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Measurement of Circulating Filarial Antigen Levels in Human Blood with a Point-of-Care Test Strip and a Portable Spectrodensitometer

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Abstract. The Alere Filariasis Test Strip (FTS) is a qualitative, point-of-care diagnostic tool that detects *Wuchereria bancrofti* circulating filarial antigen (CFA) in human blood, serum, or plasma. The Global Program to Eliminate Lymphatic Filariasis employs the FTS for mapping filariasis-endemic areas and assessing the success of elimination efforts. The objective of this study was to explore the relationship between the intensity of positive test lines obtained by FTS with CFA levels as determined by enzyme-linked immunosorbent assay (ELISA) with blood and plasma samples from 188 individuals who live in a filariasis-endemic area. The intensity of the FTS test line was assessed visually to provide a semiquantitative score (visual Filariasis Test Strip [vFTS]), and line intensity was measured with a portable spectrodensitometer (quantitative Filariasis Test Strip [qFTS]). These results were compared with antigen levels measured by ELISA in plasma from the same subjects. qFTS measurements were highly correlated with vFTS scores (ρ = 0.94; P < 0.001) and with plasma CFA levels (ρ = 0.91; P < 0.001). Thus, qFTS assessment is a convenient method for quantifying *W. bancrofti* CFA levels in human blood, which are correlated with adult worm burdens. This tool may be useful for assessing the impact of treatment on adult filarial worms in individuals and communities.

INTRODUCTION

Lymphatic filariasis (LF) is a parasitic disease that is a significant cause of disability in the developing world. About 90% of the estimated 120 million cases of LF in the world are caused by the filarial parasite *Wuchereria bancrofti*. The Global Program to Eliminate Lymphatic Filariasis (GPELF; coordinated by the World Health Organization [WHO]) aims to eliminate LF by 2020 using repeated rounds of mass drug administration (MDA). Diagnostic testing is important for each phase of this program including mapping, assessing the impact of MDA, transmission assessment surveys, and post-MDA surveillance.²–⁴

At present, three laboratory methods are used for diagnosing active infections with *W. bancrofti*, namely demonstration of microfilariae (mf) in night blood specimens, detection of circulating filarial antigens (CFA) released in the blood by adult worms, and detection of filarial DNA in human blood by polymerase chain reaction (PCR). Antigen testing is most widely used at this time, because it is more sensitive and convenient for detecting infection than mf testing or PCR.²,⁵

Two types of antigen tests are currently available: enzyme-linked immunosorbent assay (ELISA) tests performed in the laboratory, and point-of-care (POC) rapid tests. ELISA tests are based on monoclonal antibodies AD12.1 or Og4C3. They provide quantitative results⁶,⁷ but are not practical for routine use in LF elimination programs. The rapid tests include the BinaxNOW® Filariasis card test (Alere, Scarborough, ME) (immunochromatography card test [ICT]), which has been used in GPELF since 2000, and the Filariasis Test Strip (FTS), introduced in 2013 by Alere, the successor company to Binax.⁸

The WHO and the manufacturer recommend qualitative reading of ICTs and FTS as either positive or negative so that the result of surveys is generally expressed as prevalence of antigenemia. In practice, the test line shows a wide range of intensity, from clear to dense.

On the basis of the relative intensities of the test (T) and control (C) lines, ICT scores have been informally used for many years, assuming a relationship between this score and the level of CFA and, possibly, with the burden of adult worms."³⁰

Although visual scoring of rapid format filarial antigen tests is useful, more accurate quantitation would represent a step forward. Rapid quantitation of antigen levels could be used to assess the effect of treatment on adult worms in individuals and the impact of MDA on adult worm loads in communities without the need for ELISA. Therefore, the purpose of this study was to explore the use of a portable spectrodensitometer together with the FTS for measuring CFA levels in human blood to test whether the intensity of T-lines in positive FTS is correlated with the level of CFA.

MATERIALS AND METHODS

Study area and subjects. This research was performed as part of a community study in the Democratic Republic of the Congo (DRC) of the impact of semiannual mass treatment with albendazole on bancroftian filariasis. The trial was conducted in two villages (Mbumbiki and Misyay) that are situated on the right bank of the Kwilu River in the Bagata Health Zone (Bandundu Province). Filarial antigen rates assessed by FTS in June 2014, before any treatment, were 32.5% in Mbumbiki and 31.6% in Misyay.

We tested 188 blood samples in this study. These included 110 samples (95 with positive FTS results and 15 negative samples) collected in July 2014 before any treatment in the study communities and 78 samples (69 positives and nine negatives) during a follow-up survey in July 2015 after two rounds of MDA with albendazole, which has partial...
Background values from the white target were subtracted from these values to obtain $\Delta \text{Red}_{C\text{-line}}$ and $\Delta \text{Red}_{T\text{-line}}$. The quantitative Filariasi Test Strip (qFTS) ratio was defined as $\Delta \text{Red}_{T\text{-line}}/\Delta \text{Red}_{C\text{-line}}$. Thus, a qFTS ratio close to 0 should be theoretically analogous to a vFTS score of 0, a qFTS ratio between 0 and 1 to a vFTS score of 1, a qFTS ratio of approximately 1 to a vFTS score of 2, and a qFTS ratio > 1 to a vFTS score of 3.

Measurement of circulating filarial antigens by ELISA. Finger prick blood was collected into heparinized capillary tubes and stored in a cooler. Tubes were centrifuged, and plasma was separated and stored at $-20^\circ$C. The Tropbio Og4C3 ELISA kit (Cellabs, New South Wales, Australia) was used to measure CFA levels according to the manufacturer’s instructions. Samples were tested in duplicate. Kit control standards (S1–S7) and a conjugate control were also tested in duplicate on each plate. According to the manufacturer’s instructions, the standard control sample 1 (S1) should contain less than 10 antigen units (AU); samples with optical density (OD) values lower than the OD produced by S2 (with 32 AU) were considered to be negative. Samples with OD values between those obtained by S2 and S3 (with 128 AU) were considered to be equivocal. Samples with OD values greater or equal to the OD obtained with S3 were considered to be positive for CFA. ELISA assays were performed blindly without reference to the vFTS or qFTS results. The laboratory testing was performed in the Department of Parasitology at the National Institute of Biomedical Research in Kinshasa.

Statistical analysis. All reported means are arithmetic means unless otherwise specified. Differences in mean qFTS ratios and mean ELISA OD values in the different vFTS score groups were analyzed using Cuzick’s trend test. We used Spearman’s rank correlation coefficient to assess the associations between qFTS, vFTS, and ELISA OD values. Receiver operating characteristic (ROC) analysis was used to select cutoff values for ELISA and qFTS data. We first determined the optimal cutoff for the qFTS ratio using vFTS positivity as the reference standard. Subsequently, we did the same using Og4C3 ELISA results as the reference standard. Finally, kappa scores were calculated to indicate the degree of agreement between different antigen test methods. All statistical analyses were performed using STATA 14.0 (StataCorp, College Station, TX), and GraphPad Prism version 6.0e (GraphPad Software, Inc., La Jolla, CA).

RESULTS

Description of qFTS results. The study was performed with blood samples from 188 subjects that included 164 (87.2%) with positive vFTS results. Of study participants, 24 had a vFTS score of 0 (12.8%), 52 had a score of 1 (27.7%), 38 had a score of 2 (20.2%), and 74 had a score of 3 (39.4%).

Description of qFTS results. Spectrodensitometry data for C- and T-lines and T/C ratios are shown in Figure 1. A slight but significant decrease in C-line intensity was observed with increasing vFTS scores (11.6% decrease in mean C-line intensity for tests with vFTS scores of 3 relatively to the mean for tests with vFTS scores of 0, $P < 0.001$ by Cuzick’s trend test). Mean T-line intensities increased from 0.64 (±0.14) for vFTS negative individuals to 1.89 (±0.13), 3.51 (±0.28), and 5.34 (±0.19) for test strips with vFTS scores of 1, 2, and 3, respectively ($P < 0.001$ by Cuzick’s trend test). The mean qFTS ratio was 0.16 (±0.03) for samples that were negative by
vFTS; qFTS ratios were 0.50 (±0.03), 0.98 (±0.03), and 1.77 (±0.05) for samples with vFTS scores of 1, 2, or 3, respectively (P < 0.001 by Cuzick’s trend test). Although C-line intensities were slightly decreased in samples with vFTS scores of 3, we decided that qFTS ratios were better than T-line densities for presenting qFTS results, since the ratios tend to correct for variable volumes of plasma due to variable hematocrits between people present in whole blood samples added to sample application pads. There were highly significant correlations between qFTS ratios and vFTS scores when all samples were considered (Spearman’s rank correlation coefficient 0.94; P < 0.001) and when samples collected before and after MDA were considered separately (ρ = 0.93 and 0.94, respectively; both P < 0.001) (Table 1).

Filarial antigenemia ELISA results. Kit standards produced valid results on all five plates tested with OD values < 0.20 for the negative control standard S1 and OD values > 2.0 for the strong positive control standard S7. Plasma samples from individuals with vFTS scores of 0, 1, 2, or 3 had mean OD (± standard deviation) values 0.18 (±0.04), 0.61 (±0.04), 1.32 (±0.05), and 2.12 (±0.05), respectively (P < 0.001 by Cuzick’s trend test) (Figure 2).

Agreement between results of vFTS, qFTS, and ELISA. Spearman’s rank correlation coefficients between Og4C3 ELISA OD values and vFTS scores were 0.91, 0.92, and 0.90 (all P < 0.001) in the whole, pre-, and post-MDA populations, respectively (Table 1). Spearman’s rank correlation coefficient for relationship between ELISA OD and qFTS scores was strong for the whole sample (ρ = 0.91; P < 0.001) (Figure 3), and in pre- and posttreatment samples (ρ = 0.90 [P < 0.001] and 0.90 [P < 0.001] respectively) (Table 1). This suggests that qFTS is as useful as ELISA for estimating CFA levels and that albendazole treatment does not influence the correlation.

Sensitivity analysis. Selection of positive cutoff values for qFTS using vFTS results as a reference standard. An ROC analysis compared qFTS ratios to qualitative vFTS results.
The results of a ROC analysis to determine the cutoff for the qFTS ratios using vFTS results as the reference standard

<table>
<thead>
<tr>
<th>qFTS</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Correctly classified</th>
<th>PPV</th>
<th>NPV</th>
<th>PLR</th>
<th>NLR</th>
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<td>0.43</td>
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<td>90.1</td>
<td>98.8</td>
<td>56.1</td>
<td>11.2</td>
<td>0.11</td>
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NLR = negative likelihood ratio; NPV = negative predictive value; PPV = positive predictive value; ROC = receiver operating characteristic; vFTS = visual Filariasis Test Strip; qFTS = quantitative Filariasis Test Strip ratios.

Selection of a positive cutoff value for qFTS using Og4C3 ELISA results as reference standard. Samples were sorted into different groups according to their respective OD values. The negative group contained individuals with an Og4C3 ELISA OD below the OD of the kit standard 2 (32 AU). A second group contained individuals with Og4C3 results between OD values obtained with the kit standards 2 and 3 (128 AU) that are equivocal according to the kit guidelines. A third, positive group contained individuals with ELISA ODs higher than that obtained with the kit standard 3 (128 AU). OD values are obtained with standards S2 and S3, respectively. ELISA = enzyme-linked immunosorbent assay; OD = optical density; qFTS = quantitative Filariasis Test Strip.

Comparison of vFTS scores and Og4C3 ELISA results using different cutoff values determined by ROC analysis when only the negative group was considered negative (cutoff = 0.37) or when both the negative and equivocal groups were considered to be negative for CFA (cutoff = 0.61). Solid horizontal lines represent geometric means and 95% confidence intervals. ELISA = enzyme-linked immunosorbent assay; OD = optical density; qFTS = quantitative Filariasis Test Strip.

<table>
<thead>
<tr>
<th>Table 3</th>
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<tr>
<td>Comparison of vFTS scores and Og4C3 ELISA results using different ELISA cutoff criteria</td>
</tr>
<tr>
<td>S2 as cutoff</td>
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<tr>
<td>Negative</td>
</tr>
<tr>
<td>vFTS scores</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
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<tr>
<td>3</td>
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vFTS = visual Filariasis Test Strip; ELISA = enzyme-linked immunosorbent assay. The optical density values are obtained with standards S2 and S3, respectively.
FTS for this purpose. These guidelines assume qualitative antigen testing (positive or negative), and they do not mention use of these tests for quantifying CFA. We have recently demonstrated the value of semiquantitative reading of ICTs, and this study goes one step further by using spectrodensitometry to measure the relative concentration of CFA in blood samples. This method allows the user to quantify antigen levels in the field, and it avoids the cost and laboratory infrastructure required for antigen testing by ELISA. It is very interesting that qFTS ratios were strongly correlated with vFTS scores and with OD values obtained with the Og4C3 ELISA. Since CFA levels are believed to be correlated with adult *W. bancrofti* worm numbers, qFTS ratios should be very useful for assessing the impact of treatment on adult filarial worms in individuals. Because of its low cost and simplicity, qFTS holds great promise as a practical, field-friendly tool for GPELF to measure adult worm burdens at the community level before and after MDA, much as community microfilarial load is sometimes used to monitor the impact of MDA on the community parasite reservoir in LF and onchocerciasis.

Although qFTS provides a more accurate and objective reading than vFTS, qFTS was slightly less sensitive than vFTS for reading weak positive antigen tests.

A comparison of qFTS and vFTS results with Og4C3 ELISA results suggests that both the qFTS and vFTS are more sensitive than the ELISA when the S3 antigen standard is used as the cutoff for definite positivity as recommended by the manufacturer. Our results suggest that a significant proportion of samples that produce OD values in the Og4C3 ELISA between those produced by the S2 and S3 kit standards are true positives. Low ELISA OD values for some samples that were positive by vFTS also indicate a lower sensitivity of the ELISA. Hence, filarial infection rates based on CFA in the blood measured by Og4C3 ELISA will tend to be underestimated.

Some inconsistencies were detected between results obtained by qFTS and vFTS; specifically, there was some overlap between qFTS ratios of samples with vFTS scores of 0 and 1. Although this could indicate that some vFTS readings were falsely positive, we think it is more likely that this overlap is due to imperfect or inconsistent performance of the spectrodensitometer when T-lines are very light. With the methods used in this study, vFTS seems better than qFTS for classifying samples as positive or negative when antigen levels are very low. It should be noted that the spectrodensitometer used in this study was designed for use in the printing industry and not optimized for reading FTS. Our homemade template for positioning FTS strips may have introduced minor reading errors. However, our study has provided an interesting proof of principle for quantitative reading of filariasis POC tests. A purpose-built instrument might produce better results. Such instruments already exist but they are very expensive. However, a recent review describes cellphone applications that have been used to read POC tests for several analytes and markers of infectious diseases such as malaria and human immunodeficiency virus, and we look forward to further development of this approach.

We noticed a slight decrease in C-line density (by about 12%) for samples with vFTS scores of 3. This is a minor limitation, because it will tend to increase qFTS ratios for strongly positive samples. The sample application pad in the FTS contains an excess amount of labeled antibody to CFA, and the intensity of C-lines was the same for samples with vFTS scores of 0, 1, or 2. However, samples with high levels of CFA resulted in strong T-lines (vFTS score of 3) with less labeled antibody available to produce the C-line. This did not significantly affect the main findings of our study. To check on this, we have recalculated the correlation between qFTS ratios and Og4C3 levels after increasing C-line intensities by 12% for samples with FTS scores of 3. The correlation was barely affected by this adjustment ($\rho = 0.90; P < 0.001$). To our knowledge, reduced intensity of C-lines with strongly positive samples has not previously been described for the FTS or for other rapid diagnostic tests with a similar design. Researchers interested in quantitating lateral flow test results should note this issue.

In conclusion, this study has clearly shown that qFTS ratios closely correspond to CFA levels as measured by ELISA. Although further optimization is certainly possible, the spectrodensitometry method used in this study provides an important proof of principle. Spectrodensitometric reading of FTS provides a field-friendly method for rapidly measuring CFA levels that are related to adult filarial worm counts, which is much more convenient and less expensive than previously described methods. Additional work is needed to confirm and extend these preliminary observations for filariasis and to further explore the use of spectrodensitometry for measurement of other analytes detected by POC tests. While POC tests are already widely used in wealthy countries, they are increasingly being used in resource-limited settings where physicians and public health workers do not have ready access to high-quality clinical laboratories.
REFERENCES


