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# Sensitivities and specificities of diagnostic tests and infection prevalence of *Schistosoma haematobium* estimated from data on adults in villages northwest of Accra in Ghana

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## Abstract

Substantial uncertainties surround the sensitivities and specificities of diagnostic techniques for urinary schistosomiasis. We used Latent Class (LC) modeling to address this problem. In this study 220 adults in three villages northwest of Accra in Ghana were examined using five *Schistosoma haematobium* diagnostic measures: microscopic examination of urine for detection of *S. haematobium* eggs, dipsticks for detection of haematuria, tests for circulating antigens, serological antibody tests and ultrasound scans of the urinary system. Testing of the LC model indicated non-invariance of the performance of the diagnostic tests across different age groups while measurement invariance held for males and females and for the three villages. We therefore recommend the use of LC models for comparison between, and the identification of, the most accurate schistosomiasis diagnostic tests. Furthermore, microscopy and haematuria dipsticks were indicated through these models as the most appropriate techniques for detection of *S. haematobium* infection.

## INTRODUCTION

In spite of the prolific generation of new knowledge in the area of urinary schistosomiasis, such as that of global burden, treatment and associated morbidity [1–4], there remains the unsolved practical issue associated with the basic diagnosis of this important parasitic disease. This relates to both the direct (i.e. microscopical examination of filters of urine for detection of *S. haematobium* eggs) as well as with the indirect (i.e. detection of haematuria, detection of

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schistosome-specific antibodies, detection of circulating egg antigens and ultrasound scans of the urinary system) diagnostic methods of this schistosome infection. There are several reasons for the limitations in the diagnosis of urinary schistosomiasis infections, such as, for example daily variation in egg excretion levels and/or duration of infection influencing the potential accuracy of determining the correct current infection status.[5] Haematuria (blood in urine) alone has been proposed as a valid indication of current infection in *S. haematobium* endemic populations.[6] Microhaematuria can be detected by reagent strips (dipsticks) which recognize blood and protein. However, for the distinction of an active from a previous infection, particularly after treatment, in many populations and individuals, the circulating schistosome antigen has been proposed as the most reliable test.[7,8] In addition, although the serological diagnosis of schistosomiasis is generally accurate[9], it can also produce false negatives, particularly in patients with longstanding infections while elevated antibody levels can be still detectable many years after treatment.[10] Ultrasound is currently the diagnostic tool of choice for detecting pathological conditions associated with urinary schistosomiasis, such as dilatation of the renal pelvis and bladder wall lesions, although its usefulness has been questioned, particularly in low transmission areas, because of its lack of specificity.[11] In addition, large variations of sensitivity and specificity estimates have been observed among different endemic zones, age groups and sexes for all the aforementioned diagnostic methods of urinary schistosomiasis in several studies. [12–16]

One explanation for the inconsistencies between all these diagnostic tests relates to the current lack of a definitive ‘gold standard’ reference test for urinary schistosomiasis. Consequently, the diagnosis of schistosomiasis as well as the control of this disease becomes problematic. Diagnostic assays with low sensitivities are unsuitable for evaluation of schistosomiasis control programmes, such as those aimed at morbidity reduction through mass human chemotherapy. [17] Indeed, methods that allow infections to be correctly diagnosed are a prerequisite for effective disease control.[18] One solution may therefore relate to the need for more sophisticated statistical models to be developed and utilized in order to obtain more reliable empirical estimates of sensitivities and specificities of diagnostic tests.[19, 20]

In the present study we assessed the performance of five diagnostic tests for *S. haematobium* infection and estimated the prevalence of this infection in different age and sex groups in three villages of northwest of Accra in Ghana. Specifically we used five different diagnostic tests for the prevalence of urinary schistosomiasis infection: that of the urine antigen detection test, performed on membranes or in ELISA plates, the serology anti-IgG test, an ultrasound assessment by recording the shape and state of the urinary bladder, the dipstick for haematuria using urine reagent strips on all urine specimens for presence of detectable blood, and finally detection of *S. haematobium* eggs by microscopy. Through the application of a latent class model to all of these five tests, the sensitivity and specificity of each test can be determined, and the overall urinary schistosomiasis prevalence levels within the different population groups estimated.

## MATERIALS AND METHODS

### Study sites and subjects

Three Ghanaian villages northwest of Accra, Ayiki Doblo, Chento and Ntoaso were visited and consenting adults over 19 years of age formed a convenience sample of passers by. However, in general, as regards to the demography in Greater Accra’s region, the age structure is still a youthful one, characterized by a somewhat high fertility which has begun to show signs of a steep downward trend.[21] The general public in the three aforementioned villages are familiar with the work of the Noguchi Memorial Institute for Medical Research and its personnel. Through discussions with local authorities the public was alerted, and people were approached and asked to participate. These volunteers were then interviewed and requested to

provide specimens of urine, stool and blood for examination. Praziquantel (at 40mg per kg) was offered and taken following diagnosis of all infected cases of schistosomiasis. At subsequent visits, bladder ultrasound scans were performed on the majority of participants. All examinations were performed at the village clinics. Participants responded to a questionnaire, the majority of which were reported to be peasant farmers and persons involved in agriculture. Others responded as traders or vendors, but most reported regular water contact in the nearby river system. Although there was municipal water available in the village of Ntoaso, many residents do not have access to clean running water, and through their daily activities were thereby potentially exposed to risks of schistosome transmission. A total of 220 individuals consented to participate, had complete data on the variables examined here and were included in the analysis of the present study. The age and sex structure as well as the village location of all the sampled individuals is given in Table 1, which illustrates a lower proportion of individuals who consented to participate and had complete data were below 39 years old and from villages Ayiki Doblo and Chento.

### Urine-antigen detection test

Detection of schistosome antigen in urine was performed after the method of Bosompem and colleagues[22] which has shown that *S. haematobium* antigen complexed with complement C3 can be isolated from the urine of infected people using a mouse monoclonal antibody. The authors demonstrated that goat-antihuman C3 would also detect schistosome antigen/complement complex in the urine of infected people, but not in non-infected people as case controls, and subsequently developed a monoclonal antibody dipstick test based on these findings.[23] Briefly, methanol treated polyvinylidene difluoride (PVDF) membrane strips were incubated in test urine for 30min at room temperature (21–25°C), rinsed with Tris-buffered saline (TBS) (50mM Tris and 200 mM NaCl, pH7.4) and then blocked for 15 min in 5% skimmed milk in TBS. The strips were then incubated in a reagent mixture of *S. haematobium* species-specific MoAb (1:100) and goat anti-mouse-immunoglobulins conjugated to horseradish peroxidase (1:10) in 0.1% skimmed milk in TBS for 1 h. The strips were washed three times each by 10 min incubation in TBS and then incubated in substrate solution 0.05% (w/v) (3,3-diaminobenzidine), 0.15% (v/v) H2O2 and 5 mM Co (NO3)2.6H2O in TBS for 1 min. A bluish-black reaction represented positive results while negative results remained colourless.

### Serology anti-IgG test

Detection of anti-schistosome IgG in serum was performed on serum eluted from dried blood spots on Whatman No1 filter paper. Blood spots filled a 1 cm diameter circle were taken at the time of examination, desiccated and kept dry until analysis. These were eluted in 1 ml PBS, diluted 1:100, and tested in ELISA plates (Immunolon-2) in triplicate. Analyses were repeated if there was more than 10% discrepancy. Plates were sensitized with SWAP antigen (6.44 mg/ml) prepared from *S. mansoni* adult worms provided by Biomedical Research Institute, Rockville MD. Antigen dilution was optimized against sera from known positive *S. haematobium* infections and known schistosome negative sera. Optical densities were read from a Vmax kinetic microplate reader (Molecular Devices. USA). Results were scored positive when the OD exceeded 2 × SD of the negative controls.

### Ultrasound examination

A portable ultrasound apparatus, Aloka SSD-500 portable ultrasound with 3.5 MHz curvilinear probe (Aloka, Tokyo, Japan) was used for ultrasound examination, with the diagnoses made by a medically qualified person with prior training in ultrasound examination and interpretation. Examinations were performed using a curvilinear probe and recorded photographically. Diagnosis of pathological lesions was made *in situ*, and later confirmed by

review of the ultraradiograph. For the purpose of this study, lesions were classified as positive or negative. Positive cases were registered when any two of the following situations were evident: epithelium enlarged more than 5 mm, evidence of polyps in the bladder wall, calcification of the epithelium, evidence of hydronephrosis.

## Parasitological examination

Classic parasitological methods usually used by field clinicians were employed and evaluated in this study. Microscopy was performed on the product of a single measure of filtration of 10 ml urine taken from a specimen passed between 10:00 and 14:00, the time of optimum egg passage.[24] Urine specimens were kept cool in an insulated ice box and processed in the laboratory within 4 hours of passing. The presence of any *S. haematobium* eggs was recorded as positive. Haematuria was detected by the use of standard "hemastix", with any positive reaction being designated positive for urinary schistosomiasis (Multistix, Bayer Diagnostics).

## Statistical analysis

By considering the true *S. haematobium* infection status of a sample of Ghanaian adults as a latent variable with two categories: 'infected' and 'non-infected', we validated the five diagnostic tests. In other words, we considered the observed data of the five diagnostic tests (urine antigen detection, serology anti-IgG test, ultrasound, dipstick for haematuria and microscopy) as indicators of an underlying, not directly observable variable (i.e. *S. haematobium* infection). Results of the five diagnostic tests are directly observed and are known as *manifest* variables while the *S. haematobium* infection is the unobservable latent variable.[25]

Given a sample of individuals with unknown infection status, for whom results from several diagnostic tests are available, latent class analysis can model the probability of each combination of tests results conditional on latent class (i.e. infection status). The manifest binary variables ($x_{1j}$, $x_{2j}$, $x_{3j}$, $x_{4j}$ and $x_{5j}$) were defined such that $x_{ij}=0$ represents a negative result for test i and $x_{ij}=1$ represents a positive test result for test i on individual j. We tested whether correlations between these manifest variables could be accounted for by a single latent dichotomous variable *Y* (i.e. the absence *Y*=0 or presence *Y*=1 of *S. haematobium* infection) and we defined $\eta = P(Y=1)$ the probability of being in the infected latent class. In other words, we divided the studied population into two classes (i.e. non infected and infected) assuming that the $x_{ij}$'s were mutually independent within each class (i.e. true infection status). It is expected that the $x_{ij}$'s are correlated as they are attempting to measure the presence of the same infection; the model assumes that these correlations are negligibly small only once one has accounted for an individual's true infection status (i.e. latent class membership). This assumption results in a more parsimonious model compared to one in which residual correlations are estimated, and one that is often adequate for the data. In the unlikely case that there are substantial residual correlations between the $x_{ij}$'s, additional latent classes would likely be required for an adequate fit to the data.

The likelihood function of the latent class (LC) model was

$$L(X)=\prod_{j=1}^{N}\left(\eta\prod_{i=1}^{d}\pi_{i1}^{x_{ij}}(1-\pi_{i1})^{1-x_{ij}}+(1-\eta)\prod_{i=1}^{d}\pi_{i0}^{x_{ij}}(1-\pi_{i0})^{1-x_{ij}}\right) \quad (1)$$

Such a model has two types of parameters. First, there is the unconditional probability η that a person is in the infected latent class.

The second type of parameters are the conditional probabilities $\pi_{i1}$ and $\pi_{i0}$ that an individual in a particular latent class has a specified value of each of the manifest variables.[26] In fact, $\pi_{i1}$ represents the sensitivity and is the conditional probability $P(x_i=1|y_j=1)$ while $(1-\pi_{i0})$ represents the specificity and is the conditional probability $P(x_i=0|y_j=0)$. The LC model hence produces an estimate of disease prevalence as $\eta$ is the proportion of individuals in the population of which our sample is expected to be in infection class $Y=1$. It also provides direct estimates of sensitivity and specificity for all the diagnostic tests.[27]

A natural way to extend the LC model (1) is to include stratification or grouping variables and examine group differences of measurement invariance. In this study such group differences are examined for males/females, different village locations and age groups. Likelihood ratio tests between less and more restrictive models were used to examine differences in infection prevalence and measurement invariance between groups. A significant measurement invariance tests suggests that specificities and sensitivities of the diagnostic tests vary by group and should be estimated for each group. Such an approach is referred to in the literature as multigroup latent class analysis (LCA) and comparisons of this sort are useful for at least two purposes: (a) to test whether the distribution of the latent variable is the same in each group and (b) to test whether the manifest observed variables are equally reliable indicators of the latent variable in each group.[28]

Expectation-maximization (EM) algorithm was applied to produce maximum likelihood estimates for all parameters in the model using PROC LCA in SAS Version 9.1 (SAS Institute, Cary, NC). Identifiability of maximum likelihood parameter estimates was checked by using several different seed values.

## RESULTS

Table 2 represents the observed positive results expressed as percentages of *S. haematobium* infection for the five diagnostic tests. Different diagnostic tests gave different proportions of positive results.

Table 3 presents the results of one latent class model as it was dictated by likelihood ratio tests. Specifically, this model and denoted in table as ‘LC Model 1’ is a latent class model where measurement invariance was found to hold among males and females. Because of the measurement invariance found here, we obtain a common set of specificities and sensitivities for both males and females. The best diagnostic test for the detection of the prevalence of *S. haematobium* infection among the five diagnostic tests examined here was microscopy with a specificity estimated as 97.9 % and a sensitivity estimated as 92.5 %. In addition, ‘LC Model 1’ yielded quite high specificities and sensitivities for haematuria and ultrasound. From this same model estimates of prevalence of *S. haematobium* infection by sex were also obtained. It is estimated that the prevalence of *S. haematobium* infection was highest among males (20.6 %) compared to females (9.7 %).

‘LC Model 2’ in Table 4 is a latent class analysis model where measurement invariance was found to hold among different village locations as this is again the reason why we obtain only a set of specificities and sensitivities for this group of sampled subjects. Results of this model agree with results of LC Model 1 in Table 3. The best diagnostic test for the detection of the prevalence of *S. haematobium* infection was again microscopy with specificity estimated as 94.6 % and sensitivity as 100.0 %. In addition, ‘LC Model 2’ yielded quite high specificities and sensitivities also for haematuria and ultrasound. Furthermore, ‘LC Model 2’ also indicated Chento village as the one with the highest prevalence of *S. haematobium* infection (38.9 %) among the three examined villages here.

Finally, 'LC Model 3' in Table 5 is a latent class model where measurement non-invariance was found for different age groups and this is the reason why different specificities and sensitivities are calculated for each of these groups. Using this model, diagnostic tests which could be characterized as acceptable for the detection of the prevalence of *S. haematobium* infection were those of ultrasound, haematuria and microscopy in the age groups of 19--29 and 40--49 years old; haematuria and microscopy were indicated as good diagnostic tests in the age group of 30--39 years as they both gave quite high specificities and sensitivities at the same time. Finally, in the age group of ≥60 years old the estimates of specificity and sensitivity were sufficiently high (93.2 % and 100.0 % respectively) only for haematuria, whilst for the age group of 50--59 years old, when taking into consideration both estimates of specificity and sensitivity, none of the diagnostic tests examined here was indicated as appropriate. From this same model estimates of prevalence of *S. haematobium* infection by age group were also obtained. 'LC model 3' shows that the highest prevalence of active, i.e. by egg passage *S. haematobium* infection was determined among the youngest age group of the sampled individuals of this study (29.8 %).

## DISCUSSION

Current estimates of the prevalence of schistosomiasis depend on the use of well-established, but imperfect, diagnostic tests.[29] Appropriate schistosomiasis diagnosis becomes increasingly important for several reasons. For example, clinical diagnosis might lose its value because of lack of specificity and mass treatment might only remain cost effective through the use of appropriate diagnostic tools to only target further drug treatment to those groups of people actually infected.[10] The purpose of the epidemiological survey reported here was to assess the performance of five diagnostic tests for *S. haematobium* infection and examine if the prevalence of this infection varied across different age and sex groups of sampled individuals from three villages northwest of Accra in Ghana where there has been reported previously medium *S. haematobium* prevalence.[30] We have addressed this specific problem by taking into account the absence of a gold standard diagnostic test for *S. haematobium* infection and by fitting latent class models with a frequentist approach to these data obtained from adults in northwest of Accra in Ghana. Although latent class models have been used extensively in the epidemiological literature of several infectious diseases,[31–36] they have rarely been used in parasite epidemiology and particularly in the area of schistosomiasis. More precisely, to our knowledge, only two previously published studies, both based within Côte d' Ivoire, have used latent class models through a Bayesian approach in order to assess performance of the Kato-Katz technique in diagnosing *S. mansoni* and hookworm co-infections as well as to estimate reduction of prevalence and intensity for hookworm infection in humans post-praziquantel treatment[37, 38], while only one study in the Philippines has provided estimates of sensitivity and specificity of a faecal examination method for *Schistosoma japonicum* infection in mammals, using also a statistical modelling approach within a Bayesian framework.[39]

Our study therefore provides the first, to our knowledge, evaluation of the performance of multiple diagnostic criteria and estimation of the prevalence of *S. haematobium* infection in Africa which raises important implications to consider with reference to reliable tests for the diagnosis of urinary schistosomiasis. Such findings should be also of direct relevance and application to current mass chemotherapeutic control programmes. Nevertheless, as the current dataset focuses on adults, we would recommend additional similar studies aimed to assess the application of such latent class models on data from school-aged children across varying schistosomiasis endemic regions within sub-Saharan Africa since school children form the major target age group of current mass chemotherapeutic control in human helminthiasis[40]

The results of this study clearly demonstrate that in adults the microscopic detection of the parasite's eggs in the urine is the best currently available diagnostic tool for *S. haematobium*

infection (results in Table 3, Table 4 and Table 5 support this argument) with the exception for the age group of ≥50 years old where very low specificities were estimated (Table 5). Standard errors of the estimates were larger for the older age groups compared to the young age groups due to the smaller sample sizes here (Table 1) and therefore such results should be interpreted cautiously. Based on these findings, we would thus recommend the inclusion of microscopic examination in the monitoring process of human mass chemotherapy programs whenever financial resources allow for this option, mainly because of its relatively low operational cost compared to other urinary schistosomiasis diagnostic techniques and its feasibility under most conditions. Furthermore, as microscopic examination can quantify the intensity of the *S. haematobium* infection, it enables evaluation of important indicators in the control planning, such as possible risk factors, presence of severe clinical forms, degree of transmission and reinfection in the area, and intervals for necessary re-treatments.

In addition, this study confirms that haematuria dipsticks can be sufficiently sensitive and specific indicators (results in Table 3, Table 4 and Table 5 support this argument with the exception of results in Table 5 where for the age group of 50--59 years old haematuria dipsticks yielded a very low sensitivity (45%)) for detection of *S. haematobium* infection in endemic areas, and therefore we would also recommend their inclusion in the monitoring process of human mass chemotherapy program. Indeed, in recent studies we have also found that semiquantitative reading of dipsticks correlates well with intensity of *S. haematobium* infection and ultrasound pathology.[2, 41]

On the other hand, whilst the urine antigen detection test showed similar sensitivity to microscopy (results in Table 3, Table 4 and Table 5 support this argument), it was also suggested that false-positive urine antigen detection tests may be more common than previously reported.[23] One potential explanation for the low specificity of this test might be that potentially cross-reactive parasites are more prevalent in the age group studied here and polyparasitism is of course common in these areas. Indeed, Dunyo et al. 1996 [42] found filarial infections in the towns or in the villages east of Accra in a similar age group and we would thus recommend further studies to define both the prevalence of such parasites in this same endemic area and examine any potential cross-reactivity between helminth species within the urine antigen detection test. Results from the current study suggests that the urine-antigen detection tests we evaluated should perhaps not be used for the identification of high risk groups which, due to the possibility of false positive reactions produced by such tests, could artificially inflate the actual numbers of people targeted for mass chemotherapy. Furthermore, estimates from all latent class models presented here yielded low sensitivities and specificities for the serology anti-IgG tests. The observation here that antibody detection lacks specificity is consistent with findings of other epidemiological studies which reported that antibody is often found without concomitant parasitological evidence of infection.[43, 44]

Furthermore, antigen detection methods are generally more expensive than antibody ones.[45] On the other hand, microscopy and haematuria dipsticks require relatively unsophisticated equipment and, in areas of high endemicity, personnel with only basic training. These two latter diagnostic tests could therefore constitute the lowest cost option when technical assistance is plentiful. Thus the current findings, if combined with consideration of costs involved, which is a critical issue in the economically developing countries, leads us to the conclusion that antibody and antigen detection tests should not be used in the determination of the prevalence of long term urinary schistosomiasis infections.

With reference to the detection of urinary schistosomiasis infection through ultrasound examination, the results of this study indicated that the performance of this diagnostic tool was quite acceptable in all age groups except in those of 30--39 years old and ≥50 years old. An explanation for the variability in these results among different age groups might be that

successive episodes of infection would result in recrudescence of urinary tract abnormalities and more severe pathology caused by urinary schistosomiasis would be expected to be observed because of continuing reinfection. Thus, we would conclude that ultrasound examination is not a reasonable substitute for microscopy or dipsticks in regards to determining the prevalence of *S. haematobium* infection. Nevertheless, we would still support the argument that the best currently available diagnostic tool for morbidity assessment in *S. haematobium* infections is the visualization of urinary tract pathology through ultrasound examination .

Finally, with statistical analysis alone, one can never be certain about the validity of a dependence model as it is not known from the observed data how each of the examined diagnostic tests relates to the others conditional on disease status.[46] Consequently, we recognize that the results of this study depend upon the assumption of conditional independence assumed by the models fitted here. In addition, latent class models based on current assumptions may not be appropriate for some similar alternative datasets as very large correlations (if these are present after accounting for latent class membership i.e. the true infection status) could potentially bias parameter estimates and result in an underestimation of the error rates of the examined tests.[47]

Through the use of latent class models we assessed the prevalence of *S. haematobium* infection, because accurate sensitive and specific measures for this indicator are imperative, particularly at later stages of successful mass chemotherapy control programmes. We demonstrate that latent class models proved a useful tool for validation research in the absence of a perfect gold-standard diagnostic technique. These models have suggested microscopy and haematuria dipsticks as sensitive and specific indicators of prevalence of *S. haematobium* infection in Ghanaian adults. In addition, they have provided estimated prevalences of *S. haematobium* infection that fit well with those previously obtained by those such as Nsowah-Nuamah and colleagues[48] in Southern Ghana, and Amankwa and colleagues[49] in upper-east region of Ghana as well as the focality of this infection even within small areas of the same country. However, it must be also considered that in the general context of chemotherapy programs, if monitoring and evaluation results are based exclusively on determining infection prevalence, the impact data obtained may inaccurately reflect the success of any programme. Therefore, it is fundamental to also monitor the impact of such control programmes on the intensity of the infection and morbidity changes in the treated population, particularly as modern day chemotherapy programs are aimed at reducing morbidity and hence intensity and further research in this area is thereby warranted.

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## TABLE 1

Participation by age class, sex and village

| Variable | Number of individuals who consented to participate and had complete data (%) | Number of individuals who dropped out or did not have complete data (%) | p-value* |
|---|---|---|---|
| *Age class* | | | |
| 19–29 years old | 51 (29.8) | 120 (70.2) | <0.001 |
| 30–39 years old | 57 (42.5) | 77 (57.5) | |
| 40–49 years old | 56 (57.1) | 42 (42.9) | |
| 50–59 years old | 33 (52.4) | 30 (47.6) | |
| ≥60 years old | 23 (37.7) | 38 (62.3) | |
| *Sex* | | | |
| Female | 117 (40.8) | 170 (59.2) | 0.618 |
| Male | 103 (42.9) | 137 (57.1) | |
| *Village location* | | | |
| Ayiki Doblo | 102 (49.0) | 106 (51.0) | <0.001 |
| Chento | 39 (26.2) | 110 (73.8) | |
| Ntoaso | 79 (46.5) | 91 (53.5) | |
| ***Total n*** | ***220*** | ***307*** | |

* p-value for chi-square test.

**TABLE 2**

Positive results expressed as percentages by each of the five diagnostic tests among the 220 Ghanaian adults studied

| Diagnostic tests | Positive results expressed as % with (95 % CI)* |
|---|---|
| Urine-antigen detection | 68.6 (62.5–74.8) |
| Serology anti-IgG | 44.1 (37.5 50.7) |
| Ultrasound | 31.8 (25.7–38.0) |
| Haematuria | 21.8 (16.4–27.3) |
| Microscopy | 15.5 (10.7 –20.2) |

* CIs are based on normal approximation methods

**TABLE 3**

Sensitivity and specificity of diagnostic tests as estimated from latent class model 1 when measurement invariance was imposed across males and females

| *LC Model 1* | | *Diagnostic tests* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***S. haematobium* prevalence (%)** | **Urine-antigen detection** | | **Serology anti-IgG** | | **Ultrasound** | | **Haematuria** | | **Microscopy** | |
| | | **Specificity (%)** | **Sensitivity (%)** | **Specificity (%)** | **Sensitivity (%)** | **Specificity (%)** | **Sensitivity (%)** | **Specificity (%)** | **Sensitivity (%)** | **Specificity (%)** | **Sensitivity (%)** |
| ***Sex*** | | | | | | | | | | | |
| Male | 21 | 36 | 98 | 57 | 48 | 74 | 65 | 87 | 73 | 98 | 93 |
| Female | 10 | | | | | | | | | | |

**TABLE 4**

Sensitivity and specificity of diagnostic tests as estimated from latent class model 2 when measurement invariance was imposed across different village locations

| *LC Model 2* | | *Diagnostic tests* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***S. haematobium* prevalence (%)** | **Urine antigen detection** | | **Serology anti-IgG** | | **Ultrasound** | | **Haematuria** | | **Microscopy** | |
| ***Village location*** | | **Specificity (%)** | **Sensitivity (%)** | **Specificity (%)** | **Sensitivity (%)** | **Specificity (%)** | **Sensitivity (%)** | **Specificity (%)** | **Sensitivity (%)** | **Specificity (%)** | **Sensitivity (%)** |
| Ayiki Doblo | 7 | 35 | 100 | 56 | 47 | 73 | 70 | 86 | 91 | 95 | 100 |
| Chento | 39 | | | | | | | | | | |
| Ntoaso | 2 | | | | | | | | | | |

**TABLE 5**

Sensitivity and specificity of diagnostic tests as estimated from latent class model 3 when measurement invariance was not imposed across different age groups

| *LC Model 3* | | **Diagnostic tests** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***S. haematobium* prevalence (%)** | **Urine antigen detection** | | **Serology anti-IgG** | | **Ultrasound** | | **Haematuria** | | **Microscopy** | |
| ***Age group (in years)*** | | **Specificity (%)** | **Sensitivity (%)** | **Specificity (%)** | **Sensitivity (%)** | **Specificity (%)** | **Sensitivity (%)** | **Specificity (%)** | **Sensitivity (%)** | **Specificity (%)** | **Sensitivity (%)** |
| 19–29 | 30 | 36 | 100 | 43 | 82 | 89 | 74 | 88 | 84 | 93 | 82 |
| 30–39 | 9 | 31 | 81 | 50 | 0 | 77 | 41 | 86 | 100 | 94 | 99 |
| 40–49 | 14 | 31 | 100 | 58 | 13 | 73 | 75 | 88 | 75 | 100 | 100 |
| 50–59 | 20 | 61 | 100 | 78 | 20 | 72 | 53 | 100 | 45 | 100 | 45 |
| >=60 | 11 | 39 | 100 | 60 | 71 | 46 | 0 | 93 | 100 | 100 | 0 |

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