0.03) | +3% |
| **Malawi** | | | | | | |
| diastolic blood pressure, HAEMATO_C lymphocyte count, neutrophil count, pulse rate, temperature, fever duration | fever duration neutrophil count | fever duration neutrophil count | L | RFA: 0.74(.05) | neutrophil count: 0.72(.06) | +3% |
| | | | S | SW: 0.73(.06) | neutrophil count: 0.72(.07) | +1% |
| | | | E | RFA: 0.66(.16) | WBC count: 0.7 (0.05) | -6% |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Brazil** | | | | | | |
| diastolic blood pressure, haematocrit lymphocyte count, neutrophil count, pulse rate, temperature, fever duration, respiratory rate, WBC count | WBC count respiratory rate neutrophil count | WBC count respiratory rate | L | RFA: 0.82 (0.08) | WBC count: 0.81 (0.08) | +1% |
| | | | S | RFA: 0.82 (0.08) | WBC count: 0.81 (0.08) | +1% |
| | | | E | RFA: 0.84 (0.07) | WBC count: 0.83 (0.07) | +1% |

E, electronic classification group; S, strict classification group; L, loose classification group; RF, Rulefit; RFA, logistic recursive feature addition; SW, stepwise logistic regression. Green (gain, i.e. multivariate models have better performances than univariate models); red (loss, i.e. univariate models have better performances than multivariate models).
*Multivariate performances for Gabon were computed using the Overall population-trained model as a predictor model and tested with Gabon data due to the limited data.

**Supplementary Table 16: Multivariate analysis – non-malaria population; protein biomarkers**

| **Protein biomarkers** | | | | | | |
|---|---|---|---|---|---|---|
| **Overall** | | | | | | |
| **Multivariate models' variables** | | | **Classification group** | **Best multivariate model/models: mean (SD) AUROC** | **Best host-biomarker: mean (SD) AUROC** | **Multivariate AUROC gain/loss (%)** |
| **Rulefit** | **Logistic - RFA** | **Logistic - SW** | | | | |
| CRP AGP LBP NGAL pulse rate respiratory rate diastolic blood pressure temperature country | CRP country LBP NGAL pulse rate | CRP country NGAL pulse rate respiratory rate temperature | L | RF/RFA/SW: 0.66 (0.05) | LBP: 0.62 (0.04) | +6% |
| | | | S | RF: 0.74 (0.04) | LBP: 0.66 (0.05) | +12% |
| | | | E | RFA: 0.76 (0.04) | LBP: 0.75 (0.04) | +1% |
| **Gabon*** | | | | | | |
| Gabon performance evaluation using the Overall model and Gabon data extracted from the Overall test sets | | | L | SW: 0.64 (0.12) | LBP: 0.62 (0.04) | +3% |
| | | | S | RFA: 0.7 (0.11) | LBP: 0.66 (0.05) | +6% |
| | | | E | RFA: 0.7 (0.09) | LBP: 0.75 (0.04) | -7% |
| **Malawi** | | | | | | |
| IP-10 Gal-9 NGAL temperature CRP respiratory rate fever duration pulse rate diastolic blood pressure | Gal-9 NGAL temperature | Gal-9 NGAL temperature pulse rate fever duration | L | SW: 0.7 (0.06) | Lipocalin. 2: 0.65 (0.06) | +8% |
| | | | S | RF/ SW: 0.67 (0.06) | Lipocalin. 2: 0.64 (0.06) | +5% |
| | | | E | RF: 0.71 (0.12) | IP-10: 0.69 (0.08) | +3% |
| **Brazil** | | | | | | |
| CRP, Gal-9, AGP | Gal-9, TRAIL, | | L | RF: 0.67 (0.04) | CRP: 0.65 (0.06) | +3% |

| | | | | | | |
|---|---|---|---|---|---|---|
| pulse rate, diastolic blood pressure respiratory rate, temperature | NGAL | Gal-9, pulse rate, fever duration, NGAL, temperature | S | SW/RFA: 0.66(.04) | CRP: 0.65 (0.05) | +1% |
| | | | E | SW/RFA: 0.65(.05) | CRP: 0.63 (0.08) | +3% |

E, electronic classification group; S, strict classification group; L, loose classification group; RF, Rulefit; RFA, logistic recursive feature addition; SW, stepwise logistic regression. Green (gain, i.e. multivariate models have better performances than univariate models); red (loss, i.e. univariate models have better performances than multivariate models).

* Multivariate performances for Gabon were computed using the Overall population-trained model as a predictor model and tested with Gabon data.

**Supplementary Table 17: Multivariate analysis – non-malaria population; haematological and protein biomarkers**

| **Haematology + protein biomarkers** | | | | | | |
|---|---|---|---|---|---|---|
| **Overall** | | | | | | |
| **Multivariate models' variables** | | | **Classification group** | **Best multivariate model/models: mean (SD) AUROC** | **Best host-biomarker: mean (SD) AUROC** | **Multivariate AUROC gain/loss (%) ** multivariate and single host-biomarkers ratio** |
| **Rulefit** | **Logistic - RFA** | **Logistic - SW** | | | | |
| AGP<br>LBP<br>NGAL<br>neutrophil count<br>WBC count<br>Country<br>temperature<br>fever duration<br>pulse rate<br>respiratory rate | Country<br>neutrophil count<br>fever duration<br>LBP | Country<br>neutrophil count<br>fever duration<br>respiratory rate | L | SW/RFA/RF:0.75(.03) | WBC count: 0.7 (.03) | +7% |
| | | | S | SW:0.83(.04) | WBC count: 0.78(.03) | +6% |
| | | | E | SW/RFA:0.83 (.03) | WBC count: 0.77 (0.04) | +8% |
| **Brazil** | | | | | | |
| Gal-9, neutrophil count, WBC count, CRP, sPLA, respiratory rate, temperature, diastolic blood pressure, fever duration, pulse rate | neutrophil count, WBC count, respiratory rate, Gal-9 | WBC count, Gal-9 respiratory rate | L | SW: 0.82 (0.06) | WBC count: 0.8 (0.06) | +2.5% |
| | | | S | RFA: 0.82 (0.06) | WBC count: 0.8 (0.06) | +2.5% |
| | | | E | SW: 0.85 (0.06) | WBC count: 0.83 (0.07) | +2% |
| **Gabon*** | | | | | | |
| Gabon performance evaluation using the overall model and Gabon data extracted from the Overall test sets | | | L | SW/RFA: 0.7 (0.12) | WBC count: 0.7 (.03) | - |
| | | | S | SW/RFA: 0.76 (0.12) | WBC count: 0.78(.03) | -3% |
| | | | E | RFA: 0.77 (0.07) | WBC count: 0.77 (0.04) | - |
| **Malawi** | | | | | | |
| IP-10<br>Gal-9<br>LBP<br>neutrophil count | neutrophil count, WBC count | neutrophil count<br>WBC count, fever duration, | L | SW/RFA: 0.74 (0.06) | neutrophil count: 0.72 (0.03) | +3% |

| | | | | | | |
|---|---|---|---|---|---|---|
| WBC count<br>NGAL<br>pulse rate<br>respiratory rate<br>temperature<br>diastolic blood pressure<br>fever duration | fever duration, IP-10 | IP-10, temperature | S | SW: 0.73 (0.06) | neutrophil count: 0.72 (0.07) | +1% |
| | | | E | RFA: 0.72 (0.6) | WBC count: 0.7 (0.) | +2% |

E, electronic classification group; S, strict classification group; L, loose classification group; RF, Rulefit; RFA, logistic recursive feature addition; SW, stepwise logistic regression. Green (gain, i.e. multivariate models have better performances than univariate models); red (loss, i.e. univariate models have better performances than multivariate models).

* Multivariate performances for Gabon were computed using the Overall population-trained model as a predictor model and tested with Gabon data.

**Supplementary Table 18: Multivariate analysis – malaria population; haematological biomarkers**

| **Haematological biomarkers** | | | | | | |
|---|---|---|---|---|---|---|
| **Overall** | | | | | | |
| **Multivariate models' variables** | | | **Classification group** | **Best multivariate model/models: mean (SD) AUROC** | **Best host-biomarker: mean (SD) AUROC** | **Multivariate AUROC gain/loss (%)** |
| **Rulefit** | **Logistic - RFA** | **Logistic - SW** | | | | |
| haematocrit<br>lymphocyte count<br>neutrophil count<br>diastolic blood pressure<br>fever duration<br>pulse rate<br>respiratory rate<br>country<br>temperature | neutrophil count<br>WBC count<br>country | lymphocyte count<br>neutrophil count<br>country | L | RFA: 0.68 (0.04) | neutrophil count: 0.65 (0.05) | +5% |
| | | | S | SW: 0.66 (0.05) | neutrophil count: 0.6 (0.08) | +10% |
| | | | E | RF: 0.69 (0.07) | neutrophil count: 0.61 (0.08) | +13% |
| **Gabon*** | | | | | | |
| Gabon performance evaluation using the Overall model and Gabon data extracted from the Overall test sets | | | L | SW: 0.67 (0.18) | neutrophil count: 0.65 (0.05) | +3% |
| | | | S | SW: 0.75 (0.2) | neutrophil count: 0.6 (0.08) | +25% |
| | | | E | Not sufficient data | | |
| **Malawi** | | | | | | |
| diastolic blood pressure<br>lymphocyte count<br>neutrophil count<br>temperature<br>WBC count<br>haematocrit<br>pulse rate<br>respiratory rate<br>fever duration | neutrophil count,<br>WBC count,<br>temperature | WBC count, | L | RFA: 0.7 (0.06) | WBC count: 0.69 (0.05) | +1% |
| | | | **S** | SW: 0.69 (0.07) | WBC count: 0.69 (0.07) | - |
| | | | **E** | RFA: 0.6 (0.14) | lymphocyte count: 0.67 (0.05) | -10% |

E, electronic classification group; S, strict classification group; L, loose classification group; RF, Rulefit; RFA, logistic recursive feature addition; SW, stepwise logistic regression. Green (gain, i.e. multivariate models have better performances than univariate models); red (loss, i.e. univariate models have better performances than multivariate models).

* Multivariate performances for Gabon were computed using the Overall population-trained model as a predictor model and tested with Gabon data.

**Supplementary Table 19: Multivariate analysis – malaria population; protein biomarkers**

| Protein biomarkers | | | | | | |
|---|---|---|---|---|---|---|
| **Overall** | | | | | | |
| **Multivariate models' variables** | | | **Classification group** | **Best multivariate model/models: mean (SD) AUROC** | **Best host-biomarker: mean (SD) AUROC** | **Multivariate AUROC gain/loss (%)** |
| **Rulefit** | **Logistic - RFA** | **Logistic - SW** | | | | |
| AGP<br>diastolic blood pressure<br>Gal-9<br>C2<br>LBP<br>pulse rate<br>respiratory rate<br>temperature<br>fever duration | C2 | country<br>respiratory rate<br>temperature<br>AGP | L | SW: 0.62 (0.07) | CHI3L1: 0.57 (0.03) | + 9% |
| | | | S | SW: 0.64 (0.04) | _NGAL: 0.6 (0.06) | + 7% |
| | | | E | SW: 0.67 (0.08) | C2: 0.63 (01) | + 6% |
| **Gabon*** | | | | | | |
| Gabon performance evaluation using the Overall model and Gabon data extracted from the Overall test sets | | | L | SW: 0.67 (0.17) | CHI3L1: 0.57 (0.03) | + 18% |
| | | | S | RFA: 0.81 (0.12) | NGAL: 0.6 (0.06) | +35%[$] |
| | | | E | Not sufficient data | | |
| **Malawi** | | | | | | |
| diastolic blood pressure<br>CHI3L1<br>IP-10<br>fever duration<br>Gal-9<br>C2<br>pulse rate<br>respiratory rate<br>temperature | respiratory rate, sPLA | respiratory rate, sPLA | L | RFA/SW: 0.57 (0.06) | IP-10: 0.57 (0.05) | - |
| | | | S | SW/RFA: 0.62 (0.09) | HCC2_PL: 0.62 (0.06) | - |
| | | | E | SW/RFA: 0.61 (0.06) | IP-10: 0.66 (0.09) | -7% |

E, electronic classification group; S, strict classification group; L, loose classification group; RF, Rulefit; RFA, logistic recursive feature addition; SW, stepwise logistic regression. Green (gain, i.e. multivariate models have better performances than univariate models); red (loss, i.e. univariate models have better performances than multivariate models).

*Multivariate performances for Gabon are computed using the Overall population-trained model as a predictor model and tested with Gabon data. [$]This output has to be considered an outlier due to biomarker data imbalance between pipeline data and the available Gabon data set.

**Supplementary Table 20: Multivariate analysis – malaria population; haematological and protein biomarkers**

| Protein + haematological biomarkers | | | | | | |
|---|---|---|---|---|---|---|
| **Overall** | | | | | | |
| **Multivariate models' variables** | | | **Classification group** | **Best multivariate model/models: mean (SD) AUROC** | **Best host-biomarker: mean (SD) AUROC** | **Multivariate AUROC gain/loss (%)** |
| **Rulefit** | **Logistic - RFA** | **Logistic - SW** | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| AGP_Pl<br>diastolic blood pressure<br>Gal-9<br>C2<br>LBP.<br>NGAL<br>neutrophil count<br>respiratory rate<br>temperature<br>pulse rate<br>fever duration | country<br>WBC count | country,<br>Wbc_c, | L | SW/RFA: 0.68 (0.04) | neutrophil count: 0.65 (0.05) | +5% |
| | | | **S** | RFA/SW: 0.66 (0.05) | neutrophil count: 0.6 (0.08) | +10% |
| | | | **E** | RFA/SW: 0.66 (0.11) | HCC2_PL: 0.63 (0.1) | +5% |
| **Gabon*** | | | | | | |
| Gabon performance evaluation using the Overall model and Gabon data extracted from the Overall test sets | | | **L** | **RFA/SW: 0.66 (0.18)** | neutrophil count: 0.65 (0.05) | +1% |
| | | | **S** | RFA/SW: 0.7 (0.2) | neutrophil count: 0.6 (0.08) | +17% |
| | | | E | Not sufficient data | | |
| **Malawi** | | | | | | |
| CHI3L1<br>IP-10<br>Gal-9<br>C2<br>neutrophil count<br>respiratory rate<br>temperature<br>diastolic blood pressure<br>pulse rate<br>fever duration | C2<br>neutrophil count<br>WBC count | WBC count | **L** | **SW: 0.69 (0.05)** | **WBC count: 0.69 (0.05)** | - |
| | | | **S** | RFA: 0.73 (0.07) | WBC count: 0.69 (0.07) | +6% |
| | | | **E** | RFA: 0.72. (0.1) | lymphocyte count: 0.67 (0.05) | +7% |

E, electronic classification group; S, strict classification group; L, loose classification group; RF, Rulefit; RFA, logistic recursive feature addition; SW, stepwise logistic regression. Green (gain, i.e. multivariate models have better performances than univariate models); red (loss, i.e. univariate models have better performances than multivariate models).

*Multivariate performances for Gabon are computed using the Overall population-trained model as a predictor model and tested with Gabon data.

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# Cross-Sectional Evaluation of Host Biomarkers for Guiding Antibiotic Use in Bacterial and Non-Bacterial Acute Febrile Illness in Low- and Middle-Income Tropical Settings



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# Cross-Sectional Evaluation of Host Biomarkers for Guiding Antibiotic Use in Bacterial and Non-Bacterial Acute Febrile Illness in Low- and Middle-Income Tropical Settings

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# ABSTRACT

## Objectives

To evaluate the effectiveness of 18 different host biomarkers in differentiating bacterial from non-bacterial acute febrile illness (AFI) in resource-limited settings, specifically in Brazil, Malawi, and Gabon.

## Design

Multinational, cross-sectional study

## Setting

The study was carried out across multiple primary healthcare facilities, including urban and rural settings, with a total of three participating centers. Recruitment took place from October 2018 to July 2019 in Brazil, May to November 2019 in Gabon, and April 2017 to April 2018 in Malawi.

## Participants

A total of 1,915 participants, including children and adults aged 21 to 65 years with a fever of ≤7 days, were recruited through convenience sampling from outpatient clinics in Brazil, Gabon, and Malawi. Individuals with signs of severe illness were excluded. Written consent was obtained from all participants or their guardians.

## Intervention

Not applicable as the study primarily focused on biomarker evaluation without specific therapeutic interventions.

## Primary and Secondary Outcome Measures

The primary outcome measure was the ability of each host biomarker to differentiate between bacterial and non-bacterial AFI, as evaluated by area under the receiver operating characteristic (AUROC) curves. Secondary outcomes included the performance of individual biomarkers across the different study sites and in a multivariable setting.

**Results**

A Kruskal-Wallis test, adjusted by Benjamini-Hochberg, was performed for each biomarker to identify covariates with a significant difference in the distribution of biomarker values. The analysis revealed that country of origin (Brazil, Gabon, Malawi), age, sex, and malaria status significantly impacted biomarker distribution ($p \leq 0.001$). The most widely known biomarkers, such as white blood cell count and C-reactive protein (CRP), demonstrated the best performance in distinguishing between bacterial and non-bacterial infections, with AUROCs reaching up to 0.83 [0.77 - 0.88] for white blood cell count and 0.71 [0.59 - 0.82] for CRP. However, none of the evaluated novel host biomarkers exhibited high performance (AUROC < 0.70 in most cases), and variations in biomarker performance were observed across the three settings. Multivariable analyses demonstrated that while the best combination of biomarkers achieved higher AUROCs, the increase was modest (1–13%), suggesting that the interaction of biomarkers contributed minimally to predictive accuracy.

**Conclusions**

There is a continued need for innovation in the host-biomarker space as the available markers do not meet the needs of diverse populations around the globe. This highlights the importance of targeted evaluations in non-severe patients in multiple settings to understand true potentials for real-life use. The findings highlight that not one-marker fits all settings and novel innovations remain urgently needed.

**Trial Registration**

Clinical trial number: NCT03047642

**Keywords**

Antimicrobial Resistance, AMR, CRP, Host Biomarkers, Prospective study, biomarker, non-malaria fever, primary health care, Malawi, Brazil, Gabon

## STRENGTHS AND LIMITATIONS OF THIS STUDY

- **Diverse Evaluation**: This study is an extensive evaluation of 18 host biomarkers across low- and middle-income countries (LMICs) to differentiate bacterial from non-bacterial infections.
- **Methodological Alignment**: The study protocol aligns with FDA-approved classifications for distinguishing between bacterial and non-bacterial infections, enhancing methodological rigor.
- **No Control Group**: The absence of a control group limits the ability to establish baseline biomarker performance or to assess asymptomatic carriers.
- **Time and Geographic Variability**: The short enrollment period and heterogeneity of acute febrile illness causes may limit the generalizability of findings across different times and geographical contexts, particularly in Asia.
- **Subjectivity in Classification**: The two-step clinical classification process may introduce subjectivity, particularly as clinicians had access to hematology biomarker results during classification, potentially biasing results.

## INTRODUCTION

Globally, acute febrile illness (AFI) is one of the leading reasons individuals, particularly children aged less than 5 years, present to primary healthcare facilities [1]. AFI has various causes, both infectious and non-infectious, that vary according to geography, age group, and season [1]. In malaria-endemic settings, malaria was long considered the primary cause of all fevers; however, the introduction of rapid diagnostic tests (RDTs) for malaria in the past decade has disproved this. Modelling estimates suggest that approximately 70% of all fevers can be attributed to non-malarial causes, even in malaria-endemic settings [2]. In the Integrated Management of Childhood Illness (IMCI), introduced by the World Health Organization (WHO) and UNICEF in the mid-1990s and subsequently implemented in more than 100 countries, the standard "fever" algorithm currently includes a malaria RDT but no diagnostic test for other infections [3]. Hence, at primary care level, the only evidence-based treatment decision that can be made relies on the malaria RDT, resulting in extremely high levels of antibiotic use in malaria-negative patients [4]. In this context of limited knowledge about the causes of AFI and limited diagnostic and human capacity, it is unsurprising that healthcare providers prescribe antibiotics to avoid negative outcomes in their patients.

To assist healthcare providers with clinical decision-making, a simple diagnostic tool is required to differentiate patients with AFI of bacterial and non-bacterial aetiology and provide appropriate care. In well-resourced settings, in both high-income countries (HICs) and low- and middle-income countries (LMICs), some nonspecific host-biomarkers are used for this purpose, most frequently C-reactive protein (CRP) and procalcitonin (PCT), although these biomarkers are less useful in settings with a higher frequency of comorbidities [5]. Thus, in 2015, an international group of experts was convened to define the target product profile (TPP) of such a tool, specifically for low-resource settings, to guide product development and implementation as part of integrated treatment management guidelines [6]. Since then, the

ongoing viral pandemic (SARS-CoV-2) has further highlighted the challenge of differential diagnosis and shows yet again that better antimicrobial stewardship interventions are needed to counter the overprescribing of antibiotics in patients with viral infections [7].

Host biomarkers other than CRP and PCT have been evaluated for distinguishing bacterial from non-bacterial infections, including human neutrophil lipocalin (HNL), heparin-binding protein (HBP), and chitinase 3-like protein 1 (CHI3L1) [8]. There are also some commercially available tests. ImmunoXpert™, from MeMed, uses a biomarker combination comprising CRP, interferon gamma-inducible protein 10 (IP-10), and TNF-related apoptosis-inducing ligand (TRAIL), while FebriDx®, from Lumos Diagnostics, uses an MxA and CRP biomarker combination. While these biomarker signatures show promise, they have only been evaluated in limited settings. Any potential impact of co-infections or comorbidities, common in LMICs, on their effectiveness is unknown. Other characteristics of host-biomarker studies that hamper direct comparisons include: (i) just one/a few biomarkers in the study; (ii) small sample sizes, increasing the probability of recruiting unrepresentative study populations; (iii) narrow population subgroups (e.g. children only, hospitalised only, respiratory infections only, etc), limiting the generalisability of study results to the broader AFI population; (iv) studies conducted in one country, so co-infections/comorbidities may not be comparable with those of other countries; (v) retrospective studies that used convenience sampling and case-control study designs, increasing the risk of bias; and (vi) the lack of a standard definitions for classifying bacterial versus non-bacterial infections [9].

Here, we describe the Biomarker for Fever Diagnostic (BFF-Dx) study, specifically designed to evaluate host biomarkers to distinguish bacterial from non-bacterial infections in line with the published TPP and the final use case of such diagnostic tests. To our knowledge, this is the only study to evaluate host biomarkers in the intended target population (non-severe patients), prospectively, in multiple settings with a large sample set. We evaluated 18 host-biomarkers in

three distinct settings, in Brazil, Gabon, and Malawi with the main objective to provide a performance comparison of host biomarkers in the non-severe AFI population from resource-limited settings, with the goal to overcome many of the previously described limitations (eg. sample size, retrospective vs prospective, focused populations, biased analysis) [10]. The described comparison was conducted within the pragmatic context of diagnostic product development and aimed to identify host biomarkers or biomarker combinations for utilisation in next-generation rapid diagnostic tests.

# METHODOLOGY

## Study settings

This multinational, cross-sectional study was conducted in Brazil, Gabon, and Malawi; Gabon and Malawi were selected as high-malaria endemicity settings, while Brazil was selected as a low-malaria endemic setting. The study sites were UPA Manguinhos and Family Health Clinics Armando Palhares in Rio de Janeiro, Brazil; the Clinical Trials Unit Center of Medical Research Lambaréné (CERMEL), Lambaréné, Gabon; and Malawi Epidemiology and Intervention Research Unit (MEIRU), Chilumba campus, Malawi. The enrollment sites were an urban primary healthcare facility, a hospital in a semi-rural setting, and a rural primary healthcare facility in Brazil, Gabon, and Malawi, respectively. Participants were recruited from October 2018 to July 2019, May to November 2019, and April 2017 to April 2018, in Brazil, Gabon, and Malawi, respectively. The study protocol was submitted to clinicaltrial.gov (NCT03047642) and ethical approval was obtained from all relevant institutional committees in Brazil (Research Ethics Committee of INI-FIOCRUZ and Comissão Nacional de Ética em Pesquisa ; National Research Ethics Committee), Gabon (Comité National d'Ethique pour la Recherche) and Malawi (National Health Science Research Committee ; Observational and Intervention Research Ethics Committee of the London School of Hygiene and Tropical Medicine , UK) and all details of the design have been previously published [10]. Reporting complies with the STARD-15 checklist.

## Study population and study procedure

Participants were obtained through convenience sampling and included both children and adults, aged between 2 and 65 years, who presented at the outpatient clinics with a history of fever of ≤7 days duration (Brazil and Gabon) or fever at presentation (Malawi). Patients with signs of severe illness were not included in the study. The overarching study protocol was

slightly adapted to each site due to local requirements (logistical or ethical). Detailed criteria for inclusion by study sites have been published previously [10]. Outcomes were based on the TPP criteria and while no patient input was used, external expert input was used to define target population and criteria. Only patients who met the eligibility criteria and who provided written consent (patient or guardian for children) were enrolled in the study. Data and samples were systematically collected and analysed as previously described. To ensure consistent quality and comparability of data, the same standard operating procedures were used at all sites (for data collection and laboratory testing) [10].

**Patient and Public Involvement statement**

None

**Bacterial/non-bacterial classification and biomarker selection and testing**

A two-step process was used to classify the patients into "bacterial" and "non-bacterial" groups. First, the cause of fever (bacterial/non-bacterial) was classified according to laboratory-determined parameters ("electronic group"). The electronic group was based on predefined and widely accepted laboratory parameters, including direct pathogen detection, a fourfold increase in anti- body titre, or a positive PCR or antigen RDT result. The list of tests performed is described in detail in by Escadafal et al. [10]. Next, cases that could not be classified by laboratory-determined parameters were assessed by a panel of three independent clinical experts. Patient's history and clinical and laboratory data was provided to the experts. Clinical expert's assessments were then compared.If the three panel members unanimously assigned a diagnostic label, patients were considered to have "bacterial" or "non-bacterial" infections; if two out of three panel members reported a classification of "bacterial" or "non-bacterial", these

patients were considered to have “probable bacterial infection” or “probable non-bacterial infection”, respectively.

Data were analysed based on three groups of patients: 1) the “electronic group”, i.e. subjects with a cause of fever defined based on laboratory parameters; 2) the “strict group”, which comprised the electronic group and the patients that were unanimously classified by the clinical panel of three experts; and 3) the “loose group”, which comprised the electronic and strict groups as well as those patients for whom two of the clinical experts agreed they had either probable bacterial or probable non-bacterial infection. Subjects with undetermined cause of fever according to the three classification criteria considered (“electronic group”, “strict group”, “loose group”) were excluded from the statistical analysis. This outcome-oriented approach, based on methods previously developed for host-biomarker studies and described previously, was used to ensure the total intended-use population of any future test was represented in the final analysis [10, 11].

The evaluated biomarkers were selected based on previously reported performances, and haematological markers as well as CRP were included as comparators (Table 1 and Supplementary Table 1 and 2) [8, 12].

At the end of data collection, all biomarker data were analysed to assess the percentage of missing values and the percentage of values below the lower limit or above the upper limit of detection of the used tests. Biomarkers with more than 50% of missing data or more than 95% of saturated values below the lower limit of quantification of the used test, were excluded from the following statistical analysis.

**Table 1**. Novel biomarkers identified in the literature and evaluated in the BFF-Dx study, including sample type used, evaluation method, and sample origin.

| Abbreviation | Biomarker name | Sample type | Evaluation method | Sample origin |
|---|---|---|---|---|
| AGP | A-1-acid glycoprotein | EDTA-plasma | Luminex | B, G, M |
| C2 | Complement 2 | EDTA-plasma | Luminex | B, G, M |
| C4b | Complement C4b | EDTA-plasma | Luminex | B, G, M |
| CHI3L1 | Chitinase-3-like protein 1 | EDTA-plasma | Luminex | B, G, M |
| CRP | C-reactive protein | EDTA-plasma | CRP Nycocard/ NycoCardReader II, ELISA | B, G, M |
| Gal-9 | Galectin-9 | EDTA-plasma | Luminex | B, G, M |
| HBP | Heparin-binding protein | EDTA-plasma | ELISA | B, M |
| HNL | Human neutrophil lipocalin | Heparin-activated plasma time-controlled activation# | ELISA | M |
| | | EDTA-plasma | ELISA | B, G, M |
| HP | Haptoglobin | EDTA-plasma | Luminex | B, G, M |
| IFN-gamma | Interferon gamma | EDTA-plasma | Luminex | B, G, M |
| IL-4 | Interleukin-4 | EDTA-plasma | Luminex | B, G, M |
| IL-6 | Interleukin-6 | EDTA-plasma | Luminex | B, G, M |
| IP-10 | Gamma-induced protein 10 | EDTA-plasma | Luminex | B, G, M |
| LBP | Lipopolysaccharide binding protein | EDTA-plasma | Luminex | B, G, M |
| NGAL | Neutrophil gelatinase-associated lipocalin | Frozen heparin-activated plasma | Luminex | M |
| | | EDTA-plasma | Luminex | B, G, M |
| PCT | Procalcitonin | EDTA-plasma | Luminex; ELISA | B, G, M |
| sPLA2 | Secretory phospholipase 2 | EDTA-plasma | Luminex | B, G, M |
| sTREM-1 | Soluble triggering receptor expressed on myeloid cells 1 | EDTA-plasma | Luminex | B, G, M |
| TRAIL | TNF-related apoptosis-inducing ligand | EDTA-plasma | Luminex | B, G, M |

B, Brazil; G, Gabon; M, Malawi

# Whole blood samples were collected in lithium heparin tubes and activation was performed within 60 min prior to freezing and subsequent ELISA testing [13]. All biomarkers were tested using the same standard operating procedures (SOPs) and all sites were trained on the SOPSs. For CRP and PCT different devices were used at different sites, repeat testing was performed at the central facility (NMI).

## Statistical analysis

a. Kruskal-Wallis Analysis and Definition of Covariates Influence on Biomarkers

A Kruskal-Wallis test, adjusted by Benjamini-Hochberg, was conducted for each biomarker to determine which covariates exhibited statistically significant differences in the distribution of biomarker values. The covariates studied were country (i.e., the country of origin of the patients), age, sex, malaria status, comorbidities (i.e., presence of one or more diseases among cardiovascular, neurological, respiratory, renal, genitourinary, connective tissue, cancer, or infectious diseases), malnutrition status calculated based on WHO body mass index criteria, self-reported use of antibiotics prior to visiting the health facility, axillary temperature ≥38°C, and positive result to Chikungunya test. The Kruskal-Wallis test was performed for each of the three patient groups defined in the previous section ("electronic", "strict", "loose"). The results of the Kruskal-Wallis test allowed the identification of covariates that most significantly impacted the biomarker distribution ($p \leq 0.001$, adjusted by Benjamini-Hochberg). The most significant covariates were considered for defining subgroups of patients in which the following univariate analyses were performed, or included as covariates in the multivariable analyses.

b. Univariate analysis

As an exploratory step, the ability of each biomarker to discriminate between bacterial and non-bacterial infections was assessed by the area under the receiver operating characteristic curve (AUROC). In particular, subjects were ranked based on the values of the single variable of interest (i.e. based on ordered values) and, using this as score, calculated the ROC curve and the corresponding area under the curve. Such univariate analysis was conducted for each patient group ("electronic", "strict", "loose") and specific patient subgroup (Malaria status, Country and Age).

However, since the univariate analyses did not yield satisfactory results, we also explored multivariable models to potentially improve the predictive capabilities by incorporating a broader range of information.

c. Multivariable analysis

Multivariable classification models were developed to assess the discrimination ability of combinations of biomarkers and covariates. For the multivariable analysis, both linear (logistic regression) and non-linear classification models (RuleFit) were explored [14]. The candidate features for each model included a group of host-biomarkers and some additional covariates (age, temperature, fever duration, diastolic blood pressure, respiration rate, and pulse rate). Regarding host-biomarkers, three different groups of biomarkers were considered: haematology biomarkers only (i.e. white blood cell, neutrophil, red blood cell, lymphocyte counts), protein biomarkers only (i.e. novel biomarkers + CRP), and haematology plus protein biomarkers (i.e. all biomarkers).

For each patient subgroup and each candidate feature set, three multivariable models were developed: i) a logistic regression model with stepwise (SW) feature selection; ii) a logistic regression model with features selected based on recursive feature addition (RFA; a variant of the method proposed in [15]); iii) RuleFit, a non-linear model in which a set of rules from an ensemble of decision trees (typically from a tree-based model like a Random Forest or Gradient Boosted Trees) is generated and then fit a sparse linear regression model (regularized with LASSO), where the features are the rules generated from the trees [14, 15]. To further tackle the number of biomarkers and variables included in the best models, we introduced an additional selection step, employing a plateau seeking approach. The primary objective of this approach was to pinpoint a concise set of variables capable of attaining an AUROC score similar to that of our comprehensive model, which already incorporated the

most impactful and previously selected variables. This was to ensure that our model is not only effective in terms of performance but also efficient in its variable inclusion.

Each model was trained and tested using the following pipeline. The data were randomly split into training and test sets (80% and 20% of the data, respectively) stratifying by the outcome variable. Missing data in the training and test sets were imputed using the MICE (multiple imputation by chained equation) algorithm. The n_imp parameter for MICE imputation was set to 1, resulting in a single imputed dataset; however, the imputation process was integrated in a robust bootstrapping pipeline, generating ten independent datasets. This approach ensured variability in our results, stemming not only from the MICE imputation but also from the bootstrapping process. This dual approach guarantees that each imputed dataset is distinct [16]. All quantitative variables were scaled into the range [0,1] by subtracting their minimum value and dividing by the difference between the maximum and minimum values in the training set. The categorical variables with n categories were encoded using n-1 binary "dummy" variables. The model was then trained on the imputed and scaled training set, and its performance was assessed on the imputed and scaled test set by computing the AUROC. The AUROC on the test set was also calculated for single host biomarkers, to allow a fair comparison of the performance of the multivariable classification models vs. single host biomarkers.

To assess the robustness and variability in the results of the developed models, the entire pipeline were bootstrapped, i.e. it was run ten times with different random training-test set splits. Finally, the mean and the standard deviation (SD) or the minimum and maximum reached of the AUROC across the ten training-test splits were calculated for each multivariable model and each single host biomarker.

a. Software

All statistical analyses and model development were performed using the R programming language (version 4.1.2). Specifically, the *mice* package was used for data imputation, while

the *pre* and *stats* packages were used for RuleFit and logistic regression model development, respectively.

# RESULTS

## Study population

In total, 1915 patients with AFI were included in the study (Brazil: n=500; Gabon: n=415; Malawi: n=1000). Just under half (862/1915, 45%) of participants at each study site were male. Children aged <5 years comprised 45/500 (9%), 182/415 (43·9%), and 367/1000 (36·7%) participants in Brazil, Gabon, and Malawi, respectively; the median (range) age was 3 (2–4) years (Table 2). Detailed baseline characteristics of patients and analyses of differences will be described in a separate manuscript (Alabi et al in preparation).

**Table 2: Baseline characteristics of patients.**

| | Brazil | Gabon | Malawi | All |
|---|---|---|---|---|
| 0–5 years (median, IQR, n) | 3, [2-4], 45 | 3, [2-5],182 | 3, [2-5], 367 | 3, [2-4], 594 |
| 5–15 years (median, IQR, n) | 11, [8-14], 85 | 9, [7-12], 214 | 9 [7-12], 276 | 9, [7-12], 575 |
| >15 years (median, IQR, n) | 34, [24-45], 370 | 16, [16-16·5], 19 | 28, [21-38], 357 | 30, [21-42], 746 |
| Male (%, n) | 49·6%, 248 | 45·1%, 187 | 42·7%, 427 | 45·0%, 862 |
| Temperature, °C (median, IQR, n) | 37·7, [36·7-38·4], 500 | 36·8, [36·4-37·4], 415 | 38·1, [37·1-38·8], 999 | 37·8, [37·3-38·5], 1914 |
| WBC count, $10^9$/L (median, IQR, n) | 7·28, [5·47-10·39], 494 | 7·7, [5·7-10], 411 | 6·7, [5·1-9·1], 985 | 7·1, [5·3-9·8], 1890 |
| Neutrophil count, $10^9$/L (median, IQR, n) | 4·97, [3·63-7·4], 494 | 2·77, [1.96-3·9], 408 | 4·3, [3·1-6·8], 906 | 4·1, [2·8-6], 1812 |
| RBC count, $10^9$/L (median, IQR, n) | 40·1, [36·5-43·2], 494 | 33·2, [29·4-35·8], 412 | 36·2, [33·1-39·5], 984 | 36·3, [33-40·2], 1892 |
| Lymphocyte count, $10^9$/L (median, IQR, n) | 1·15, [0·7-1·99], 493 | 2·73, [1·8-4·16], 411 | 1·5, [1·1-2·2], 982 | 1·63, [1-2.6], 1883 |
| CRP NycoCard# – mg/L (median, IQR, n) | 70·5, [35-98·75], 498 | 28, [5-73], 415 | 47, [12-106·5], 987 | 49, [13-98], 1900 |
| Malaria-positive by RDT on-site (% all, n) | 0·2%, 1 | 56·4%, 234 | 45·9%, 458 | 36·2%,693 |
| Malaria-positive by qPCR or microscopy (% all, n) | - | - | 50·5%, 505 | - |
| HIV-positive by RDT (% all, n) | 1·4%, 7 | 1·2%, 5 | 4·2%, 42 | 2·8%,54 |
| History of antibiotic-use pre-presentation (% all, n) | 8·8%, 44 | 2·41%, 10 | 7·2%, 72 | 6·5%,124 |
| History of antipyretic-use pre-presentation (% all, n) | 83·2%, 416 | 79·76%, 331 | 55·1%, 551 | 62·2%,1298 |
| Cough (%, n) | 35·8%, 179 | 30·1%, 125 | 48·2%, 482 | 41%, 786 |

| | | | | |
|---|---|---|---|---|
| Diarrhea or vomiting (%, n) | 31·8%, 159 | 28·9%, 120 | 27·5%, 275 | 28·9%, 554 |
| Dysuria or urinary urgency (%, n) | 0·9%, 45 | 5·12%, 21 | 7·6%, 73 | 7·4%, 142 |
| Headache (%, n) | 76·4%, 382 | 46·5%, 193 | 71·1%, 711 | 67·2%, 1286 |
| Sore throat or swallow pain (%, n) | 39%, 195 | 8·92%, 37 | 15·8%, 158 | 20%, 390 |
| Rash (%, n) | 24·4%, 122 | 4·1%, 17 | 2·5%, 25 | 8·6%, 164 |

# NycoCard was found to be equivalent to reference testing in the relevant range (Supplementary Figure 1). CRP, C-reactive protein; IQR, interquartile range; qPCR, quantitative PCR; RBC, red blood cell; RDT, rapid diagnostic test; WBC, white blood cell; -: data not available

**Bacterial and non-bacterial outcomes by classification groups**

Using the electronic classification grouping, 15·1% (290/1915) of cases were bacterial infections, 20·2% (387/1915) were non-bacterial infections, and 64.5% (1238/1915) had an undetermined cause of fever (Figure 1). Under the strict classification grouping, 24·3% (366/1509), 66.9% (1010/1509), and 9·0% (133/1509) were classified as bacterial, non-bacterial, and undetermined infections, respectively, while using the loose classification grouping 25·7% (491/1915), 67·3% (1286/1915), and 7·0% (133/1915) were classified as bacterial, non-bacterial, and undetermined infections, respectively (Figure 1). Subjects with undetermined cause of fever/infections were excluded from the following univariate and multivariable analyses.

**Exclusion of biomarkers with too many missing or saturated values**

The biomarkers C4b, HNL and PCT had more than 50% missing values and were therefore excluded. The high number of missing values is due to fact that biomarkers were analysed in groups based on the required dilution using Luminex platform. For some biomarkers the dilution was not optimal, and it was only possible to re-measure biomarkers with a different dilution a limited number of times. IFN-gamma and sTREM-1 were excluded due to more than 95% of values saturated to the minimum/maximum level detectable by the measurement instrument. All the biomarkers retained in the analysis had less than 12% missing values (Supplementary Table 3).

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**Identification of relevant subgroups for analyses**

According to the Kruskal-Wallis analysis on the "electronic group", the variables "country", "malaria status" and "age" showed statistically significant differences in the distributions of many host biomarkers ($p \leq 0{\cdot}001$ for strong differences, $0{\cdot}001 \leq p < 0{\cdot}01$ for high differences; Supplementary Table 4). The variables "sex", "comorbidities", "history of antibiotic use" showed no ($p > 0{\cdot}05$) or slight ($p \leq 0{\cdot}05$) differences in all the host biomarkers. The effects of "chikungunya status" and "fever above 38°C" were generally significant ($p \leq 0.01$), but the sample sizes for these groups were either too small or exhibited an imbalance. Additionally, while we conducted subgroup analyses by clinical syndromes (i.e. cough, diarrhea or vomiting, dysuria or urinary urgency, headache, sore throat or swallow pain, rash), the resulting datasets were similarly limited in size, restricting our ability to make robust interpretations from these analyses. The primary focus remained centered on populations grouped by study country and malaria status variables - both of which showed strong statistical differences with the value of the biomarkers in the "strict" and "loose" groups (Supplementary Table 5, 6) - other significant covariates were also included in the multivariable analysis. This inclusion was due to their influence, and factors like the study country were considered as variables in the overall scenario.

**Individual host-biomarker performance – univariate analysis**

The performance of 18 host biomarkers was consistent across the three patient classification groups in each of the settings (Table 3 and Supplementary Tables 7-9). White blood cell (WBC) and neutrophil counts were the most effective biomarkers for differentiating bacterial and non-bacterial infections. For the malaria-negative population, the mean (95% confidence interval) of AUROC for WBCs was between 0·60 (0·48–0·72) and 0·83 (0·77–0·88) and for neutrophils

it was between 0·67 (0·57–0·77) and 0·80 (0·74–0·86) across the three countries and the three groups ("electronic", "strict", "loose"). Neutrophil and WBC counts showed the highest AUROCs in the Brazilian population, between 0·80 (0·74–0·86) and 0·83 (0·77–0·88), respectively. All protein biomarkers showed relatively poor performances (<0·7 in most cases, Table 4) in all three settings. Galactin-9, CRP, IP-10, and NGAL were the best-performing protein biomarkers across the three settings and criteria. Protein biomarkers showed better performances in Malawi and Gabon, as in Brazil most protein biomarkers showed performances of <0·6. When the biomarker results were stratified by age, the AUROCs were slightly higher for children (≤15 years) compared with those seen for adults in the malaria-negative population (Supplementary Tables 10-15). Among the malaria-positive population, WBC, lymphocyte, and neutrophil counts were the best-performing biomarkers in both Gabon and Malawi (in most cases between 0·6 and 0·7).

**Table 3: Univariate analysis of 18 individual biomarkers# among malaria-negative patients for all three countries (a-c).**

Common biomarkers such as CRP and haematological biomarkers were included for reference. In this context we defined performance as follows: dark blue (AUROC ≥0·7), light blue (AUROC > 0·65 and <0.7), orange (AUROC 0·6–0·65), and red (AUROC <0·6).

**a) Brazil**

| | Brazil AUROC** (CI), N | | |
|---|---|---|---|
| | **Electronic** | **Strict** | **Loose** |
| **Haematological biomarkers** | | | |
| **Lymphocyte count** | 0·67 (0·59-0·74), 257 | 0·66 (0·59-0·72), 408 | 0·66 (0·6-0·72), 442 |
| **Neutrophil count** | 0·77 (0·7-0·84), 257 | 0·8 (0·74-0·86), 408 | 0·79 (0·73-0·84), 442 |
| **RBC count** | 0·61 (0·52-0·69), 258 | 0·58 (0·51-0·65), 408 | 0·58 (0·51-0·64), 442 |
| **WBC count** | 0·81 (0·75-0·87), 257 | 0·83 (0·77-0·88), 408 | 0·82 (0·77-0·87), 442 |
| **Protein biomarkers** | | | |
| **AGP** | 0·59 (0·51-0·68), 252 | 0·54 (0·47-0·61), 402 | 0·52 (0·46-0·59), 434 |
| **Chitinase 3-like 1** | 0·58 (0·5-0·66), 246 | 0·54 (0·47-0·6), 394 | 0·55 (0·49-0·61), 424 |
| **CRP*** | 0·61 (0·52-0·69), 259 | 0·61 (0·54-0·68), 412 | 0·62 (0·55-0·68), 446 |
| **IP-10/IP-10/CRG-2** | 0·6 (0·52-0·68), 252 | 0·53 (0·46-0·59), 402 | 0·53 (0·47-0·59), 434 |
| **Galectin-9** | 0·63 (0·55-0·71), 252 | 0·56 (0·49-0·63), 401 | 0·57 (0·5-0·63), 433 |
| **hCC2** | 0·51 (0·43-0·6), 244 | 0·51 (0·44-0·58), 392 | 0·52 (0·46-0·59), 424 |
| **HBP***** | 0·67 (0·52-0·81), 113 | 0·68 (0·55-0·8), 144 | 0·64 (0·51-0·76), 151 |
| **HPTGN** | 0·48 (0·4-0·57), 248 | 0·51 (0·44-0·58), 398 | 0·51 (0·45-0·58), 430 |
| **IL-4** | 0·58 (0·5-0·65), 249 | 0·53 (0·47-0·59), 398 | 0·54 (0·48-0·59), 429 |

| | | | |
|---|---|---|---|
| **IL-6** | 0·49 (0·43-0·54), 247 | 0·49 (0·44-0·54), 395 | 0·48 (0·43-0·52), 426 |
| **LBP** | 0·58 (0·5-0·66), 248 | 0·54 (0·48-0·61), 397 | 0·52 (0·46-0·58), 429 |
| **Lipocalin-2/NGAL** | 0·49 (0·41-0·57), 249 | 0·51 (0·44-0·57), 396 | 0·51 (0·44-0·57), 428 |
| **sPLA/Lp-PLA2** | 0·54 (0·46-0.62), 252 | 0·53 (0·46-0·59), 402 | 0·52 (0·45-0·58), 434 |
| **TRAIL** | 0·56 (0·49-0·64), 252 | 0·53 (0·47-0·59), 402 | 0·53 (0·48-0·59), 434 |

**b) Gabon**

| | **Gabon AUROC** (CI), N** | | |
|---|---|---|---|
| | **Electronic** | **Strict** | **Loose** |
| **Haematological biomarkers** | | | |
| **Lymphocyte count** | 0·58 (0·45-0·71), 81 | 0·52 (0·4-0·63), 167 | 0·55 (0·45-0·65), 222 |
| **Neutrophil count** | 0·78 (0·66-0·89), 80 | 0·72 (0·62-0·83), 165 | 0·67 (0·57-0·77), 219 |
| **RBC count** | 0·55 (0·41-0·68), 81 | 0·52 (0·41-0·63), 167 | 0·53 (0·43-0·63), 222 |
| **WBC count** | 0·67 (0·54-0·79), 81 | 0·6 (0·48-0·72), 167 | 0·61 (0·5-0·71), 222 |
| **Protein biomarkers** | | | |
| **AGP** | 0·77 (0·65-0·9), 80 | 0·7 (0·59-0·82), 163 | 0·65 (0·55-0·75), 220 |
| **Chitinase 3-like 1** | 0·6 (0·46-0·74), 79 | 0·6 (0·48-0·72), 162 | 0·62 (0·52-0·72), 217 |
| **CRP*** | 0·71 (0·59-0·82), 81 | 0·65 (0·55-0·75), 167 | 0·63 (0·53-0·72), 224 |
| **IP-10/IP-10/CRG-2** | 0·6 (0·48-0·73), 80 | 0·51 (0·4-0·62), 164 | 0·52 (0·43-0·62), 221 |
| **Galectin-9** | 0·7 (0·58-0·83), 80 | 0·6 (0·48-0·71), 163 | 0·54 (0·43-0·64), 219 |
| **hCC2** | 0·55 (0·41-0·69), 77 | 0·52 (0·4-0·64), 159 | 0·51 (0·41-0·61), 216 |
| **HBP***** | .. | .. | .. |
| **HPTGN** | 0·64 (0·5-0·78), 77 | 0·62 (0·51-0·74), 159 | 0·55 (0·45-0·66), 214 |
| **IL-4** | 0·46 (0·4-0·52), 79 | 0·49 (0·45-0·53), 163 | 0·51 (0·47-0·55), 220 |
| **IL-6** | 0·51 (0·47-0·55), 80 | 0·51 (0·48-0·55), 164 | 0·51 (0·47-0·55), 221 |
| **LBP** | 0·69 (0·56-0·83), 78 | 0·67 (0·55-0·78), 160 | 0·6 (0·5-0·71), 217 |
| **Lipocalin-2/NGAL** | 0·67 (0·54-0·8), 79 | 0·6 (0·49-0·72), 163 | 0·58 (0·48-0·68), 219 |
| **sPLA/Lp-PLA2** | 0·58 (0·44-0·71), 80 | 0·54 (0·43-0·65), 164 | 0·58 (0·48-0·68), 221 |
| **TRAIL** | 0·5 (0·5-0·5), 74 | 0·5 (0·49-0·5), 156 | 0·49 (0·48-0·5), 212 |

**c) Malawi**

| | **Malawi AUROC** (CI), N** | | |
|---|---|---|---|
| | **Electronic** | **Strict** | **Loose** |
| **Haematological biomarkers** | | | |
| **Lymphocyte count** | 0·56 (0·47-0·66), 154 | 0·51 (0·45-0·58), 303 | 0·52 (0·47-0·58), 461 |
| **Neutrophil count** | 0·67 (0·58-0·77), 143 | 0·73 (0·67-0·79), 273 | 0·7 (0·65-0·76), 414 |
| **RBC count** | 0·46 (0·36-0·56), 155 | 0·53 (0·46-0·59), 305 | 0·56 (0·5-0·61), 463 |
| **WBC count** | 0·69 (0·6-0·78), 155 | 0·72 (0·66-0·78), 304 | 0·68 (0·63-0·73), 461 |
| **Protein biomarkers** | | | |
| **AGP** | 0·56 (0·46-0·66), 158 | 0·54 (0·48-0·6), 309 | 0·54 (0·49-0·59), 466 |
| **Chitinase 3-like 1** | 0·49 (0·39-0·59), 155 | 0·5 (0·43-0·56), 304 | 0·5 (0·44-0·55), 462 |
| **CRP*** | 0·55 (0·45-0·65), 156 | 0·6 (0·54-0·67), 305 | 0·58 (0·53-0·63), 462 |
| **IP-10/IP-10/CRG-2** | 0·66 (0·56-0·75), 158 | 0·6 (0·53-0·66), 309 | 0·61 (0·56-0·66), 466 |
| **Galectin-9** | 0·71 (0·62-0·8), 158 | 0·61 (0·55-0·67), 309 | 0·63 (0·57-0·68), 466 |
| **hCC2** | 0·59 (0·49-0·69), 158 | 0·55 (0·49-0·62), 309 | 0·55 (0·5-0·6), 466 |

| | | | |
|---|---|---|---|
| **HBP*** ** | 0·53 (0·39-0·68), 63 | 0.55 (0.44-0·66), 106 | 0·52 (0·41-0·63), 124 |
| **HPTGN** | 0·54 (0·45-0·64), 157 | 0·51 (0·45-0·58), 307 | 0·51 (0·46-0·57), 464 |
| **IL-4** | 0·48 (0·4-0·57), 157 | 0·48 (0·42-0·53), 306 | 0·47 (0·42-0·51), 463 |
| **IL-6** | 0·56 (0·47-0·65), 158 | 0·61 (0·55-0·67), 307 | 0·59 (0·54-0·64), 465 |
| **LBP** | 0·52 (0·42-0·61), 157 | 0·54 (0·47-0·61), 267 | 0·53 (0·47-0·59), 394 |
| **Lipocalin-2/NGAL** | 0·56 (0·46-0·66), 156 | 0·65 (0·59-0·72), 265 | 0·61 (0·56-0·67), 392 |
| **sPLA/Lp-PLA2** | 0·58 (0·47-0·68), 158 | 0·55 (0·49-0·61), 308 | 0·56 (0·51-0·61), 466 |
| **TRAIL** | 0·61 (0·51-0·71), 157 | 0·62 (0·56-0·68), 306 | 0·62 (0·57-0·67), 463 |

*CRP was measured with a NycoCard device. **AUROC has a value between 0 and 1, where 1 corresponds to an effect classifier, 0·5 to one that assigns classes randomly. #Freeze–thaw experiments to evaluate the stability of the biomarkers after five cycles (referred to as "treated") were performed with Luminex 9- and 2-plexes. Three samples each were freeze–thawed up to six times and compared with samples after the first thawing (referred to as "untreated"; biomarkers were considered stable with 80–120% recovery). Samples were analysed in triplicate and showed good stability up to five freeze–thaw cycles for all analytes showing acceptable results, except for the C2 and C4b biomarkers (C2: 2/3 [66·7%] samples were stable; C4b: two samples failed the sixth freeze–thaw cycle). As a result, these biomarkers were excluded as they would never be suitable as the basis of a diagnostic test. ***HBP was evaluated in a small group of patients in Malawi and Brazil; however, HBP did not show promise and was not evaluated further.

**Combinations of host-biomarkers and additional covariates – multivariable analysis**

The best-performing biomarkers in the univariate analysis were compared with the best performances from the multivariable analyses, which several feature-selected biomarkers and covariates (Table 4 and Supplementary Tables 16-21). In most cases the best combination of biomarkers showed higher AUROCs than the top-performing individual biomarkers, with a low/moderate "gain" (range 1–13%). The best-performing AUROCs were very similar, irrespective of the multivariable model used, especially for the "strict" and "loose" groups (difference in AUROC range 0·02–0·03 for Malawi and Brazil). Biomarkers identified as top performing by the multivariable analyses differed depending on the model used. While SW and RFA selected three to five biomarkers or combinations, RuleFit selected more biomarkers (ten variables on average) to be part of the signature. The relatively low increase in AUROC when comparing the top-performing single biomarker with multivariable models indicates that biomarkers in addition to the single best-performing biomarker do not make a major contribution.

**Table 4: Multivariable analysis of biomarkers among malaria-negative patients, including the gain/loss of performance when comparing multivariable analysis and single host-biomarkers comprising both haematological and protein host-biomarkers.**

| Classification group | Best multivariable model/models: mean (min-max) AUROC | Best host-biomarker: mean (min-max) AUROC | Multivariable AUROC gain/loss (%) *** multivariable and single host-biomarkers ratio |
|---|---|---|---|
| **Overall (Brazil + Gabon + Malawi)*** | | | |
| L | SW/RFA/RF:0·75 (0.69-0.81) | WBC count: 0·7 (0.64, 0.76) | +7% |
| S | SW:0.83 (0.75 - 0.91) | WBC count: 0·78 (0.72 - 0.84) | +6% |
| E | SW/RFA:0.83 (0.77 - 0.89) | WBC count: 0·77 (0.69 - 0.85) | +8% |
| **Brazil** | | | |
| L | SW: 0·82 (0.70 - 0.94) | WBC count: 0·8 (0.68 - 0.92) | +2·5% |
| S | RFA: 0·82 (0.70 - 0.94) | WBC count: 0·8 (0.68 - 0.92) | +2·5% |
| E | SW: 0·85 (0.73 - 0.97) | WBC count: 0·83 (0.69 - 0.97) | +2% |
| **Gabon**** | | | |
| L | SW/RFA: 0·7 (0.46 - 0.94) | WBC count: 0·7 (0.64 - 0.76) | .. |
| S | SW/RFA: 0·76 (0.52 – 0.96) | WBC count: 0·78 (0.72 - 0.84) | -3% |
| E | RFA: 0·77 (0.63 - 0.91) | WBC count: 0·77 (0.69 - 0.85) | .. |
| **Malawi** | | | |
| L | SW/RFA: 0·74 (0.62 - 0.86) | neutrophil count: 0·72 (0.66 - 0.78) | +3% |
| S | SW: 0·73 (0.61 - 0.85) | neutrophil count: 0·72 (0.58 - 0.86) | + 1% |
| E | RFA: 0·72 (0.60 - 0.84) | WBC count: 0·7 (0.56, 0.84) | + 2% |

E, electronic classification group; S, strict classification group; L, loose classification group; RF, RuleFit; RFA, logistic recursive feature addition; SW, stepwise logistic regression.

* In the "Overall" scenario, the model was developed using the data of all countries and the variable indicating the country was used as a covariate in the model.

**Multivariable performances for Gabon were computed using as a predictor model the model trained in the "Overall" scenario (all participants from the three analysed countries) then evaluated using Gabon data only. Indeed, the sample size of Gabon data was not sufficient to allow the development of a reliable model specific for this country.

*** Performance comparison was computed as: [ (multivariable AUROC – univariate AUROC) / univariate AUROC ] * 100 Green (gain, i.e. the multivariable models show better performances than univariate models); red (loss, i.e. the univariate models show better performances than multivariable models).

## DISCUSSION

We present the most extensive and diverse host-biomarker evaluation study to differentiate bacterial from non-bacterial infections in LMICs. The study aimed to identify if next-generation host-biomarkers for distinguishing bacterial from non-bacterial cases of AFI, which could replace existing biomarkers such as CRP, PCT, and WBC/neutrophil assessments. The data show that none of the promising host-biomarkers exhibited high AUROCs in our non-severe AFI population in either low malaria prevalence (Brazil) or high malaria prevalence (Gabon, Malawi) settings. Haematology biomarkers and CRP were included a baseline to identify better-performing markers; however, they remain those with the highest AUROC values (approximately 0·60–0·70 AUROC) in our population.

Overall, the performance of all markers was underwhelming, yet not surprising. It aligns with previous data where a marked reduction in performance was observed when shifting the population from in- to outpatients [17-19]. Previously, it was hypothesised that the decrease in performance in host biomarkers between HIC and LMIC settings, or even between Africa and Asia, was due to the untreated comorbidities (e.g. diabetes, malaria, neglected tropical diseases) which contribute to inflammation and the nonspecific triggering of host biomarkers, unrelated to the current acute presentation [19, 20]. In our data the performance was indeed poorer in malaria-positive patients (AUROC <0·6); however, even in the malaria-negative population, biomarkers showed low performances (~0·6–0·7) in our cohort. Similarly, sex and arboviral status appeared to have no major effect on biomarker performance. Our data notably indicated that combining biomarkers can enhance performance. However, this improvement was not consistently observed. When combining several biomarkers and additional covariates, the "gain" in AUROC values was low/moderate (range 1–13%) compared to the top-performing individual biomarkers. From a diagnostic development perspective, a low gain in performance would not justify the additional complexity and cost of developing a simple multiplex test.

Adding to the challenges of host-biomarker studies is the lack of consistent reference standards and that most studies have focused their analyses solely on the subpopulation of patients with a microbiologically confirmed diagnosis. This approach ignores the largest group (>70%) of patients and intended-use population of any future test [21]. The group with laboratory confirmed diagnosis will decrease further in the non-severe AFI population; presenting at primary care level. Going forward more clarity will likely follow as a recent host-biomarker test (BVtest, MeMed, Israel) was approved by the FDA and subsequent guidance will prescribe more clearly how studies have to be designed to standardize the classification of "bacterial" vs "non-bacterial" evaluated to guide prescribing for bacterial or non-bacterial infections [9, 22]. Our protocol is aligned with the FDA approved classification hence we are confident our methodology is robust.

While our study aimed to mitigate the challenges described, it still had several limitations. The study did not include a control group, so no baseline information was available for biomarker performance or asymptomatic carrier populations. The enrolment period in Brazil and Gabon lasted for less than one year and given the heterogeneity of causes of AFI across time a the performance of the biomarkers may not be generalisable to different times of the year and geographical settings, particularly in Asia. The study utilised a two-step process to classify outcomes, and the clinical classification based on recorded clinical information may have introduced subjectivity. Notably, clinicians had access to the haematology biomarker results (WBCs, neutrophils) during outcome classification, which might have introduced a bias in favour of these biomarkers. However, comparing AUROCs between all classification groups (E, L, S) suggests this potential bias had no major impact as the results are similar across groups. There were some heterogeneities in the inclusion criteria across the various study sites, including age groups and fever criteria. In Brazil and Gabon, the inclusion criterion was a history of fever in the past 7 days, while it was fever at presentation in Malawi. Studies have

found that acute fever at presentation has implications for the interpretation of host biomarkers [23]; however, our sub-analysis by acute fever showed no differences, so we do not consider that these different inclusion criteria impacted interpretation. Despite best efforts to standardise procedures, there was a level of adaptability required in the choice of testing methods by the clinical teams in each country, for arbovirus and respiratory pathogen detection. Further, the choice to follow the TPP and focus on non-severe patients in the recruitment was based on the need's definition by the WHO and others, while this still holds as a major priority, in hindsight this focus did not allow us to stratify by severity (eg. SOFA score).

Overall, the results of this diverse study highlight the difficulties in identifying single host-biomarkers or simple host-biomarker combinations that can help solve the problem of undifferentiated prescribing at primary healthcare, particularly to be used across diverse global settings. On the 8th birthday of the original TPP for a diagnostic assay to distinguish bacterial and non-bacterial infections in resource-limited settings, a more recent consultation confirmed that the need for such an assay remains and is in fact increasingly urgent [6, 24]. Yet again, the consultation concluded primary healthcare clinics and their equivalents must have the ability to perform tests other than just malaria RDTs [24]. The lack of diagnostics infrastructure at the lower levels of health systems is well documented and requires urgent improvement to support medical staff in their decision making.. While no novel host-biomarker assay meets these needs, evidence for existing biomarkers, e.g. CRP, and various haematology biomarkers, should be utilised to drive such improvements, albeit utilizing slightly different approaches and cut-offs across settings. In addition to utilising existing tools, increased investment into lower level health infrastructures are critical and the first step to improved care. Recent studies have shown that even simple host-biomarkers, such as CRP, can have a major impact on how clinical staff use antibiotics [25, 26, 27]. The current study confirms that the existing biomarkers are imperfect and hence should only be used as guidance, in conjunction with expanded clinical

algorithms [28, 29]. Such guidelines, alongside adopted policies, strengthened infrastructues and accessible haematology/biochemisty data could enable healthcare workers to use simple tools to gain additional data points to help form a more evidence-based diagnosis that has to be guided by the local epidemiology. Optimising existing haematology or biochemistry tools and their maintenance requirements to meet the needs of low resourced settings could be one step towards more expanded use of these well-known markers. In conclusion, our study reinforces the continued need for innovation in the host-biomarker space and highlights the importance of targeted evaluations of such innovations, in diverse intended-use settings, to fully understand their true value.

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**Competing Interests**

SD, BLFC, CE, VH, SO, CH, AM, SL are or were employed by FIND, the global alliance for diagnostic during the study period. All other authors do not declare any competing interests.

**Author contribution**

SD, CE, SO, AM, AMS, SG, STA, MML, ATA conceptualised the study and study design; CE, AS, SG, STA, AMS, JKM, VH, JM, ALK, AA, JCBO, MML, PNE, JAM, PB, LB, AdRM, BCC, MAMS, AMBdF, EAdS, RdS, MCSL, JH, AG, MJ, NSM, CH, SJL, implemented the study and data collection; MA, MV, SL, SO, BDC, BLFC, SD, SP, SG, AMS, STA conducted data analysis and interpretation. BLFC, SD wrote the first draft of the manuscript and all authors contributed to the final version of the manuscript. Guarantor is SD.

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547 report or decision to submit for publication.

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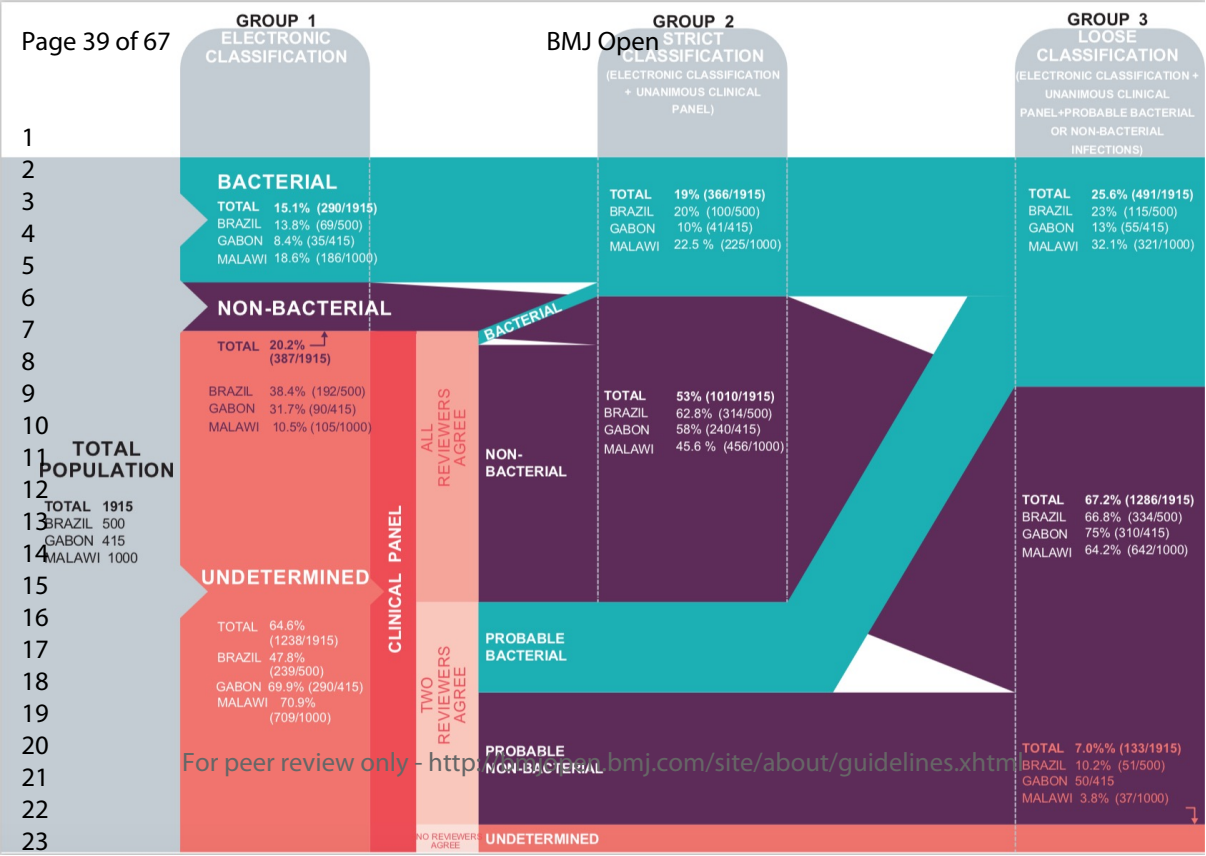
**Figure 1: Classification criteria to assign bacterial versus non-bacterial infection categories for the analysis.** The flows in different colours (turquoise=bacteria, purple=non-bacterial, red=undetermined) represent the proportion of patients that were assigned into the respective group (bacteria/non-bacteria/undetermined) after each classification step. Group 1 representing only patients assigned using laboratory data; group 2 representing patients with a unanimous decision after review by the clinical panel; group 3 after clinical panel review and group 3 including all patients, even if only 2 panel members agreed on the probable cause. The study follows the STARD-15 checklist and reporting guidelines.



# Supplementary Material

## Evaluation of host biomarkers to support the development of a point-of-care diagnostic test to guide antibiotic use in bacterial/non-bacterial acute febrile illness cases

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*authors contributed equally

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# Biomarker selection

Biomarkers evaluated were selected based on reported performances for distinguishing bacterial versus non-bacterial infections in prior publications, which were systematically reviewed in 2016 by Kapasi et al.[1] and other key publications (Supplementary Table 1). Biomarker performances reported in the 2016 systematic review were compared with reported performances in a later systematic review conducted in 2020.[2]

**Supplementary Table 1. Biomarkers included based on Kapasi et al.'s (2016) systematic review and other key publications.**

| **Biomarker** | **Performance, 2016 systematic review** |
|---|---|
| C-reactive protein (CRP) | 1 |
| FebriDx (MxA+CRP) | 2 |
| Galectin-9 | *2* |
| Gamma-induced protein 10 (IP-10) | 2* |
| Haptoglobin | 2[#] |
| Heparin-binding protein (HBP) | 3 |
| Human neutrophil lipocalin (HNL) | 2 |
| Interferon gamma (IFN-gamma) | 3 |
| Interleukin-4 (IL-4) | 2 |
| Interleukin-6 (IL-6) | 3 |
| Lipopolysaccharide binding protein (LBP) | 3[$] |
| Procalcitonin (PCT) | 1 |
| Secretory phospholipase 2 (sPLA2) | 2 |
| Soluble triggering receptor expressed on myeloid cells 1 (sTREM-1) | 3[§] |
| TNF-related apoptosis-inducing ligand (TRAIL) | 2* |
| | |
| *Included based on key publications in the field* | |
| **Biomarker** | **Publication** |
| A-1-acid glycoprotein | Struck et al.[3] |
| Chitinase-3-like protein 1 (CHI3L1) | Erdman et al.[4] |
| Complement 2 | Struck et al.[3] |
| Complement C4b | Struck et al.[3] |
| Neutrophil gelatinase-associated lipocalin (NGAL) | Huang et al.[5] |

Performances were scored as: 1, high-performing biomarker (meets the current TPP minimum diagnostic performance criteria, i.e. ≥0.90 and 0.80 sensitivity/specificity); 2, moderately performing biomarker (≥0.65 and 0.65 and <0.90 and 0.80 sensitivity/specificity); 3, AUROC >0.8; 4, low-performing biomarker; 5, not evaluated. *As part of the signature CRP+IP-10+TRAIL; # as part of the signature Haptoglobin+IL-10+TIMP1; $ in respiratory tract infections as part of the signature CRP+LBP; § as part of the signature sTREM+CRP; 1 only in the context of meningitis, otherwise low performance.

# Reference laboratory methodology

## Materials, equipment, and software

All assay reagents used were delivered with the commercial kits and were used as described in the corresponding kit manuals. Supplementary Table 2 shows the commercial human multi-analyte kits and ELISA kits used.

**Supplementary Table 2:** Commercial human multi-analyte kits and ELISA kits used.

| Analytes | Assay type | Provider | Reference laboratory that performed the analysis |
|---|---|---|---|
| CHI3L1, Gal-9, IL-4, IL-6, IP-10, IFN-gamma, sPLA2, sTREM-1, TRAIL | Luminex, 9-plex | Biotechne/ R&D Systems | NMI |
| NGAL, LBP | Luminex, 2-plex | Biotechne/ R&D Systems | NMI |
| C2, C4b | Luminex, 2-plex | Merck | NMI |
| HP, AGP | Luminex, 2-plex | Merck | NMI |
| PCT | Luminex, 1-plex | Biotechne/ R&D Systems | NMI |
| | Immunoassay | Elecsys BRAHMS, Roche | MVZ Limbach |
| HNL | ELISA | Diagnostics Development | NMI |

| | | | |
|---|---|---|---|
| CRP | ELISA | Biotechne/ R&D Systems | NMI |
| | Immunoassay | Elecsys BRAHMS, Roche | MVZ Limbach |
| HBP | ELISA | Axis-Shield | on-site |

NMI, The Natural and Medical Sciences Institute (NMI) at the University of Tübingen, Reutlingen, Germany; MVZ Labor, Dr. Limbach & Kollegen, Heidelberg, Germany

For data generation, the Luminex FLEXMAP 3D instrument, operated with xPONENT Software V4.2, was used for the bead-based Luminex assays. The data evaluation was performed using Bio-Rad Bio-Plex Manager Software 6.1.1. To generate the data for the ELISAs at NMI a BioTek ELx 808 absorption reader was used. The embedded software Gen5 (BioTek) was used for data evaluation. At MVZ Limbach, a Cobas 8000 immunoanalyzer (Roche Diagnostics) was used for data generation.

## Methods

All assays were processed according to the manufacturer's protocol. Standard curves, quality control (QC) samples, and blanks were analysed in duplicate; samples were assayed singly. Two or three QC samples were measured on each assay plate. QC samples were taken to cover the range of the standard curve (low, mid, and high level). All QC samples were prepared and aliquoted in larger quantities at the beginning of sample screening so that a fresh aliquot could be used for each measurement, and all QC samples underwent the same freeze–thaw cycle. The performance of the standard curves was controlled over the entire measurement period based on %CVs of the standard point duplicates (<20% and <25% for the last standard point) and percentage recovery on the basis of the nominal concentrations. If permitted by the dilution factor, samples out of the dynamic range were re-analysed with a lower or higher dilution factor.

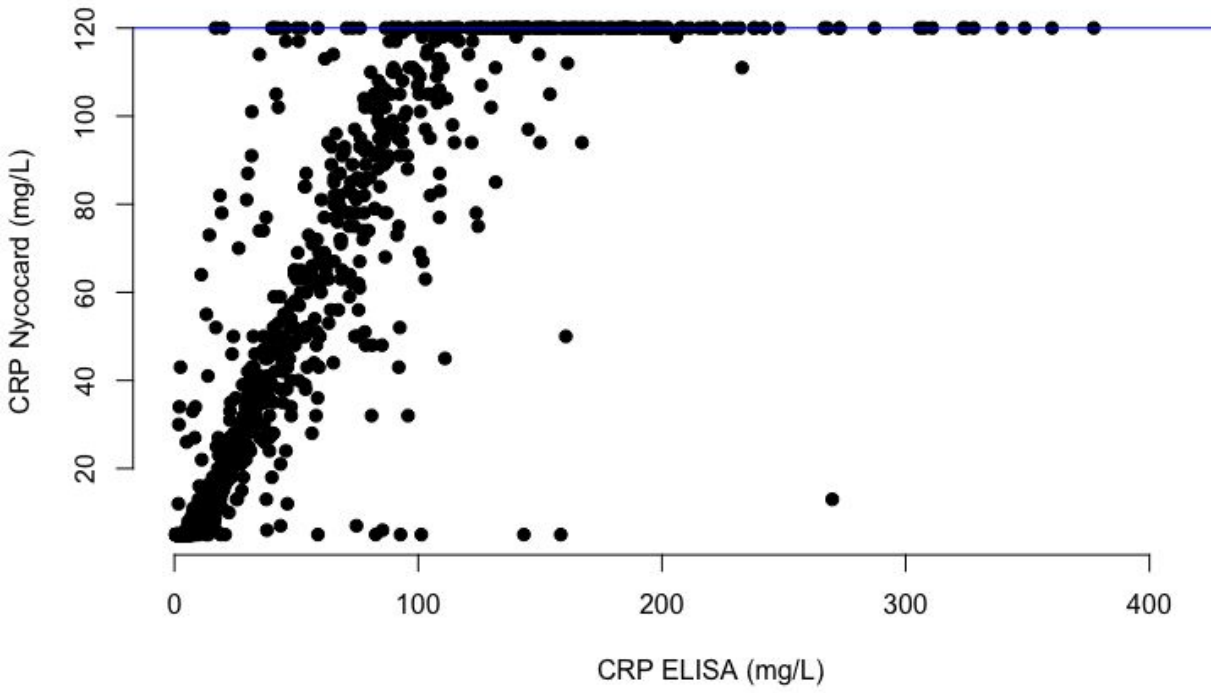
### Heparin-binding protein (HBP) assay

The commercially available Axis-Shield heparin-binding protein ELISA for citrated plasma was validated for human EDTA plasma. Calibration curve, limit of detection (LOD), assay range, precision, parallelism, and spike-in recovery experiments were performed.

The ELISA was processed according to the assay protocol provided with the kit. Validation was performed using a fit-for-purpose approach and under consideration of the recommendations for assay validation given in guidelines from health authorities (European Medicine Agency (2011); Food and Drug Administration (2018)). This was a short validation with a limited number of samples.

Except for the percentage recovery, all analysed parameters met the criteria during the validation of the HBP ELISA using human EDTA plasma instead of the recommended citrated plasma matrix. The assay performance seemed to be stable for the sample evaluation using the kit.

**Supplementary Figure 1: Analytical assessment of CRP Nycocard vs CRP ELISA**



# Statistical analysis

This section contains additional figures and tables related to the statistical analysis.

**Supplementary Table 3: Number and percentage of missing values for the biomarkers included in the statistical analysis**

| | Electronic group¶ [n (%)] | Strict group§ [n (%)] | Loose group# [n (%)] |
|---|---|---|---|
| White blood cells | 6 (0.8%) | 11 (0.8%) | 15 (0.8%) |
| HAEMATO COUNT | 6 (0.8%) | 11 (0.8%) | 15 (0.8%) |
| Lymphocytes | 6 (0.8%) | 12 (0.9%) | 17 (1%) |
| Neutrophils | 22 (3%) | 64 (5%) | 90 (5%) |
| CRP NYCOCARD | 5 (0.7%) | 10 (0.7%) | 14 (0.8%) |
| IL-6 | 10 (1.5%) | 20 (1%) | 24 (1%) |
| Gal-9 | 10 (1.5%) | 20 (1%) | 24 (1%) |
| CHI3L1 | 10 (1.5%) | 20 (1%) | 25 (1%) |
| IP-10 | 10 (1.5%) | 20 (1%) | 24 (1%) |
| TRAIL | 10 (1.5%) | 20 (1%) | 24 (1%) |
| IL-4 | 13 (2%) | 24 (2%) | 29 (2%) |
| sPLA2 | 10 (1.5%) | 20 (1%) | 24 (1%) |
| NGAL | 29 (4%) | 138 (10%) | 197 (11%) |
| LBP | 30 (4%) | 139 (10%) | 198 (11%) |
| C2 | 10 (1.5%) | 21 (1.5%) | 25 (1%) |
| AGP | 10 (1.5%) | 21(1.5%) | 25 (1%) |
| HP | 11(1.6%) | 24 (2%) | 29 (2%) |

¶ Total number of subjects in the Electronic group: 677
§ Total number of subjects in the Strict group: 1376
# Total number of subjects in the Loose group: 1777

## Kruskal-Wallis tables

**Supplementary Table 4: Kruskal-Wallis table results for the electronic classification**

| | Age | Sex | Malaria | Country | Comorbidities | Malnutrition* | Prior antibiotics | Temperature ≥38°C | Chikungunya |
|---|---|---|---|---|---|---|---|---|---|
| White blood cells | 1.2145E-13 | 1.9808E-01 | 1.0985E-02 | 3.4408E-01 | 8.4018E-01 | 2.7154E-01 | 4.3535E-01 | 3.4408E-01 | 5.4183E-09 |
| HAEMATO COUNT | 2.8040E-45 | 1.0446E-09 | 4.3461E-28 | 1.3185E-36 | 6.8045E-02 | 9.1321E-01 | 6.9000E-01 | 9.9455E-01 | 3.6951E-08 |
| Lymphocytes | 1.3850E-45 | 8.0680E-03 | 3.1562E-29 | 4.5414E-32 | 1.0022E-05 | 4.4874E-01 | 4.5900E-01 | 5.4198E-08 | 1.9910E-11 |
| Neutrophils | 5.6495E-03 | 3.9147E-01 | 1.1337E-04 | 1.8674E-17 | 1.5980E-02 | 4.2719E-01 | 4.3608E-01 | 3.0003E-08 | 6.5439E-04 |
| CRP NYCOCARD | 1.4485E-03 | 4.2297E-01 | 1.3861E-15 | 3.0332E-07 | 2.1171E-01 | 4.6667E-01 | 8.4615E-01 | 3.0231E-03 | 2.1171E-01 |
| IL-6 | 9.2626E-06 | 2.5277E-01 | 4.6686E-34 | 4.2810E-21 | 6.1106E-03 | 7.1615E-01 | 5.8674E-02 | 2.0177E-10 | 9.2626E-06 |
| Gal-9 | 7.8084E-11 | 3.3296E-01 | 1.2731E-07 | 2.2471E-07 | 4.3173E-01 | 5.3845E-01 | 9.9020E-02 | 3.6659E-01 | 8.5282E-04 |
| CHI3L1 | 3.6874E-01 | 1.5427E-01 | 2.2593E-04 | 3.5942E-05 | 9.0961E-01 | 8.0977E-01 | 7.9973E-01 | 2.5264E-02 | 2.5264E-02 |
| IP-10 | 7.0235E-01 | 7.0235E-01 | 4.0429E-09 | 7.0486E-10 | 4.9729E-01 | 7.0235E-01 | 4.0169E-01 | 3.6086E-08 | 3.3476E-01 |
| TRAIL | 1.4108E-03 | 1.5429E-02 | 6.7710E-19 | 6.9473E-56 | 9.2177E-01 | 2.2485E-02 | 9.5591E-01 | 9.7926E-04 | 1.8702E-06 |
| IL-4 | 1.4190E-03 | 8.9566E-02 | 1.7896E-25 | 1.1179E-73 | 4.2256E-01 | 8.9341E-03 | 8.9692E-01 | 3.0403E-03 | 2.2958E-09 |
| sPLA2 | 9.5993E-05 | 9.2127E-01 | 2.8477E-20 | 5.6810E-03 | 1.5011E-01 | 9.2127E-01 | 6.1633E-01 | 7.4323E-03 | 7.4323E-03 |
| NGAL | 2.6841E-02 | 7.1924E-01 | 1.2498E-05 | 6.4604E-21 | 7.1924E-01 | 2.6841E-02 | 5.1387E-01 | 1.2498E-05 | 9.6273E-03 |
| LBP | 2.2658E-11 | 5.1481E-02 | 1.8527E-54 | 2.1544E-101 | 8.2974E-02 | 5.3837E-03 | 1.1745E-01 | 3.5938E-09 | 6.0583E-19 |
| C2 | 1.7219E-02 | 3.0063E-01 | 6.8628E-13 | 6.8628E-13 | 6.2951E-02 | 8.5874E-01 | 5.6324E-01 | 4.4637E-01 | 6.2045E-03 |
| AGP | 5.1888E-03 | 2.0274E-01 | 3.6747E-16 | 1.3445E-16 | 1.5176E-01 | 9.8963E-01 | 6.3154E-01 | 2.3325E-01 | 3.1922E-05 |
| HP | 2.9420E-07 | 2.7390E-01 | 1.8393E-25 | 2.4997E-25 | 2.7390E-01 | 2.7390E-01 | 4.0178E-01 | 7.2077E-01 | 2.9140E-03 |
| C4b | 5.6159E-19 | 6.7010E-02 | 4.5041E-81 | 1.9491E-84 | 6.7179E-03 | 6.7179E-03 | 3.3168E-01 | 1.8052E-01 | 8.0363E-18 |

Different colours based on significance: green ($p < 0.05$, slight significance); orange ($p < 0.01$, high significance); red ($p < 0.001$, strong significance). * Malnutrition status calculated based on WHO body mass index criteria.

## Kruskal-Wallis tables

**Supplementary Table 5: Kruskal-Wallis table results for the strict classification**

| | Age | Sex | Malaria | Country | Comorbidities | Malnutrition* | Prior antibiotics | Temperature ≥38°C | Chikungunya |
|---|---|---|---|---|---|---|---|---|---|
| White blood cells | 3.1149E-20 | 2.4091E-01 | 3.6749E-09 | 9.3997E-03 | 3.1632E-01 | 6.3502E-02 | 6.3502E-02 | 9.1443E-01 | 1.7973E-08 |
| HAEMATO COUNT | 6.1835E-100 | 1.9994E-04 | 5.6304E-55 | 3.7852E-68 | 1.6199E-04 | 8.0189E-01 | 7.1282E-01 | 2.9137E-01 | 1.7149E-10 |
| Lymphocytes | 8.4778E-84 | 1.5291E-01 | 2.6779E-44 | 2.7404E-58 | 6.3047E-07 | 6.1980E-03 | 4.5554E-01 | 7.1024E-22 | 8.6226E-15 |
| Neutrophils | 8.9513E-04 | 1.7152E-01 | 7.9838E-14 | 1.9134E-37 | 4.5549E-02 | 5.2789E-01 | 4.5549E-02 | 3.0001E-19 | 4.1217E-02 |
| CRP NYCOCARD | 1.6547E-02 | 5.7656E-02 | 2.4570E-38 | 6.2991E-11 | 7.4370E-01 | 3.0220E-01 | 7.4370E-01 | 9.7289E-15 | 3.0220E-01 |
| IL-6 | 2.5704E-02 | 1.2888E-01 | 2.5131E-68 | 3.4758E-27 | 1.4641E-01 | 8.1220E-01 | 6.6933E-02 | 4.3924E-26 | 2.5371E-04 |
| Gal-9 | 7.4424E-19 | 3.5455E-03 | 1.3432E-11 | 1.3757E-08 | 1.1615E-01 | 3.9116E-01 | 1.3397E-01 | 2.2573E-01 | 2.4249E-03 |
| CHI3L1 | 2.8335E-01 | 1.5433E-01 | 3.6787E-11 | 7.4319E-16 | 2.8335E-01 | 2.8335E-01 | 2.8335E-01 | 8.7744E-06 | 1.5017E-03 |
| IP-10 | 2.4521E-01 | 6.8716E-01 | 8.5656E-31 | 1.5503E-36 | 2.1157E-01 | 3.0336E-01 | 3.2906E-01 | 4.1236E-22 | 3.2906E-01 |
| TRAIL | 6.4358E-04 | 2.4206E-01 | 3.7467E-46 | 4.5806E-127 | 7.7652E-01 | 8.3869E-04 | 7.7652E-01 | 2.8337E-17 | 1.7642E-08 |
| IL-4 | 4.2108E-04 | 5.9858E-01 | 2.5949E-55 | 2.7083E-159 | 3.3368E-01 | 8.0705E-05 | 6.5563E-01 | 2.2888E-11 | 2.2888E-11 |
| sPLA2 | 3.0005E-14 | 1.1264E-01 | 4.1355E-60 | 4.7055E-09 | 6.7473E-04 | 2.2676E-01 | 3.6531E-01 | 1.0844E-09 | 4.7059E-05 |
| NGAL | 7.7462E-02 | 1.1300E-01 | 6.0927E-16 | 1.3720E-35 | 5.9955E-01 | 4.9221E-02 | 4.4419E-01 | 1.4382E-19 | 8.8808E-03 |
| LBP | 1.3509E-14 | 3.4123E-01 | 6.0660E-94 | 1.9360E-197 | 2.1248E-02 | 3.6673E-05 | 3.0644E-01 | 2.3473E-28 | 7.4289E-21 |
| C2 | 7.2674E-07 | 4.3157E-01 | 2.3145E-26 | 4.5324E-25 | 6.8236E-03 | 4.3157E-01 | 4.3157E-01 | 8.8206E-03 | 2.1062E-03 |
| AGP | 4.8513E-04 | 1.7379E-01 | 5.0587E-21 | 7.1496E-23 | 1.5900E-01 | 7.9521E-01 | 9.7767E-01 | 1.1305E-01 | 1.4880E-05 |
| HP | 1.2127E-13 | 6.3311E-01 | 1.6366E-46 | 3.0053E-46 | 2.9299E-03 | 5.6523E-01 | 5.6523E-01 | 9.0316E-01 | 4.8596E-04 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| C4b | 6.3193E-21 | 1.923 1E-02 | 1.6664E-139 | 3.1999E-147 | 1.9749E-04 | 2.6638E-04 | 9.3349 E-01 | 8.0678E-03 | 3.0903E-25 |

Different colours based on significance: green ($p < 0.05$, slight significance); orange ($p < 0.01$, high significance); red ($p < 0.001$, strong significance). * Malnutrition status calculated based on WHO body mass index criteria.

## Kruskal-Wallis tables

**Supplementary Table 6: Kruskal-Wallis table results for the loose classification**

| | Age | Sex | Malaria | Country | Comorbidities | Malnutrition* | Prior antibiotics | Temperature ≥38°C | Chikungunya |
|---|---|---|---|---|---|---|---|---|---|
| White blood cells | 2.0574E-28 | 9.875 9E-01 | 1.8484E-08 | 4.5260E-03 | 9.0171E-02 | 4.8259E-02 | 1.0890 E-01 | 7.4007E-01 | 1.8484E-08 |
| HAEMATO COUNT | 1.3083E-126 | 1.861 9E-04 | 6.2835E-56 | 7.7962E-76 | 1.1102E-06 | 7.8862E-01 | 7.9391 E-01 | 2.9434E-01 | 1.2853E-10 |
| Lymphocytes | 4.9651E-101 | 2.946 1E-01 | 4.6796E-45 | 1.6372E-67 | 4.8743E-07 | 6.6823E-04 | 2.9461 E-01 | 2.4236E-29 | 4.3110E-15 |
| Neutrophils | 1.1310E-04 | 7.267 7E-01 | 7.2742E-15 | 1.6127E-46 | 2.0313E-01 | 4.6743E-01 | 2.0038 E-01 | 1.2920E-24 | 2.9723E-02 |
| CRP NYCOCARD | 1.3614E-01 | 4.4123E-03 | 1.0347E-57 | 2.4703E-15 | 4.0226E-01 | 5.2068E-01 | 5.9738 E-01 | 6.7648E-18 | 1.3614E-01 |
| IL-6 | 9.5250E-02 | 4.8736E-02 | 8.6303E-95 | 1.9688E-31 | 1.5356E-01 | 8.2374E-01 | 9.3076 E-02 | 6.1774E-34 | 2.1766E-05 |
| Gal-9 | 2.0463E-27 | 1.4431E-03 | 1.9318E-13 | 6.8273E-10 | 2.3586E-01 | 2.3586E-01 | 3.6447E-02 | 2.3586E-01 | 3.0166E-03 |
| CHI3L1 | 2.7483E-01 | 5.354 1E-02 | 3.6128E-14 | 3.6128E-14 | 2.8535E-01 | 7.9359E-01 | 3.0946 E-01 | 1.4718E-04 | 7.1655E-04 |
| IP-10 | 4.1384E-01 | 7.867 4E-01 | 6.5193E-43 | 4.2202E-47 | 7.9605E-02 | 3.6101E-01 | 4.1384 E-01 | 1.4436E-34 | 4.1902E-01 |
| TRAIL | 2.4722E-02 | 1.391 8E-01 | 6.2828E-56 | 2.9185E-156 | 8.2684E-01 | 6.2797E-05 | 8.2684 E-01 | 2.4486E-17 | 1.1148E-09 |
| IL-4 | 1.1448E-02 | 3.191 1E-01 | 3.0844E-69 | 1.7484E-206 | 3.9276E-01 | 4.7672E-08 | 5.7785 E-01 | 2.1611E-12 | 1.2664E-13 |
| sPLA2 | 8.3753E-18 | 2.731 7E-01 | 1.5890E-82 | 1.2702E-09 | 1.2356E-04 | 3.7225E-01 | 4.1002 E-01 | 8.1232E-15 | 4.0213E-05 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| NGAL | 1.5706E-01 | 2.065 0E-02 | 3.748 6E-27 | 2.284 8E-43 | 3.7129E-01 | 1.4239E-01 | 3.9957 E-01 | 1.3734E -24 | 5.3057E-03 |
| LBP | 1.656 7E-10 | 4.386 5E-01 | 2.110 7E-116 | 2.427 8E-254 | 8.2765E-03 | 5.4993E-07 | 6.1624 E-01 | 1.4861E -39 | 1.4254E-24 |
| C2 | 2.103 5E-04 | 1.459 3E-01 | 7.600 5E-28 | 2.186 5E-27 | 4.8543E-02 | 2.9326E-01 | 3.8932 E-01 | 9.8425E -03 | 1.2901E-03 |
| AGP | 2.507 6E-03 | 9.527 3E-02 | 1.987 0E-26 | 3.272 6E-28 | 9.3140E-02 | 8.9492E-01 | 9.5756 E-01 | 9.5273E -02 | 3.2225E-06 |
| HP | 5.764 0E-15 | 7.268 5E-01 | 2.837 6E-51 | 7.966 7E-51 | 7.2760E-03 | 6.9555E-01 | 6.9555 E-01 | 9.7145E -01 | 1.7228E-04 |
| C4b | 3.907 7E-15 | 9.303 7E-03 | 9.356 7E-160 | 3.444 9E-171 | 6.9926E-04 | 2.2357E-03 | 8.6228 E-01 | 2.2357E -03 | 1.0351E-29 |

Different colours based on significance: green ($p < 0.05$, slight significance); orange ($p < 0.01$, high significance); red ($p < 0.001$, strong significance). * Malnutrition status calculated based on WHO body mass index criteria.

**Supplementary Table 7: Univariate analysis of 18 individual biomarkers[#] among malaria-negative patients with all reference groups (electronic, strict, loose).** Common biomarkers such as CRP and haematological biomarkers were included for reference. In this context we defined performance as follows: green (AUROC ≥0·7), yellow (AUROC > 0·65 and <0.7), orange (AUROC 0·6–0·65), and red (AUROC <0·6).

| | Brazil AUROC** (CI), N | | | Gabon AUROC** (CI), N | | | Malawi AUROC** (CI), N | | |
|---|---|---|---|---|---|---|---|---|---|
| | Electronic | Strict | Loose | Electronic | Strict | Loose | Electronic | Strict | Loose |
| **Haematological biomarkers** | | | | | | | | | |
| **Lymphocyte count** | 0·67 (0·59-0·74), 257 | 0·66 (0·59-0·72), 408 | 0·66 (0·6-0·72), 442 | 0·58 (0·45-0·71), 81 | 0·52 (0·4-0·63), 167 | 0·55 (0·45-0·65), 222 | 0·[illegible] (0·47-0·64), 354 | 0·51 (0·45-0·58), 303 | 0·52 (0·47-0·58), 461 |
| **Neutrophil count** | 0·77 (0·7-0·84), 257 | 0·8 (0·74-0·86), 408 | 0·79 (0·73-0·84), 442 | 0·78 (0·66-0·89), 80 | 0·72 (0·62-0·83), 165 | 0·67 (0·57-0·77), 219 | 0·[illegible] (0·68-0·[illegible]), 343 | 0·73 (0·67-0·79), 273 | 0·7 (0·65-0·76), 414 |
| **RBC count** | 0·61 (0·52-0·69), 258 | 0·58 (0·51-0·65), 408 | 0·58 (0·51-0·64), 442 | 0·55 (0·41-0·68), 81 | 0·52 (0·41-0·63), 167 | 0·53 (0·43-0·63), 222 | 0·[illegible] (0·36-0·[illegible]), 355 | 0·53 (0·46-0·59), 305 | 0·56 (0·5-0·61), 463 |
| **WBC count** | 0·81 (0·75-0·87), 257 | 0·83 (0·77-0·88), 408 | 0·82 (0·77-0·87), 442 | 0·67 (0·54-0·79), 81 | 0·6 (0·48-0·72), 167 | 0·61 (0·5-0·71), 222 | 0·[illegible] (0·6-0·[illegible]), 355 | 0·72 (0·66-0·78), 304 | 0·68 (0·63-0·73), 461 |
| **Protein biomarkers** | | | | | | | | | |
| **AGP** | 0·59 (0·51-0·68), 252 | 0·54 (0·47-0·61), 402 | 0·52 (0·46-0·59), 434 | 0·77 (0·65-0·9), 80 | 0·7 (0·59-0·82), 163 | 0·65 (0·55-0·75), 220 | 0·[illegible] (0·46-0·[illegible]), 358 | 0·54 (0·48-0·6), 309 | 0·54 (0·49-0·59), 466 |
| **Chitinase 3-like 1** | 0·58 (0·5-0·66), 246 | 0·54 (0·47-0·6), 394 | 0·55 (0·49-0·61), 424 | 0·6 (0·46-0·74), 79 | 0·6 (0·48-0·72), 162 | 0·62 (0·52-0·72), 217 | 0·[illegible] (0·39-0·[illegible]), 355 | 0·5 (0·43-0·56), 304 | 0·5 (0·44-0·55), 462 |
| **CRP*** | 0·61 (0·52-0·69), 259 | 0·61 (0·54-0·68), 412 | 0·62 (0·55-0·68), 446 | 0·71 (0·59-0·82), 81 | 0·65 (0·55-0·75), 167 | 0·63 (0·53-0·72), 224 | 0·[illegible] (0·45-0·[illegible]), 356 | 0·6 (0·54-0·67), 305 | 0·58 (0·53-0·63), 462 |
| **IP-10/IP-10/CRG-2** | 0·6 (0·52-0·68), 252 | 0·53 (0·46-0·59), 402 | 0·53 (0·47-0·59), 434 | 0·6 (0·48-0·73), 80 | 0·51 (0·4-0·62), 164 | 0·52 (0·43-0·62), 221 | 0·[illegible] (0·56-0·[illegible]), 358 | 0·6 (0·53-0·66), 309 | 0·61 (0·56-0·66), 466 |
| **Galectin-9** | 0·63 (0·55-0·71), 252 | 0·56 (0·49-0·63), 401 | 0·57 (0·5-0·63), 433 | 0·7 (0·58-0·83), 80 | 0·6 (0·48-0·71), 163 | 0·54 (0·43-0·64), 219 | 0·[illegible] (0·62-0·[illegible]), 358 | 0·61 (0·55-0·67), 309 | 0·63 (0·57-0·68), 466 |
| **hCC2** | 0·51 (0·43-0·6), 244 | 0·51 (0·44-0·58), 392 | 0·52 (0·46-0·59), 424 | 0·55 (0·41-0·69), 77 | 0·52 (0·4-0·64), 159 | 0·51 (0·41-0·61), 216 | 0·59 (0·49-0·69), 358 | 0·55 (0·49-0·62), 309 | 0·55 (0·5-0·6), 466 |
| **HBP***** | 0·67 (0·52-0·81), 113 | 0·68 (0·55-0·8), 144 | 0·64 (0·51-0·76), 151 | .. | .. | .. | 0·53 (0·39-0·68), 363 | 0.55 (0.44-0·66), 106 | 0·52 (0·41-0·63), 124 |
| **HPTGN** | 0·48 (0·4-0·57), 248 | 0·51 (0·44-0·58), 398 | 0·51 (0·45-0·58), 430 | 0·64 (0·5-0·78), 77 | 0·62 (0·51-0·74), 159 | 0·55 (0·45-0·66), 214 | 0·54 (0·45-0·64), 357 | 0·51 (0·45-0·58), 307 | 0·51 (0·46-0·57), 464 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **IL-4** | 0·58 (0·5-0·65), 249 | 0·53 (0·47-0·59), 398 | 0·54 (0·48-0·59), 429 | 0·46 (0·4-0·52), 79 | 0·49 (0·45-0·53), 163 | 0·51 (0·47-0·55), 220 | 0·48 (0·44-0·57), 257 | 0·48 (0·42-0·53), 306 | 0·47 (0·42-0·51), 463 |
| **IL-6** | 0·49 (0·43-0·54), 247 | 0·49 (0·44-0·54), 395 | 0·48 (0·43-0·52), 426 | 0·51 (0·47-0·55), 80 | 0·51 (0·48-0·55), 164 | 0·51 (0·47-0·55), 221 | 0·56 (0·47-0·65), 258 | 0·61 (0·55-0·67), 307 | 0·59 (0·54-0·64), 465 |
| **LBP** | 0·58 (0·5-0·66), 248 | 0·54 (0·48-0·61), 397 | 0·52 (0·46-0·58), 429 | 0·69 (0·56-0·83), 78 | 0·67 (0·55-0·78), 160 | 0·6 (0·5-0·71), 217 | 0·52 (0·42-0·65), 257 | 0·54 (0·47-0·61), 267 | 0·53 (0·47-0·59), 394 |
| **Lipocalin-2/NGAL** | 0·49 (0·41-0·57), 249 | 0·51 (0·44-0·57), 396 | 0·51 (0·44-0·57), 428 | 0·67 (0·54-0·8), 79 | 0·6 (0·49-0·72), 163 | 0·58 (0·48-0·68), 219 | 0·46 (0·36-0·56), 256 | 0·65 (0·59-0·72), 265 | 0·61 (0·56-0·67), 392 |
| **sPLA/Lp-PLA2** | 0·54 (0·46-0.62), 252 | 0·53 (0·46-0·59), 402 | 0·52 (0·45-0·58), 434 | 0·58 (0·44-0·71), 80 | 0·54 (0·43-0·65), 164 | 0·58 (0·48-0·68), 221 | 0·58 (0·47-0·68), 258 | 0·55 (0·49-0·61), 308 | 0·56 (0·51-0·61), 466 |
| **TRAIL** | 0·56 (0·49-0·64), 252 | 0·53 (0·47-0·59), 402 | 0·53 (0·48-0·59), 434 | 0·5 (0·5-0·5), 74 | 0·5 (0·49-0·5), 156 | 0·49 (0·48-0·5), 212 | 0·51 (0·46-0·57), 257 | 0·62 (0·56-0·68), 306 | 0·62 (0·57-0·67), 463 |

**Supplementary Table 8: Univariate analysis – Overall (malaria-positive and malaria-negative) population**

| | Overall - Malaria negatives AUROC (CI), N | | | Overall - Malaria positives AUROC (CI), N | | |
|---|---|---|---|---|---|---|
| | Electronic | Strict | Loose | Electronic | Strict | Loose |
| **WBC count** | 0.74, (0.7-0.79), 493 | 0.75, (0.71-0.78), 880 | 0.72, (0.68-0.75), 1127 | 0.65, (0.57-0.73), 174 | 0.65, (0.58-0.71), 481 | 0.64, (0.59-0.7), 630 |
| **RBC count** | 0.58, (0.53-0.63), 494 | 0.52, (0.48-0.56), 880 | 0.51, (0.47-0.54), 1127 | 0.58, (0.5-0.67), 175 | 0.5, (0.44-0.56), 481 | 0.51, (0.46-0.57), 630 |
| **Lymphocyte count** | 0.66, (0.61-0.71), 491 | 0.57, (0.53-0.61), 877 | 0.55, (0.51-0.58), 1123 | 0.63, (0.54-0.71), 174 | 0.57, (0.5-0.63), 480 | 0.54, (0.49-0.6), 627 |
| **Neutrophil count** | 0.71, (0.66-0.75), 480 | 0.75, (0.71-0.79), 847 | 0.73, (0.69-0.76), 1079 | 0.67, (0.59-0.75), 172 | 0.65, (0.58-0.71), 461 | 0.65, (0.59-0.71), 603 |
| **IL-4** | 0.36, (0.31-0.42), 486 | 0.4, (0.35-0.44), 868 | 0.61, (0.57-0.64), 1113 | 0.66, (0.58-0.74), 175 | 0.59, (0.53-0.65), 478 | 0.58, (0.53-0.63), 624 |
| **TRAIL** | 0.36, (0.3-0.41), 489 | 0.63, (0.59-0.67), 871 | 0.63, (0.59-0.67), 1117 | 0.68, (0.6-0.76), 175 | 0.6, (0.54-0.66), 478 | 0.58, (0.53-0.64), 625 |
| **IL-6** | 0.61, (0.55-0.66), 489 | 0.49, (0.45-0.53), 873 | 0.49, (0.45-0.53), 1120 | 0.42, (0.33-0.5), 175 | 0.57, (0.5-0.63), 478 | 0.53, (0.48-0.59), 626 |
| **CRP NycoCard** | 0.52, (0.47-0.57), 496 | 0.57, (0.53-0.61), 884 | 0.57, (0.53-0.6), 1132 | 0.52, (0.43-0.6), 175 | 0.49, (0.43-0.56), 481 | 0.5, (0.44-0.55), 630 |
| **Gal-9** | 0.52, (0.47-0.57), 490 | 0.54, (0.5-0.58), 875 | 0.56, (0.52-0.59), 1122 | 0.57, (0.48-0.65), 176 | 0.54, (0.48-0.6), 480 | 0.53, (0.48-0.59), 629 |
| **CHI3L1** | 0.56, (0.51-0.62), 489 | 0.55, (0.51-0.59), 873 | 0.55, (0.51-0.59), 1119 | 0.5, (0.41-0.59), 176 | 0.52, (0.45-0.58), 480 | 0.5, (0.44-0.55), 627 |
| **IP-10** | 0.53, (0.48-0.58), 489 | 0.52, (0.48-0.56), 874 | 0.52, (0.49-0.56), 1120 | 0.56, (0.47-0.64), 176 | 0.53, (0.47-0.59), 478 | 0.51, (0.45-0.56), 627 |
| **sPLA2** | 0.52, (0.47-0.57), 490 | 0.52, (0.48-0.56), 874 | 0.52, (0.49-0.56), 1121 | 0.49, (0.4-0.58), 176 | 0.54, (0.48-0.61), 479 | 0.54, (0.49-0.6), 628 |
| **NGAL** | 0.61, (0.56-0.66), 489 | 0.62, (0.57-0.66), 833 | 0.6, (0.57-0.64), 1049 | 0.61, (0.52-0.7), 157 | 0.56, (0.49-0.62), 403 | 0.56, (0.51-0.62), 527 |
| **LBP** | 0.74, (0.69-0.78), 488 | 0.69, (0.65-0.73), 832 | 0.67, (0.64-0.71), 1048 | 0.67, (0.58-0.76), 158 | 0.58, (0.52-0.64), 404 | 0.57, (0.51-0.62), 529 |
| **C2** | 0.59, (0.54-0.64), 483 | 0.56, (0.52-0.6), 866 | 0.56, (0.52-0.59), 1113 | 0.63, (0.55-0.72), 176 | 0.59, (0.53-0.66), 480 | 0.56, (0.5-0.61), 629 |
| **AGP** | 0.67, (0.62-0.72), 490 | 0.6, (0.56-0.64), 874 | 0.58, (0.55-0.62), 1120 | 0.52, (0.43-0.6), 176 | 0.52, (0.45-0.59), 480 | 0.53, (0.47-0.59), 629 |
| **HBP** | 0.67, (0.57-0.76), 179 | 0.64, (0.56-0.72), 254 | 0.61, (0.53-0.68), 280 | 0.55, (0.37-0.72), 57 | 0.52, (0.42-0.63), 141 | 0.53, (0.43-0.64), 149 |
| **HP** | 0.55, (0.49-0.6), 489 | 0.5, (0.46-0.54), 871 | 0.52, (0.48-0.56), 1116 | 0.58, (0.49-0.66), 175 | 0.55, (0.48-0.61), 473 | 0.54, (0.48-0.59), 622 |

**Supplementary Table 9: Univariate analysis – malaria-positive population**

| | Malawi - Malaria positives AUROC (CI), N | | | Gabon - Malaria positives AUROC (CI), N | | |
|---|---|---|---|---|---|---|
| | Electronic | Strict | Loose | Electronic | Strict | Loose |
| **WBC count** | 0.67 (0.58-0.76), 132 | 0.68 (0.61 – 0.75), 369 | 0.67 (0.61-0.72), 491 | 0.67 (0.44-0.91), 42 | 0.61 (0.38-0.83), 112 | 0.61 (0.44-0.78), 139 |
| **RBC count** | 0.69 (0.6-0.79), 131 | 0.55 (0.48-0.61), 367 | 0.53 (0.47-0.59), 488 | 0.56 (0.31-0.81), 43 | 0.51 (0.3-0.71), 113 | 0.49 (0.33-0.65), 140 |
| **Lymphocyte count** | 0.7 (0.61-0.79), 131 | 0.59 (0.53-0.66), 368 | 0.57 (0.51-0.62), 488 | 0.72 (0.51-0.93), 42 | 0.66 (0.47-0.85), 112 | 0.67 (0.52-0,.82), 139 |
| **Neutrophil count** | 0.62 (0.52-0.72), 129 | 0.65 (0.57-0.72), 348 | 0.66 (0.6-0.72), 463 | 0.53 (0.31-0.76), 43 | 0.59 (0.39-0.79), 113 | 0.59 (0.43-0.75), 140 |
| **IL-4** | 0.46 (0.36-0.56), 132 | 0.47 (0.4-0.53), 369 | 0.48 (0.42-0.53), 488 | 0.44 (0.38-0.5), 40 | 0.46 (0.44-0.49), 103 | 0.5 (0.42-0.57), 127 |
| **TRAIL** | 0.6 (0.51-0.7),132 | 0.55 (0.49-0.62), 369 | 0.54 (0.48-0.59), 488 | 0.5 (0.5-0.5), 43 | 0.5 (0.5-0.5), 109 | 0.53 (0.47-0.6), 136 |
| **IL-6** | 0.6 (0.5-0.7), 131 | 0.58 (0.51-0.65), 367 | 0.54 (0.48-0.6), 485 | 0.45 (0.32 - 0.57), 42 | 0.47 (0.37-0.57), 103 | 0.45 (0.37-0.53), 127 |
| **CRP NycoCard** | 0.48 (0.38-0.58), 131 | 0.54 (0.47-0.61), 367 | 0.53 (0.47-0.59), 489 | 0.59 (0.32-0.86), 44 | 0.59 (0.36-0.82), 114 | 0.57 (0.4-0.75), 141 |
| **Gal-9** | 0.58 (0.48-0.69), 132 | 0.56 (0.49-0.62), 369 | 0.54 (0.47-0.6), 491 | 0.57 (0.34-0.8), 43 | 0.5 (0.32-0.68), 109 | 0.56 (0.42-0.71), 136 |
| **CHI3L1** | 0.56 (0.46-0.66), 132 | 0.55 (0.48-0.62), 367 | 0.55 (0.49-0.61), 487 | 0.52 (0.26-0.79), 43 | 0.53 (0.31-0.75), 106 | 0.63 (0.44-0.81), 131 |
| **IP-10** | 0.67 (0.58-0.76), 132 | 0.56 (0.49-0.63), 363 | 0.52 (0.46-0.59), 484 | 0.51 (0.33-0.69), 40 | 0.49 (0.35-0.63), 104 | 0.48 (0.35-0.61), 129 |
| **sPLA2** | 0.53 (0.43-0.64), 133 | 0.56 (0.48-0.63), 370 | 0.56 (0.5-0.62), 492 | 0.49 (0.24-0.74), 43 | 0.56 (0.34-0.77), 109 | 0.49 (0.32-0.67), 136 |
| **NGAL** | 0.5 (0.39-0.61), 114 | 0.5 (0.43-0.58), 291 | 0.49 (0.42-0.55)386 | 0.65 (0.44-0.91), 41 | 0.59 (0.41-0.77), 106 | 0.54 (0.38-0.7), 131 |
| **LBP** | 0.47 (0.35-0.59), 115 | 0.54 (0.46-0.61), 295 | 0.54 (0.48-0.6), 393 | 0.6 (0.34 - 0.85), 42 | 0.58 (0.37-0.8), 105 | 0.65 (0.48-0.81), 131 |
| **C2** | 0.62 (0.52-0.72), 133 | 0.57 (0.5-0.64), 369 | 0.54 (0.48-0.6), 491 | 0.72 (0.54-0.9), 43 | 0.72 (0.57-0.87), 105 | 0.64 (0.48-0.8), 131 |
| **AGP** | 0.54 (0.44 - 0.64), 133 | 0.52 (0.44-0.59), 371 | 0.48 (0.42-0.54), 493 | 0.51 (0.27-0.75), 43 | 0.53 (0.33-0.74), 109 | 0.58 (0.41-0.76), 136 |
| **HBP** | 0.55, (0.37-0.72), 57 | 0.53, (0.43-0.64), 143 | 0.54, (0.44-0.64), 151 | .. | .. | .. |
| **HP** | 0.58 (0.48-0.68), 133 | 0.54 (0.47-0.61), 365 | 0.51 (0.45-0.57), 487 | 0.57 (0.33-0.8), 42 | 0.56 (0.36-0.76), 107 | 0.61 (0.46-0.77), 134 |

*Green (AUROC ≥ 0.7), yellow (AUROC ≥ 0.65 and <7), orange (AUROC 0.6-0.65,) red (AUROC <0.6)*

## Univariate analysis – age subgroups

**Supplementary Table 10: Univariate analysis - age less than 6 years (non-malaria)**

| | Malawi - Malaria negatives AUROC (CI), N | | | Brazil - Malaria negatives AUROC (CI), N | | | Gabon - Malaria negatives AUROC (CI), N | | |
|---|---|---|---|---|---|---|---|---|---|
| | Electronic | Strict | Loose | Electronic | Strict | Loose | Electronic | Strict | Loose |
| **WBC count** | 0.83, (0.73-0.94), 61 | 0.79, (0.71-0.87), 122 | 0.76, (0.69-0.84), 170 | 0.52, (0.25-0.78), 21 | 0.65, (0.46-0.85), 34 | 0.69, (0.51-0.86), 38 | 0.78, (0.62-0.94), 32 | 0.68, (0.52-0.83), 75 | 0.65, (0.52-0.79), 105 |
| **RBC count** | 0.65, (0.49-0.8), 62 | 0.58, (0.48-0.68), 123 | 0.58, (0.5-0.67), 172 | 0.6, (0.33-0.86), 21 | 0.56, (0.35-0.77), 33 | 0.59, (0.39-0.78), 37 | 0.6, (0.4-0.81), 32 | 0.56, (0.4-0.72), 75 | 0.53, (0.38-0.67), 105 |
| **Lymphocyte count** | 0.58, (0.43-0.72), 60 | 0.53, (0.42-0.64), 121 | 0.48, (0.38-0.57), 170 | 0.63, (0.36-0.89), 21 | 0.67, (0.44-0.91), 34 | 0.7, (0.5-0.9), 38 | 0.71, (0.53-0.89), 32 | 0.6, (0.44-0.76), 75 | 0.63, (0.49-0.76), 105 |
| **Neutrophil count** | 0.82, (0.7-0.93), 57 | 0.79, (0.7-0.88), 108 | 0.77, (0.69-0.86), 148 | 0.58, (0.32-0.85), 21 | 0.56, (0.36-0.77), 34 | 0.6, (0.41-0.79), 38 | 0.86, (0.72-0.99), 32 | 0.79, (0.67-0.92), 74 | 0.7, (0.58-0.83), 103 |
| **IL-4** | 0.54, (0.39-0.68), 63 | 0.5, (0.41-0.59), 125 | 0.48, (0.41-0.56), 174 | 0.63, (0.38-0.88), 20 | 0.66, (0.49-0.84), 31 | 0.62, (0.44-0.8), 33 | 0.43, (0.31-0.55), 30 | 0.49, (0.43-0.56), 72 | 0.51, (0.44-0.57), 103 |
| **TRAIL** | 0.57, (0.39-0.75), 63 | 0.6, (0.5-0.69), 125 | 0.59, (0.51-0.67), 174 | 0.5, (0.23-0.77), 20 | 0.63, (0.43-0.82), 31 | 0.59, (0.4-0.79), 33 | 0.5, (0.5-0.5), 28 | 0.5, (0.5-0.5), 69 | 0.49, (0.48-0.51), 99 |
| **IL-6** | 0.59, (0.44-0.73), 63 | 0.61, (0.52-0.7), 125 | 0.6, (0.52-0.68), 174 | 0.41, (0.29-0.53), 20 | 0.39, (0.29-0.49), 29 | 0.39, (0.3-0.49), 31 | 0.5, (0.5-0.5), 31 | 0.5, (0.5-0.5), 73 | 0.49, (0.47-0.5), 104 |
| **CRP NycoCard** | 0.56, (0.37-0.74), 61 | 0.61, (0.51-0.71), 121 | 0.59, (0.5-0.68), 169 | 0.49, (0.22-0.76), 21 | 0.59, (0.38-0.79), 34 | 0.6, (0.42-0.79), 38 | 0.76, (0.57-0.95), 32 | 0.62, (0.49-0.76), 75 | 0.57, (0.45-0.69), 106 |
| **Gal-9** | 0.79, (0.66-0.92), 63 | 0.59, (0.49-0.69), 125 | 0.57, (0.48-0.66), 173 | 0.47, (0.2-0.75), 20 | 0.5, (0.28-0.72), 31 | 0.52, (0.3-0.73), 33 | 0.66, (0.45-0.87), 31 | 0.6, (0.43-0.76), 72 | 0.54, (0.4-0.69), 102 |
| **CHI3L1** | 0.56, (0.4-0.72), 62 | 0.52, (0.42-0.63), 124 | 0.54, (0.45-0.63), 173 | 0.61, (0.35-0.87), 20 | 0.66, (0.47-0.86), 31 | 0.67, (0.49-0.86), 33 | 0.68, (0.49-0.88), 31 | 0.62, (0.45-0.79), 73 | 0.61, (0.47-0.75), 102 |
| **IP-10** | 0.67, (0.51-0.83), 63 | 0.62, (0.52-0.72), 125 | 0.6, (0.51-0.68), 174 | 0.65, (0.39-0.9), 20 | 0.7, (0.51-0.89), 31 | 0.64, (0.45-0.84), 33 | 0.71, (0.53-0.9), 31 | 0.52, (0.38-0.67), 73 | 0.51, (0.38-0.63), 104 |
| **sPLA2** | 0.66, (0.5-0.82), 63 | 0.55, (0.45-0.66), 125 | 0.56, (0.47-0.65), 174 | 0.65, (0.38-0.91), 20 | 0.69, (0.48-0.9), 31 | 0.68, (0.48-0.88), 33 | 0.58, (0.37-0.78), 31 | 0.57, (0.41-0.72), 73 | 0.59, (0.45-0.73), 104 |
| **NGAL** | 0.61, (0.44-0.77), 63 | 0.68, (0.58- | 0.67, (0.59- | 0.67, (0.41-0.93), 20 | 0.58, (0.38- | 0.52, (0.31- | 0.63, (0.43-0.83), 31 | 0.6, (0.44- | 0.57, (0.43- |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0.78), 109 | 0.76), 144 | | 0.79), 31 | 0.72), 33 | | 0.77), 73 | 0.71), 103 |
| **LBP** | 0.47, (0.31-0.63), 63 | 0.5, (0.39-0.62), 109 | 0.53, (0.43-0.63), 144 | 0.47, (0.2-0.75), 20 | 0.46, (0.25-0.68), 30 | 0.48, (0.27-0.7), 32 | 0.73, (0.53-0.93), 30 | 0.7, (0.53-0.86), 70 | 0.59, (0.44-0.75), 101 |
| **C2** | 0.51, (0.34-0.69), 63 | 0.56, (0.45-0.66), 125 | 0.52, (0.44-0.61), 174 | 0.47, (0.18-0.76), 19 | 0.64, (0.41-0.87), 29 | 0.62, (0.4-0.83), 31 | 0.51, (0.29-0.73), 30 | 0.48, (0.32-0.64), 71 | 0.5, (0.36-0.64), 102 |
| **AGP** | 0.54, (0.38-0.7), 63 | 0.56, (0.45-0.66), 125 | 0.57, (0.48-0.66), 174 | 0.72, (0.48-0.96), 20 | 0.57, (0.34-0.81), 31 | 0.61, (0.39-0.82), 33 | 0.8, (0.63-0.98), 31 | 0.72, (0.56-0.88), 72 | 0.62, (0.48-0.76), 103 |
| **HBP** | 0.67, (0.45-0.89), 26 | 0.55, (0.37-0.73), 45 | 0.54, (0.37-0.71), 48 | .. | .. | .. | .. | .. | .. |
| **HP** | 0.64, (0.49-0.78), 62 | 0.57, (0.46-0.67), 124 | 0.57, (0.48-0.66), 173 | 0.68, (0.42-0.93), 20 | 0.61, (0.38-0.84), 31 | 0.62, (0.41-0.84), 33 | 0.78, (0.59-0.97), 28 | 0.72, (0.57-0.88), 69 | 0.63, (0.49-0.77), 100 |

*Green (AUROC ≥ 0.7), yellow (AUROC ≥ 0.65 and <7), orange (AUROC 0.6-0.65), red (AUROC <0.6)*

**Supplementary Table 11: Univariate analysis - aged between 7 and 15 years (non-malaria)**

| | Malawi - Malaria negatives AUROC (CI), N | | | Brazil - Malaria negatives AUROC (CI), N | | | Gabon - Malaria negatives AUROC (CI), N | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** |
| **WBC count** | 0.49, (0.26-0.73), 28 | 0.69, (0.54-0.84), 50 | 0.75, (0.64-0.86), 81 | 0.79, (0.61-0.96), 34 | 0.83, (0.71-0.95), 69 | 0.82, (0.71-0.94), 75 | 0.46, (0.27-0.65), 47 | 0.51, (0.34-0.67), 87 | 0.47, (0.31-0.62), 112 |
| **RBC count** | 0.62, (0.41-0.84), 28 | 0.54, (0.37-0.7), 51 | 0.57, (0.44-0.7), 82 | 0.7, (0.51-0.88), 34 | 0.61, (0.45-0.78), 69 | 0.6, (0.44-0.75), 75 | 0.56, (0.38-0.75), 47 | 0.55, (0.4-0.7), 87 | 0.48, (0.35-0.62), 112 |
| **Lymphocyte count** | 0.76, (0.58-0.94), 28 | 0.67, (0.51-0.83), 51 | 0.62, (0.49-0.74), 82 | 0.6, (0.37-0.83), 34 | 0.69, (0.54-0.85), 69 | 0.71, (0.56-0.86), 75 | 0.59, (0.42-0.76), 47 | 0.61, (0.48-0.74), 87 | 0.55, (0.43-0.68), 112 |
| **Neutrophil count** | 0.46, (0.23-0.7), 26 | 0.7, (0.54-0.86), 45 | 0.76, (0.64-0.87), 73 | 0.73, (0.53-0.93), 34 | 0.82, (0.69-0.95), 69 | 0.8, (0.68-0.93), 75 | 0.66, (0.46-0.86), 46 | 0.61, (0.43-0.8), 86 | 0.61, (0.44-0.78), 111 |
| **IL-4** | 0.56, (0.34-0.78), 28 | 0.46, (0.31-0.6), 50 | 0.48, (0.37-0.6), 80 | 0.73, (0.53-0.92), 33 | 0.62, (0.47-0.77), 69 | 0.59, (0.45-0.74), 75 | 0.46, (0.41-0.5), 47 | 0.48, (0.46-0.5), 86 | 0.51, (0.45-0.57), 112 |
| **TRAIL** | 0.48, (0.23-0.73), 28 | 0.6, (0.45-0.76), 50 | 0.57, (0.45-0.7), 80 | 0.55, (0.34-0.77), 33 | 0.53, (0.38-0.68), 69 | 0.52, (0.38-0.66), 75 | 0.5, (0.5-0.5), 45 | 0.49, (0.48-0.51), 83 | 0.49, (0.47-0.5), 109 |
| **IL-6** | 0.45, (0.21-0.69), 28 | 0.56, (0.4- | 0.55, (0.44- | 0.46, (0.34-0.58), 33 | 0.44, (0.33- | 0.43, (0.33- | 0.53, (0.44-0.62), 47 | 0.53, (0.46-0.6), 86 | 0.54, (0.46- |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0.71), 51 | 0.67), 82 | | 0.56), 69 | 0.53), 75 | | | 0.62), 112 |
| **CRP NycoCard** | 0.56, (0.34-0.78), 28 | 0.61, (0.46-0.77), 51 | 0.62, (0.5-0.74), 82 | 0.57, (0.33-0.81), 34 | 0.52, (0.35-0.68), 71 | 0.51, (0.35-0.68), 77 | 0.75, (0.59-0.92), 47 | 0.71, (0.55-0.87), 87 | 0.69, (0.56-0.83), 113 |
| **Gal-9** | 0.67, (0.43-0.9), 28 | 0.68, (0.53-0.84), 51 | 0.66, (0.54-0.78), 82 | 0.71, (0.52-0.9), 33 | 0.57, (0.41-0.73), 69 | 0.54, (0.39-0.7), 75 | 0.79, (0.62-0.95), 47 | 0.61, (0.44-0.77), 86 | 0.55, (0.39-0.71), 112 |
| **CHI3L1** | 0.53, (0.28-0.78), 28 | 0.6, (0.44-0.76), 51 | 0.61, (0.49-0.73), 82 | 0.69, (0.5-0.87), 32 | 0.66, (0.52-0.79), 67 | 0.59, (0.44-0.73), 71 | 0.53, (0.32-0.73), 46 | 0.58, (0.41-0.74), 84 | 0.62, (0.47-0.77), 110 |
| **IP-10** | 0.64, (0.42-0.86), 28 | 0.56, (0.39-0.72), 51 | 0.59, (0.46-0.72), 82 | 0.73, (0.53-0.92), 33 | 0.62, (0.46-0.78), 69 | 0.58, (0.42-0.73), 75 | 0.6, (0.41-0.78), 47 | 0.48, (0.31-0.66), 86 | 0.52, (0.37-0.67), 112 |
| **sPLA2** | 0.47, (0.21-0.72), 28 | 0.55, (0.39-0.72), 51 | 0.56, (0.43-0.68), 82 | 0.54, (0.33-0.76), 33 | 0.49, (0.35-0.64), 69 | 0.56, (0.43-0.7), 75 | 0.46, (0.28-0.64), 47 | 0.52, (0.36-0.67), 86 | 0.44, (0.29-0.59), 112 |
| **NGAL** | 0.56, (0.32-0.8), 28 | 0.68, (0.52-0.85), 46 | 0.73, (0.61-0.85), 73 | 0.71, (0.52-0.9), 33 | 0.68, (0.54-0.82), 69 | 0.64, (0.5-0.78), 75 | 0.7, (0.52-0.89), 46 | 0.6, (0.44-0.77), 85 | 0.59, (0.44-0.74), 111 |
| **LBP** | 0.54, (0.3-0.77), 28 | 0.59, (0.42-0.75), 46 | 0.58, (0.45-0.72), 73 | 0.68, (0.5-0.87), 33 | 0.66, (0.52-0.8), 69 | 0.67, (0.54-0.8), 75 | 0.71, (0.52-0.9), 46 | 0.66, (0.48-0.84), 85 | 0.63, (0.46-0.79), 111 |
| **C2** | 0.62, (0.34-0.9), 28 | 0.53, (0.36-0.7), 51 | 0.53, (0.41-0.66), 82 | 0.54, (0.31-0.76), 32 | 0.57, (0.4-0.74), 67 | 0.61, (0.45-0.77), 73 | 0.62, (0.42-0.81), 45 | 0.46, (0.27-0.65), 83 | 0.52, (0.36-0.68), 109 |
| **AGP** | 0.57, (0.3-0.83), 28 | 0.55, (0.39-0.71), 51 | 0.52, (0.39-0.65), 81 | 0.53, (0.3-0.76), 33 | 0.6, (0.44-0.75), 69 | 0.61, (0.46-0.75), 75 | 0.75, (0.56-0.94), 47 | 0.68, (0.5-0.86), 86 | 0.67, (0.52-0.83), 112 |
| **HBP** | 0.76, (0.28-1), 10 | 0.58, (0.29-0.87), 19 | 0.65, (0.39-0.91), 23 | ## Unbalanced classes | 0.92, (0.69-1), 8 | 0.72, (0.28-1), 9 | .. | .. | .. |
| **HP** | 0.5, (0.25-0.76), 28 | 0.51, (0.35-0.67), 51 | 0.5, (0.37-0.63), 82 | 0.52, (0.3-0.75), 32 | 0.62, (0.46-0.78), 68 | 0.6, (0.45-0.76), 74 | 0.53, (0.33-0.73), 47 | 0.54, (0.37-0.7), 85 | 0.53, (0.38-0.67), 109 |

*Green (AUROC ≥ 0.7), yellow (AUROC ≥ 0.65 and <7), orange (AUROC 0.6-0.65), red (AUROC <0.6)*

**Supplementary Table 12: Univariate analysis - aged more than 15 years (non-malaria)**

| | **Malawi - Malaria negatives AUROC (CI), N** | | | **Brazil - Malaria negatives AUROC (CI), N** | | | **Gabon - Malaria negatives AUROC (CI), N** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** |
| **WBC count** | 0.67, (0.53-0.82), 66 | 0.71, (0.62- | 0.68, (0.6- | 0.84, (0.77-0.91), 202 | 0.84, (0.77- | 0.83, (0.77- | 2 patients in total | 5 patients in total | 5 patients in total |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0.8), 132 | 0.75), 210 | | 0.9), 305 | 0.89), 329 | | | |
| **RBC count** | 0.59, (0.44-0.73), 65 | 0.53, (0.43-0.63), 131 | 0.51, (0.43-0.59), 209 | 0.56, (0.45-0.67), 203 | 0.56, (0.47-0.64), 306 | 0.55, (0.47-0.63), 330 | - | - | - |
| **Lymphocyte count** | 0.5, (0.34-0.66), 66 | 0.53, (0.43-0.63), 131 | 0.49, (0.41-0.57), 209 | 0.67, (0.58-0.76), 202 | 0.65, (0.57-0.72), 305 | 0.64, (0.57-0.71), 329 | - | - | - |
| **Neutrophil count** | 0.65, (0.49-0.81), 60 | 0.7, (0.6-0.8), 120 | 0.66, (0.59-0.74), 193 | 0.82, (0.74-0.9), 202 | 0.82, (0.76-0.89), 305 | 0.82, (0.75-0.88), 329 | - | - | - |
| **IL-4** | 0.4, (0.28-0.52), 66 | 0.47, (0.39-0.54), 131 | 0.45, (0.39-0.52), 209 | 0.56, (0.47-0.65), 196 | 0.53, (0.46-0.6), 298 | 0.54, (0.47-0.6), 321 | - | - | - |
| **TRAIL** | 0.68, (0.54-0.82), 66 | 0.65, (0.56-0.73), 131 | 0.66, (0.59-0.73), 209 | 0.57, (0.48-0.65), 199 | 0.54, (0.47-0.61), 302 | 0.54, (0.48-0.61), 326 | - | - | - |
| **IL-6** | 0.59, (0.46-0.72), 67 | 0.63, (0.54-0.72), 131 | 0.59, (0.52-0.66), 209 | 0.51, (0.44-0.58), 194 | 0.51, (0.45-0.58), 297 | 0.5, (0.44-0.56), 320 | - | - | - |
| **CRP NycoCard** | 0.53, (0.38-0.68), 67 | 0.6, (0.5-0.7), 133 | 0.57, (0.49-0.64), 211 | 0.66, (0.57-0.76), 204 | 0.65, (0.57-0.73), 307 | 0.66, (0.58-0.73), 331 | - | - | - |
| **Gal-9** | 0.72, (0.59-0.86), 67 | 0.6, (0.5-0.7), 133 | 0.63, (0.56-0.71), 211 | 0.61, (0.52-0.71), 199 | 0.56, (0.48-0.65), 301 | 0.57, (0.5-0.65), 325 | - | - | - |
| **CHI3L1** | 0.52, (0.36-0.67), 65 | 0.51, (0.41-0.61), 129 | 0.53, (0.45-0.61), 207 | 0.66, (0.58-0.75), 194 | 0.62, (0.54-0.69), 296 | 0.62, (0.55-0.69), 320 | - | - | - |
| **IP-10** | 0.64, (0.48-0.79), 67 | 0.59, (0.49-0.69), 133 | 0.61, (0.53-0.68), 210 | 0.59, (0.5-0.68), 199 | 0.52, (0.44-0.6), 302 | 0.53, (0.45-0.6), 326 | - | - | - |
| **sPLA2** | 0.53, (0.37-0.69), 67 | 0.54, (0.44-0.64), 132 | 0.54, (0.46-0.62), 210 | 0.58, (0.48-0.67), 199 | 0.56, (0.48-0.64), 302 | 0.56, (0.48-0.63), 326 | - | - | - |
| **NGAL** | 0.49, (0.33-0.65), 65 | 0.62, (0.51-0.72), 110 | 0.53, (0.44-0.62), 175 | 0.55, (0.46-0.65), 196 | 0.54, (0.46-0.62), 296 | 0.53, (0.45-0.61), 320 | - | - | - |
| **LBP** | 0.56, (0.41-0.7), 66 | 0.56, (0.45-0.67), 112 | 0.53, (0.44-0.61), 177 | 0.65, (0.56-0.74), 195 | 0.6, (0.52-0.67), 298 | 0.56, (0.49-0.64), 322 | - | - | - |
| **C2** | 0.67, (0.53-0.81), 67 | 0.59, (0.49-0.69), 133 | 0.58, (0.51-0.66), 210 | 0.5, (0.4-0.6), 193 | 0.51, (0.43-0.58), 296 | 0.51, (0.44-0.59), 320 | - | - | - |
| **AGP** | 0.6, (0.45-0.75), 67 | 0.57, (0.47- | 0.54, (0.46- | 0.65, (0.55-0.74), 199 | 0.58, (0.5- | 0.56, (0.49- | - | - | - |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0.67), 133 | 0.62), 211 | | 0.66), 302 | 0.64), 326 | | | |
| **HBP** | 0.48, (0.25 -0.71), 28 | 0.54, (0 .36-0.72), 4 4 | 0.47, (0 .31-0.63), 5 5 | 0.66, (0.51 -0.81), 107 | 0.66, (0 .53-0.79), 1 36 | 0.63, (0 .5-0.76), 1 42 | - | - | - |
| **HP** | 0.53, (0.39-0.67), 67 | 0.58, (0.48-0.68), 132 | 0.5, (0.42-0.58), 209 | 0.56, (0.46-0.66), 196 | 0.47, (0.39-0.55), 299 | 0.48, (0.4-0.55), 323 | - | - | - |

*Green (AUROC ≥ 0.7), yellow (AUROC ≥ 0.65 and <7), orange (AUROC 0.6-0.65) red (AUROC <0.6)*

**Supplementary Table 13: Univariate analysis - age less than 6 years (malaria)**

| | **Malawi - Malaria positives AUROC (CI), N** | | | **Gabon - Malaria positives AUROC (CI), N** | | |
|---|---|---|---|---|---|---|
| | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** |
| **WBC count** | 0.64, (0.47-0.81), 50 | 0.71, (0.59-0.82), 148 | 0.7, (0.6-0.8), 178 | 0.62, (0.23-1), 11 | 0.62, (0.36-0.88), 44 | 0.62, (0.41-0.83), 56 |
| **RBC count** | 0.51, (0.33-0.68), 49 | 0.55, (0.44-0.65), 147 | 0.55, (0.44-0.65), 177 | 0.7, (0.34-1), 11 | 0.63, (0.42-0.84), 44 | 0.62, (0.45-0.8), 56 |
| **Lymphocyte count** | 0.45, (0.26-0.64), 49 | 0.58, (0.47-0.7), 147 | 0.55, (0.44-0.66), 177 | 0.57, (0.17-0.96), 11 | 0.6, (0.34-0.86), 44 | 0.63, (0.42-0.85), 56 |
| **Neutrophil count** | 0.59, (0.41-0.77), 49 | 0.65, (0.53-0.76), 140 | 0.66, (0.56-0.76), 169 | 0.7, (0.3-1), 11 | 0.49, (0.24-0.75), 44 | 0.55, (0.35-0.75), 56 |
| **IL-4** | 0.68, (0.5-0.86), 50 | 0.62, (0.52-0.71), 148 | 0.58, (0.49-0.67), 178 | 0.5, (0.5-0.5), 11 | 0.47, (0.42-0.51), 39 | 0.48, (0.44-0.51), 51 |
| **TRAIL** | 0.73, (0.56-0.89), 50 | 0.59, (0.48-0.69), 148 | 0.56, (0.47-0.66), 178 | 0.5, (0.5-0.5), 11 | 0.5, (0.5-0.5), 41 | 0.5, (0.5-0.5), 53 |
| **IL-6** | 0.6, (0.4-0.79), 49 | 0.64, (0.53-0.74), 147 | 0.63, (0.53-0.72), 175 | 0.47, (0.2-0.73), 11 | 0.48, (0.33-0.62), 37 | 0.48, (0.36-0.59), 49 |
| **CRP NycoCard** | 0.52, (0.33-0.7), 48 | 0.58, (0.48-0.69), 145 | 0.56, (0.46-0.66), 175 | 0.78, (0.47-1), 11 | 0.66, (0.41-0.91), 44 | 0.63, (0.42-0.84), 56 |
| **Gal-9** | 0.58, (0.37-0.79), 49 | 0.54, (0.43-0.65), 148 | 0.53, (0.43-0.64), 178 | 0.5, (0.05-0.95), 11 | 0.63, (0.45-0.82), 41 | 0.6, (0.44-0.76), 53 |
| **CHI3L1** | 0.53, (0.36-0.7), 50 | 0.6, (0.49-0.71), 148 | 0.57, (0.47-0.67), 178 | 0.47, (0.07-0.86), 11 | 0.54, (0.28-0.79), 40 | 0.56, (0.33-0.8), 51 |
| **IP-10** | 0.73, (0.57-0.9), 50 | 0.58, (0.47-0.69), 143 | 0.57, (0.47-0.67), 172 | 0.77, (0.38-1), 11 | 0.45, (0.26-0.64), 39 | 0.48, (0.32-0.64), 51 |
| **sPLA2** | 0.49, (0.3-0.69), 50 | 0.63, (0.52-0.75), 148 | 0.62, (0.52-0.72), 178 | 0.73, (0.38-1), 11 | 0.52, (0.27-0.78), 41 | 0.52, (0.31-0.73), 53 |
| **NGAL** | 0.61, (0.43-0.79), 47 | 0.56, (0.44-0.68), 118 | 0.54, (0.43-0.65), 141 | 0.87, (0.6-1), 11 | 0.62, (0.4-0.85), 40 | 0.61, (0.41-0.8), 52 |
| **LBP** | 0.55, (0.3-0.79), 48 | 0.48, (0.37-0.59), 122 | 0.52, (0.41-0.62), 147 | 0.45, (0.03-0.87), 11 | 0.58, (0.33-0.83), 41 | 0.61, (0.4-0.81), 53 |
| **C2** | 0.57, (0.38-0.76), 50 | 0.57, (0.47-0.68), 148 | 0.56, (0.46-0.67), 178 | 0.58, (0.2-0.97), 11 | 0.78, (0.6-0.96), 38 | 0.77, (0.6-0.93), 50 |
| **AGP** | 0.68, (0.52-0.84), 50 | 0.6, (0.49-0.71), 149 | 0.57, (0.47-0.68), 179 | 0.63, (0.24-1), 11 | 0.52, (0.32-0.73), 41 | 0.46, (0.27-0.65), 53 |
| **HBP** | 0.55, (0.27-0.84), 33 | 0.62, (0.49-0.76), 78 | 0.63, (0.49-0.76), 82 | .. | .. | .. |
| **HP** | 0.72, (0.58-0.87), 50 | 0.59, (0.48-0.7), 147 | 0.56, (0.46-0.67), 177 | 0.57, (0.18-0.95), 11 | 0.45, (0.21-0.69), 40 | 0.47, (0.26-0.68), 52 |

*Green (AUROC ≥ 0.7), yellow (AUROC ≥ 0.65 and <7), orange (AUROC 0.6-0.65), red (AUROC <0.6)*

**Supplementary Table 14: Univariate analysis - aged between 7 and 15 years (malaria)**

| | Malawi - Malaria positives AUROC (CI), N | | | Gabon - Malaria positives AUROC (CI), N | | |
|---|---|---|---|---|---|---|
| | Electronic | Strict | Loose | Electronic | Strict | Loose |
| WBC count | 0.67, (0.51-0.82), 51 | 0.7, (0.6-0.8), 134 | 0.66, (0.57-0.75), 185 | ## unbalanced classes (24 non-bacterial, 1 bacterial) for 25 patients | ## unbalanced classes (54 non-bacterial, 1 bacterial) for 55 patients | 0.47, (0.03-0.91), 72 |
| RBC count | 0.74, (0.6-0.87), 51 | 0.55, (0.43-0.68), 134 | 0.53, (0.43-0.63), 185 | - | - | 0.67, (0.28-1), 73 |
| Lymphocyte count | 0.64, (0.49-0.79), 51 | 0.59, (0.47-0.7), 134 | 0.55, (0.46-0.64), 184 | - | - | 0.44, (0.14-0.75), 72 |
| Neutrophil count | 0.63, (0.47-0.79), 50 | 0.67, (0.56-0.78), 127 | 0.67, (0.58-0.76), 174 | - | - | 0.51, (0.17-0.86), 73 |
| IL-4 | 0.53, (0.36-0.7), 51 | 0.54, (0.44-0.64), 134 | 0.53, (0.45-0.61), 184 | - | - | 0.62, (0.27-0.96), 65 |
| TRAIL | 0.51, (0.35-0.68), 51 | 0.52, (0.41-0.63), 134 | 0.54, (0.45-0.63), 184 | - | - | 0.62, (0.38-0.87), 72 |
| IL-6 | 0.62, (0.46-0.78), 50 | 0.57, (0.46-0.68), 132 | 0.51, (0.41-0.6), 181 | - | - | 0.41, (0.37-0.46), 67 |
| CRP NycoCard | 0.55, (0.39-0.71), 51 | 0.52, (0.4-0.64), 134 | 0.51, (0.41-0.61), 185 | - | - | 0.59, (0.21-0.97), 73 |
| Gal-9 | 0.6, (0.44-0.76), 51 | 0.53, (0.42-0.65), 134 | 0.55, (0.45-0.65), 185 | - | - | 0.64, (0.23-1), 72 |
| CHI3L1 | 0.53, (0.36-0.69), 51 | 0.49, (0.38-0.6), 133 | 0.54, (0.45-0.64), 183 | - | - | 0.61, (0.08-1), 69 |
| IP-10 | 0.63, (0.47-0.79), 50 | 0.56, (0.45-0.68), 133 | 0.53, (0.43-0.63), 184 | - | - | 0.55, (0.11-0.99), 67 |
| NGAL | 0.55, (0.38-0.71), 51 | 0.52, (0.41-0.64), 134 | 0.53, (0.44-0.63), 185 | - | - | 0.56, (0.13-0.99), 72 |
| HNL | 0.67, (0.48-0.85), 42 | 0.47, (0.35-0.59), 108 | 0.57, (0.48-0.67), 150 | - | - | 0.66, (0.33-1), 69 |
| LBP | 0.61, (0.44-0.78), 42 | 0.59, (0.47-0.71), 108 | 0.56, (0.46-0.66), 151 | - | - | 0.9, (0.77-1), 67 |
| C2 | 0.62, (0.46-0.78), 51 | 0.57, (0.46-0.68), 133 | 0.54, (0.45-0.64), 184 | - | - | 0.73, (0.47-0.98), 70 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **AGP** | 0.6, (0.44-0.76), 51 | 0.55, (0.43-0.67), 134 | 0.52, (0.42-0.62), 185 | - | - | 0.53, (0.07-0.99), 72 |
| **HBP** | 0.64, (0.39-0.9), 21 | 0.46, (0.28-0.65), 50 | 0.49, (0.31-0.67), 55 | - | - | - |
| **HP** | 0.54, (0.37-0.7), 51 | 0.49, (0.38-0.59), 132 | 0.49, (0.4-0.59), 183 | - | - | 0.79, (0.6-0.98), 71 |

*Green (AUROC ≥ 0.7), yellow (AUROC ≥ 0.65 and <7), orange (AUROC 0.6-0.65) red (AUROC <0.6)*

**Supplementary Table 15: Univariate analysis - aged more than 15 years (malaria)**

| | **Malawi - Malaria positives AUROC (CI), N** | | | **Gabon - Malaria positives AUROC (CI), N** | | |
|---|---|---|---|---|---|---|
| | **Electronic** | **Strict** | **Loose** | **Electronic** | **Strict** | **Loose** |
| **WBC count** | 0.54, (0.32-0.76), 31 | 0.56, (0.37-0.75), 87 | 0.65, (0.51-0.78), 128 | 2 patients in total | 11 patients in total | 11 patients in total |
| **RBC count** | 0.42, (0.2-0.63), 31 | 0.58, (0.42-0.73), 86 | 0.57, (0.44-0.7), 126 | - | - | - |
| **Lymphocyte count** | 0.77, (0.61-0.94), 31 | 0.64, (0.5-0.78), 87 | 0.66, (0.55-0.77), 127 | - | - | - |
| **Neutrophil count** | 0.5, (0.28-0.73), 30 | 0.55, (0.35-0.74), 81 | 0.62, (0.48-0.77), 120 | - | - | - |
| **IL-4** | 0.53, (0.33-0.73), 31 | 0.5, (0.34-0.66), 87 | 0.48, (0.37-0.59), 126 | - | - | - |
| **TRAIL** | 0.62, (0.42-0.82), 31 | 0.6, (0.44-0.76), 87 | 0.63, (0.51-0.75), 126 | - | - | - |
| **IL-6** | 0.67, (0.47-0.87), 32 | 0.52, (0.35-0.69), 88 | 0.54, (0.41-0.66), 129 | - | - | - |
| **CRP NycoCard** | 0.57, (0.36-0.78), 32 | 0.52, (0.37-0.68), 88 | 0.52, (0.4-0.64), 129 | - | - | - |
| **Gal-9** | 0.61, (0.4-0.82), 32 | 0.59, (0.44-0.73), 87 | 0.52, (0.39-0.65), 128 | - | - | - |
| **CHI3L1** | 0.64, (0.43-0.85), 31 | 0.53, (0.37-0.69), 86 | 0.52, (0.4-0.65), 126 | - | - | - |
| **IP-10** | 0.66, (0.45-0.87), 32 | 0.52, (0.35-0.69), 87 | 0.58, (0.44-0.71), 128 | - | - | - |
| **sPLA2** | 0.62, (0.42-0.82), 32 | 0.53, (0.37-0.69), 88 | 0.56, (0.44-0.69), 129 | - | - | - |
| **NGAL** | 0.7, (0.48-0.92), 25 | 0.55, (0.35-0.75), 65 | 0.56, (0.41-0.7), 95 | - | - | - |
| **LBP** | 0.37, (0.14-0.6), 25 | 0.47, (0.29-0.66), 65 | 0.59, (0.46-0.73), 95 | - | - | - |
| **C2** | 0.64, (0.43-0.85), 32 | 0.59, (0.42-0.76), 88 | 0.47, (0.33-0.6), 129 | - | - | - |
| **AGP** | 0.68, (0.49-0.87), 32 | 0.47, (0.31-0.63), 88 | 0.52, (0.39-0.64), 129 | - | - | - |
| **HBP** | 0.8, (0.34-1), 7 | 0.62, (0.29-0.95), 23 | 0.62, (0.29-0.95), 24 | - | - | - |
| **HP** | 0.52, (0.31-0.73), 32 | 0.51, (0.35-0.67), 86 | 0.53, (0.41-0.64), 127 | - | - | - |

*Green (AUROC ≥ 0.7), yellow (AUROC ≥ 0.65 and <7), orange (AUROC 0.6-0.65) red (AUROC <0.6)*

**Supplementary Table 16: Multivariate analysis – non-malaria population; haematological biomarkers**

| Haematological biomarkers | | | | | | |
|---|---|---|---|---|---|---|
| **Overall** | | | | | | |
| **Multivariate models' variables** | | | **Classification group** | **Best multivariate model/models: mean (SD) AUROC** | **Best host-biomarker: mean (SD) AUROC** | **Multivariate AUROC gain/loss (%)** |
| **Rulefit** | **Logistic - RFA** | **Logistic - SW** | | | | |
| country , neutrophil count WBC count, lymphocyte count, fever duration, temperature, pulse rate, respiratory rate | country neutrophil count, fever duration | country neutrophil count fever duration respiratory rate | L | RF/SW/RFA: 0.75 (0.03) | WBC count : 0.7 (0.03) | +7% |
| | | | S | SW: 0.83 (0.04) | WBC count: 0.78 (0.03) | +6% |
| | | | E | SW/RFA: 0.83 (0.02) | WBC count: 0.77 (0.03) | +8% |
| **Gabon*** | | | | | | |
| Gabon performance evaluation using the Overall model and Gabon data extracted from the Overall test sets | | | L | SW:0.7 (0.12) | WBC count : 0.7 (0.03) | |
| | | | S | SW: 0.77 (0.12) | WBC count: 0.73 (0.03) | +5% |
| | | | E | RFA: 0.77 (0.08) | WBC count: 0.75 (0.03) | +3% |
| **Malawi** | | | | | | |
| diastolic blood pressure, HAEMATO_C lymphocyte count, neutrophil count, pulse rate, temperature, fever duration | fever duration neutrophil count | fever duration neutrophil count | L | RFA: 0.74(.05) | neutrophil count: 0.72(.06) | +3% |
| | | | S | SW: 0.73(.06) | neutrophil count: 0.72(.07) | +1% |
| | | | E | RFA: 0.66(.16) | WBC count: 0.7 (0.05) | -6% |
| **Brazil** | | | | | | |
| diastolic blood pressure, haematocrit lymphocyte count, neutrophil count, pulse rate, temperature, fever duration, respiratory rate, WBC count | WBC count respiratory rate neutrophil count | WBC count respiratory rate | L | RFA: 0.82 (0.08) | WBC count: 0.81 (0.08) | +1% |
| | | | S | RFA: 0.82 (0.08) | WBC count: 0.81 (0.08) | +1% |
| | | | E | RFA: 0.84 (0.07) | WBC count: 0.83 (0.07) | +1% |

E, electronic classification group; S, strict classification group; L, loose classification group; RF, Rulefit; RFA, logistic recursive feature addition; SW, stepwise logistic regression. Green (gain, i.e. multivariate models have better performances than univariate models); red (loss, i.e. univariate models have better performances than multivariate models).
*Multivariate performances for Gabon were computed using the Overall population-trained model as a predictor model and tested with Gabon data due to the limited data.

**Supplementary Table 17: Multivariate analysis – non-malaria population; protein biomarkers**

| Protein biomarkers | | | | | | |
|---|---|---|---|---|---|---|
| **Overall** | | | | | | |
| **Multivariate models' variables** | | | **Classification group** | **Best multivariate model/models: mean (SD) AUROC** | **Best host-biomarker: mean (SD) AUROC** | **Multivariate AUROC gain/loss (%)** |
| **Rulefit** | **Logistic - RFA** | **Logistic - SW** | | | | |
| CRP<br>AGP<br>LBP<br>NGAL<br>pulse rate<br>respiratory rate<br>diastolic blood pressure<br>temperature<br>country | CRP<br>country<br>LBP<br>NGAL<br>pulse rate | CRP<br>country<br>NGAL<br>pulse rate<br>respiratory rate<br>temperature | L | RF/RFA/SW: 0.66 (0.05) | LBP: 0.62 (0.04) | +6% |
| | | | S | RF: 0.74 (0.04) | LBP: 0.66 (0.05) | +12% |
| | | | E | RFA: 0.76 (0.04) | LBP: 0.75 (0.04) | +1% |
| **Gabon*** | | | | | | |
| Gabon performance evaluation using the Overall model and Gabon data extracted from the Overall test sets | | | L | SW: 0.64 (0.12) | LBP: 0.62 (0.04) | +3% |
| | | | S | RFA: 0.7 (0.11) | LBP: 0.66 (0.05) | +6% |
| | | | E | RFA: 0.7 (0.09) | LBP: 0.75 (0.04) | -7% |
| **Malawi** | | | | | | |
| IP-10<br>Gal-9<br>NGAL<br>temperature<br>CRP<br>respiratory rate<br>fever duration<br>pulse rate<br>diastolic blood pressure | Gal-9<br>NGAL<br>temperature | Gal-9<br>NGAL<br>temperature<br>pulse rate<br>fever duration | L | SW: 0.7 (0.06) | Lipocalin. 2: 0.65 (0.06) | +8% |
| | | | S | RF/ SW: 0.67 (0.06) | Lipocalin. 2: 0.64 (0.06) | +5% |
| | | | E | RF: 0.71 (0.12) | IP-10: 0.69 (0.08) | +3% |
| **Brazil** | | | | | | |
| CRP, Gal-9, AGP<br>pulse rate, diastolic blood pressure<br>respiratory rate, temperature | Gal-9, TRAIL, NGAL | Gal-9, pulse rate, fever duration, NGAL, temperature | L | RF: 0.67 (0.04) | CRP: 0.65 (0.06) | +3% |
| | | | S | SW/RFA: 0.66(.04) | CRP: 0.65 (0.05) | +1% |
| | | | E | SW/RFA: 0.65(.05) | CRP: 0.63 (0.08) | +3% |

E, electronic classification group; S, strict classification group; L, loose classification group; RF, Rulefit; RFA, logistic recursive feature addition; SW, stepwise logistic regression. Green (gain, i.e. multivariate models have better performances than univariate models); red (loss, i.e. univariate models have better performances than multivariate models).

* Multivariate performances for Gabon were computed using the Overall population-trained model as a predictor model and tested with Gabon data.

**Supplementary Table 18: Multivariate analysis – non-malaria population; haematological and protein biomarkers**

| Haematology + protein biomarkers | | | | |
|---|---|---|---|---|
| **Overall** | | | | |
| **Multivariate models' variables** | | | | |

| Rulefit | Logistic - RFA | Logistic - SW | Classification group | Best multivariate model/models: mean (SD) AUROC | Best host-biomarker: mean (SD) AUROC | Multivariate AUROC gain/loss (%) ** multivariate and single host-biomarkers ratio |
|---|---|---|---|---|---|---|
| AGP<br>LBP<br>NGAL<br>neutrophil count<br>WBC count<br>Country<br>temperature<br>fever duration<br>pulse rate<br>respiratory rate | Country<br>neutrophil<br>count<br>fever<br>duration<br>LBP | Country<br>neutrophil<br>count<br>fever duration<br>respiratory rate | L | SW/RFA/RF:0.75(.03) | WBC count: 0.7 (.03) | +7% |
| | | | S | SW:0.83(.04) | WBC count: 0.78(.03) | +6% |
| | | | E | SW/RFA:0.83 (.03) | WBC count: 0.77 (0.04) | +8% |
| **Brazil** | | | | | | |
| Gal-9, neutrophil count, WBC count, CRP, sPLA, respiratory rate, temperature, diastolic blood pressure, fever duration, pulse rate | neutrophil count, WBC count, respiratory rate, Gal-9 | WBC count, Gal-9 respiratory rate | L | SW: 0.82 (0.06) | WBC count: 0.8 (0.06) | +2.5% |
| | | | S | RFA: 0.82 (0.06) | WBC count: 0.8 (0.06) | +2.5% |
| | | | E | SW: 0.85 (0.06) | WBC count: 0.83 (0.07) | +2% |
| **Gabon*** | | | | | | |
| Gabon performance evaluation using the overall model and Gabon data extracted from the Overall test sets | | | L | SW/RFA: 0.7 (0.12) | WBC count: 0.7 (.03) | - |
| | | | S | SW/RFA: 0.76 (0.12) | WBC count: 0.78(.03) | -3% |
| | | | E | RFA: 0.77 (0.07) | WBC count: 0.77 (0.04) | - |
| **Malawi** | | | | | | |
| IP-10<br>Gal-9<br>LBP<br>neutrophil count<br>WBC count<br>NGAL<br>pulse rate<br>respiratory rate<br>temperature<br>diastolic blood pressure<br>fever duration | neutrophil count, WBC count<br>fever duration, IP-10 | neutrophil count<br>WBC count, fever duration, IP-10, temperature | L | SW/RFA: 0.74 (0.06) | neutrophil count: 0.72 (0.03) | +3% |
| | | | S | SW: 0.73 (0.06) | neutrophil count: 0.72 (0.07) | +1% |
| | | | E | RFA: 0.72 (0.6) | WBC count: 0.7 (0.) | +2% |

E, electronic classification group; S, strict classification group; L, loose classification group; RF, Rulefit; RFA, logistic recursive feature addition; SW, stepwise logistic regression. Green (gain, i.e. multivariate models have better performances than univariate models); red (loss, i.e. univariate models have better performances than multivariate models).

* Multivariate performances for Gabon were computed using the Overall population-trained model as a predictor model and tested with Gabon data.

**Supplementary Table 19: Multivariate analysis – malaria population; haematological biomarkers**

| Haematological biomarkers |
|---|

| Overall | | | | | | |
|---|---|---|---|---|---|---|
| **Multivariate models' variables** | | | **Classification group** | **Best multivariate model/models: mean (SD) AUROC** | **Best host-biomarker: mean (SD) AUROC** | **Multivariate AUROC gain/loss (%)** |
| **Rulefit** | **Logistic - RFA** | **Logistic - SW** | | | | |
| haematocrit<br>lymphocyte count<br>neutrophil count<br>diastolic blood pressure<br>fever duration<br>pulse rate<br>respiratory rate<br>country<br>temperature | neutrophil count<br>WBC count<br>country | lymphocyte count<br>neutrophil count<br>country | L | RFA: 0.68 (0.04) | neutrophil count: 0.65 (0.05) | +5% |
| | | | S | SW: 0.66 (0.05) | neutrophil count: 0.6 (0.08) | +10% |
| | | | E | RF: 0.69 (0.07) | neutrophil count: 0.61 (0.08) | +13% |
| **Gabon*** | | | | | | |
| Gabon performance evaluation using the Overall model and Gabon data extracted from the Overall test sets | | | L | SW: 0.67 (0.18) | neutrophil count: 0.65 (0.05) | +3% |
| | | | S | SW: 0.75 (0.2) | neutrophil count: 0.6 (0.08) | +25% |
| | | | E | Not sufficient data | | |
| **Malawi** | | | | | | |
| diastolic blood pressure<br>lymphocyte count<br>neutrophil count<br>temperature<br>WBC count<br>haematocrit<br>pulse rate<br>respiratory rate<br>fever duration | neutrophil count,<br>WBC count,<br>temperature | WBC count, | L | RFA: 0.7 (0.06) | WBC count: 0.69 (0.05) | +1% |
| | | | **S** | SW: 0.69 (0.07) | WBC count: 0.69 (0.07) | - |
| | | | **E** | RFA: 0.6 (0.14) | lymphocyte count: 0.67 (0.05) | -10% |

E, electronic classification group; S, strict classification group; L, loose classification group; RF, Rulefit; RFA, logistic recursive feature addition; SW, stepwise logistic regression. Green (gain, i.e. multivariate models have better performances than univariate models); red (loss, i.e. univariate models have better performances than multivariate models).

* Multivariate performances for Gabon were computed using the Overall population-trained model as a predictor model and tested with Gabon data.

**Supplementary Table 20: Multivariate analysis – malaria population; protein biomarkers**

| Protein biomarkers | | | | | | |
|---|---|---|---|---|---|---|
| **Overall** | | | | | | |
| **Multivariate models' variables** | | | **Classification group** | **Best multivariate model/models: mean (SD) AUROC** | **Best host-biomarker: mean (SD) AUROC** | **Multivariate AUROC gain/loss (%)** |
| **Rulefit** | **Logistic - RFA** | **Logistic - SW** | | | | |
| AGP<br>diastolic blood pressure<br>Gal-9 | C2 | country<br>respiratory rate<br>temperature<br>AGP | L | SW: 0.62 (0.07) | CHI3L1: 0.57 (0.03) | + 9% |
| | | | S | SW: 0.64 (0.04) | _NGAL: 0.6 (0.06) | + 7% |

| | | | | | | |
|---|---|---|---|---|---|---|
| C2<br>LBP<br>pulse rate<br>respiratory rate<br>temperature<br>fever duration | | | E | SW: 0.67 (0.08) | C2: 0.63 (01) | + 6% |
| **Gabon*** | | | | | | |
| Gabon performance evaluation using the Overall model and Gabon data extracted from the Overall test sets | | | L | SW: 0.67 (0.17) | CHI3L1: 0.57 (0.03) | + 18% |
| | | | S | RFA: 0.81 (0.12) | NGAL: 0.6 (0.06) | +35%[$] |
| | | | E | Not sufficient data | | |
| **Malawi** | | | | | | |
| diastolic blood pressure<br>CHI3L1<br>IP-10<br>fever duration<br>Gal-9<br>C2<br>pulse rate<br>respiratory rate<br>temperature | respirator y rate, sPLA | respiratory rate, sPLA | L | RFA/SW: 0.57 (0.06) | IP-10: 0.57 (0.05) | - |
| | | | S | SW/RFA: 0.62 (0.09) | HCC2_PL: 0.62 (0.06) | - |
| | | | E | SW/RFA: 0.61 (0.06) | IP-10: 0.66 (0.09) | -7% |

E, electronic classification group; S, strict classification group; L, loose classification group; RF, Rulefit; RFA, logistic recursive feature addition; SW, stepwise logistic regression. Green (gain, i.e. multivariate models have better performances than univariate models); red (loss, i.e. univariate models have better performances than multivariate models).

*Multivariate performances for Gabon are computed using the Overall population-trained model as a predictor model and tested with Gabon data. [$]This output has to be considered an outlier due to biomarker data imbalance between pipeline data and the available Gabon data set.

**Supplementary Table 21: Multivariate analysis – malaria population; haematological and protein biomarkers**

| **Protein + haematological biomarkers** | | | | | | |
|---|---|---|---|---|---|---|
| **Overall** | | | | | | |
| **Multivariate models' variables** | | | **Classification group** | **Best multivariate model/models: mean (SD) AUROC** | **Best host-biomarker: mean (SD) AUROC** | **Multivariate AUROC gain/loss (%)** |
| **Rulefit** | **Logistic - RFA** | **Logistic - SW** | | | | |
| AGP_Pl<br>diastolic blood pressure<br>Gal-9<br>C2<br>LBP.<br>NGAL<br>neutrophil count<br>respiratory rate<br>temperature<br>pulse rate<br>fever duration | country<br>WBC count | country, Wbc_c, | L | SW/RFA: 0.68 (0.04) | neutrophil count: 0.65 (0.05) | +5% |
| | | | **S** | RFA/SW: 0.66 (0.05) | neutrophil count: 0.6 (0.08) | +10% |
| | | | **E** | RFA/SW: 0.66 (0.11) | HCC2_PL: 0.63 (0.1) | +5% |
| **Gabon*** | | | | | | |
| Gabon performance evaluation using the Overall model and Gabon data extracted from the Overall test sets | | | **L** | **RFA/SW: 0.66 (0.18)** | neutrophil count: 0.65 (0.05) | +1% |
| | | | **S** | RFA/SW: 0.7 (0.2) | neutrophil count: 0.6 (0.08) | +17% |
| | | | E | Not sufficient data | | |
| **Malawi** | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| CHI3L1<br>IP-10<br>Gal-9<br>C2<br>neutrophil count<br>respiratory rate<br>temperature<br>diastolic blood pressure<br>pulse rate<br>fever duration | C2<br>neutrophil count<br>WBC count | WBC count | **L** | **SW: 0.69 (0.05)** | **WBC count: 0.69 (0.05)** | - |
| | | | **S** | RFA: 0.73 (0.07) | WBC count: 0.69 (0.07) | +6% |
| | | | **E** | RFA: 0.72. (0.1) | lymphocyte count: 0.67 (0.05) | +7% |

E, electronic classification group; S, strict classification group; L, loose classification group; RF, Rulefit; RFA, logistic recursive feature addition; SW, stepwise logistic regression. Green (gain, i.e. multivariate models have better performances than univariate models); red (loss, i.e. univariate models have better performances than multivariate models).

*Multivariate performances for Gabon are computed using the Overall population-trained model as a predictor model and tested with Gabon data.

# Supplementary Material References

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