Incidence of Blindness during the Onchocerciasis Control Programme in Western Africa, 1971–2002

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Background. Infection with Onchocerca volvulus is associated with the prevalence of severe visual impairment and blindness. However, longitudinal studies of the incidence of blindness caused by onchocerciasis are scarce.

Methods. The relationship, at the individual level, between infection with O. volvulus microfilariae and bilateral blindness was examined, by use of data collected, during the Onchocerciasis Control Programme in western Africa (OCP), from 2315 villages in 11 countries. The data were analyzed by Poisson maximum-likelihood techniques with adjustment for overdispersion.

Results. A total of 297,756 persons were eligible for follow-up in the cohort, and, during 1971–2001, these persons accumulated 367,788 person-years of follow-up without blindness. A total of 673 bilateral cases of blindness occurred during this period; 29.7% were caused by onchocerciasis. After ivermectin therapy was introduced (during 1988–2001), only 19.6% of cases were caused by onchocerciasis. The incidence of blindness was significantly and positively associated with increasing microfilarial burden (P < .001). Overall, female subjects had a ∼40% lower risk of becoming blind than did male subjects (P < .001). After an initially high incidence of blindness at the beginning of the OCP, the rate of blindness from causes other than onchocerciasis remained approximately constant during follow-up.

Conclusions. We demonstrate, in a comprehensive data set and in both sexes, a direct relationship between microfilarial load and the incidence of blindness.

Human onchocerciasis, which is caused by the parasitic filarial nematode Onchocerca volvulus, is one of the most important causes of infectious blindness worldwide, second only to trachoma [1, 2]. Because the blackfly (Simulium) vectors breed in riverine ecosystems, the disease is also known as “river blindness.” Irreversible ocular morbidity is thought to be mediated by cumulative host inflammatory responses to degenerating parasite embryos (microfilariae) in the eye [3, 4] in persons who are chronically and heavily infected. More recently, host reactions to the parasite’s Wolbachia endobacteriae have been implicated in the pathogenesis of ocular lesions [5].

The Onchocerciasis Control Programme in western Africa (OCP) was launched in 1974, with the aim of eliminating river blindness mainly in the savannah areas, where intense transmission by Simulium damnosum sensu stricto and Simulium sirbanum was associated with a high prevalence of blindness [6–8]. The OCP inherited data collection and control programs that had been initiated a few years previously (in 1971–1972) in Mali and Burkina Faso. Vector control (by the weekly larviciding of breeding sites) and surveillance activities were initiated in 7 western-African countries (Benin, Burkina Faso, Côte d’Ivoire, Ghana, Mali, Niger, and Togo). The first aerial treatments began in early 1975; by the end of 1977, they had been extended to cover a core area of 700,000 km2 [9]. In 1986, the program was extended to Guinea, Guinea-Bissau, Senegal, and Sierra Leone, to protect this core area from reinvasion by infected savannah vectors [10]. In 1989, mass ivermectin treatment (targeted against microfilariae) was introduced in
selected areas [11]. Antivectorial operations in the core OCP area were scaled down 14 years after their commencement [9].

Epidemiological surveillance was composed of repeated surveys of visual acuity in sentinel villages and assessments of microfilarial load by means of skin snips. More than 2000 villages were surveyed in the 11 western-African countries finally included in the OCP. The results of a previous, more limited analysis of the relationship between visual acuity and microfilarial load, in 66 villages during the first 5 years of the program [12], demonstrated that the prevalence of both visual damage and blindness increased with host age. The prevalence of visual damage was positively associated with the level of microfilarial infection [12].

In the present article, we examine the relationship, in the complete OCP data (1971–2001), between blindness and microfilarial load. Our study also represents an opportunity to evaluate the overall impact of the control program on the incidence of blindness in the countries covered by the program, throughout its evolution. In contrast to most studies of blindness caused by onchocerciasis [12–14], which have measured blindness prevalence, we sought to assess the incidence of blindness.

**MATERIALS AND METHODS**

_Epidemiological methods and description of the data._ The methods used in the epidemiological surveys have been described...
The countries and area covered by the OCP, as well as the locations of the surveyed villages, are shown in figure 1. During each survey, an attempt was made to conduct a complete census of the village, although not all persons in each village were examined. It has been estimated that ~84% of persons enumerated in the census were examined [16]. During a survey, skin snips were obtained, by use of a 2-mm Holth corneoscleral punch, from the left and right iliac crests of those examined, and age and sex were recorded. An assessment of visual acuity (simple and detailed examination) was conducted for all persons ≥5 years old and was based on either the illiterate E-chart (which requires the subject to orient capital Es of various sizes at a distance of 6 m) or the Sjögren hand test (at 5 m). Individuals were categorized into the following classes: no visual impairment (≥6/18); moderate impairment (<6/18 but ≥6/60); severe impairment (<6/60 but >3/60 [unable to count fingers at 1 m]), and blind (<3/60 [unable to count fingers at 1 m, with or without perception of light]) [17, 18].

The data were subject to a number of checks, including (1) consistency of the registration and examination codes; (2) consistency of the parasitological and simple visual-examination codes; (3) consistency of the codes for the simple visual examination and the detailed visual examination of left and right eyes; (4) intersurvey consistency of ages; (5) consistency of blindness and vital-status codes; (6) correct temporal sequence of registration, examination, and blindness codes; and (7) known sex. Persons were included in the analysis cohort only if they satisfied all of these consistency checks and had participated in at least 2 surveys (in the last of which they could have been declared dead). Table 1 summarizes the data used in the analysis. Blindness was deemed to have occurred during the intervening period between 2 consecutive surveys if, in the latter survey, the person was classified as blind in the simple visual examination or was blind in both eyes in the detailed visual examination (unable to count fingers at 1 m).

**Microfilarial load.** The methods used during the OCP surveys have been described elsewhere [19]. In brief, left and right iliac-crest snips were separately placed in distilled water for 30 min, and emerging microfilariae were counted under a dissection microscope. Negative snips were incubated up to 24 h in saline solution. Microfilarial counts were expressed as numbers of microfilariae per snip. For the purpose of our analyses, the microfilarial load was calculated as the arithmetic mean of the left and right skin-snip counts. As a simple yet biologically sensible model, this measure of microfilarial load was assumed to increase linearly with age, from 0 at age 0; and to vary linearly between measurements but to be constant after the last measurement. Although there is evidence of the intrauterine passage of microfilariae from infected mothers to their newborns, this occurs in only 2% of cases (1% of children <1 year old and living in villages where onchocerciasis is meso- to hyperendemic would acquire microfilaridermia by vertical transmission)—in any case, these do not represent “true” infections [20]. Microfilarial loads increase with host age (a measure of cumulative exposure) and plateau at some age, depending on the relative rates of both parasite immigration and blindness within the host [21].

Because the loss of visual acuity or sight during the study probably was caused by the microfilarial load that the subject had in the past, rather than by the current microfilarial load, this variable was “lagged” in all subsequent analyses. Table 2 presents the results of an exploratory analysis of the effect that lagging the microfilarial load by 0, 2, or 4 years had on the incidence of blindness. Because the OCP used of both antivectorial and antimicrofilarial measures, it would be desirable in the analyses to take account of the number of ivermectin treatments received by each person. Unfortunately, the OCP did not keep patient-specific records of drug administration; however, the (therapeutic) coverage of eligible people in villages where treatment was provided was 85%–95%. Therefore, to

<table>
<thead>
<tr>
<th>Data item</th>
<th>No. (no. of male subjects)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Villages</td>
<td>2315</td>
</tr>
<tr>
<td>Subjects</td>
<td></td>
</tr>
<tr>
<td>Entire database</td>
<td>754,895</td>
</tr>
<tr>
<td>Selected for cohort after application of inclusion criteria</td>
<td>297,756 (145,314)</td>
</tr>
<tr>
<td>Nonblindness, person-years of follow-up</td>
<td>367,788 (186,503)</td>
</tr>
<tr>
<td>Loss of sight</td>
<td>673 (472)</td>
</tr>
<tr>
<td>Duration, years (no. of male subjects)</td>
<td></td>
</tr>
<tr>
<td>Nonblindness, average length of follow-up</td>
<td>1.24 (1.28)</td>
</tr>
</tbody>
</table>

* Inclusion criteria include all the consistency checks described in the text plus participation in at least 2 surveys.
assess the possible effect that the introduction of mass ivermectin treatment had on the relationship between microfilarial load and mortality, certain analyses were repeated for the vector-control period (1971–1987), and others were repeated for the postivermectin period (1988–2001) only. Certain analyses were also conducted in terms of years since the start of control; the control (whether vector control or ivermectin) for each country was assumed, on average, to have started 1 year before the first survey.

**Calculation of person-years at risk.** Person-years for the period when a person was alive and not blind were calculated as described elsewhere [22], for strata defined in terms of the following parameters: age group (0–4, 5–9, ..., 70–74, or ≥75 years); country of residence (1/11 countries covered by the OCP); calendar year of follow-up (1971–1974, 1975, 1976, 1977, ..., 1999, or 2000–2001); calendar year of the first survey (1970–1974, 1975–1980, 1981–1984, 1985–1989, or 1990); sex; and microfilarial load per snip (0–1, 2–4, 5–9, 10–19, 20–49, 50–99, 100–199, 200–299, 300–399, or ≥400).

**Statistical methods.** It was assumed that the expected number of blindness events in the stratum $i$, $b_i$, with microfilarial load $MF_i$ (as a linear term), is given by

$$b_i = PYNB \times \exp \left( \gamma_0 + \gamma_1 \times MF_i + \sum \delta_j x_j \right),$$

(1)

where $PYNB$ is the number of nonblind person-years of follow-up in the stratum and $x_j$ are categorical variables (age group, country, calendar year of follow-up, calendar year of first survey, or sex). The model was fitted by Poisson maximum-likelihood techniques [23]. The statistical significance of all terms in the model was assessed by deviance-based $F$ tests, with al-

Table 2. Coefficients (95% confidence intervals [95% CI]) of a log-linear Poisson model (equation [1]) fitted to data on incidence of blindness (with allowance for overdispersion), by various assumed periods, in the entire data set of the Onchocerciasis Control Programme in Western Africa (1971–2001) and in data taken from the period before ivermectin treatment was introduced (1971–1987).

<table>
<thead>
<tr>
<th>Covariate</th>
<th>Coefficient (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 lag</td>
</tr>
<tr>
<td>Entire data set (1971–2001)</td>
<td></td>
</tr>
<tr>
<td>Microfilarial load</td>
<td>$0.96 \times 10^{-2}$ to $1.15 \times 10^{-3}$</td>
</tr>
<tr>
<td></td>
<td>$5.86 \times 10^{-1}$ to $-3.45 \times 10^{-1}$</td>
</tr>
<tr>
<td>Before ivermectin (1971–1987)</td>
<td></td>
</tr>
<tr>
<td>Microfilarial load</td>
<td>$0.97 \times 10^{-2}$ to $1.18 \times 10^{-3}$</td>
</tr>
<tr>
<td></td>
<td>$-6.41 \times 10^{-1}$ to $-3.42 \times 10^{-1}$</td>
</tr>
</tbody>
</table>

Table 3. Analysis of deviance for Poisson regression, between the covariates listed and the expected number of blindness events in the entire data set (1971–2001) of the Onchocerciasis Control Programme in Western Africa.

<table>
<thead>
<tr>
<th>Covariate</th>
<th>Degrees of freedom</th>
<th>Deviance</th>
<th>F-statistic</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overall</td>
<td>Residual</td>
<td>Overall</td>
<td>Residual</td>
</tr>
<tr>
<td>Null model</td>
<td>...</td>
<td>41,155</td>
<td>5817.95</td>
<td>...</td>
</tr>
<tr>
<td>Age group</td>
<td>12</td>
<td>41,143</td>
<td>939.06</td>
<td>4878.90</td>
</tr>
<tr>
<td>Country of residence</td>
<td>9</td>
<td>41,134</td>
<td>41.04</td>
<td>4837.86</td>
</tr>
<tr>
<td>Calendar year of follow-up</td>
<td>25</td>
<td>41,109</td>
<td>116.56</td>
<td>4721.29</td>
</tr>
<tr>
<td>Calendar year of first survey</td>
<td>4</td>
<td>41,105</td>
<td>80.61</td>
<td>4640.69</td>
</tr>
<tr>
<td>Sex</td>
<td>1</td>
<td>41,104</td>
<td>67.31</td>
<td>4573.38</td>
</tr>
<tr>
<td>Microfilarial load</td>
<td>1</td>
<td>41,103</td>
<td>170.98</td>
<td>4402.40</td>
</tr>
</tbody>
</table>

**NOTE.** The model is equation (1). Microfilarial load is lagged by 2 years.

- Because of small nos. of events in persons <20 years old, a single age category (rather than 4 categories) was used to represent this age group.
- Because there were no events in Guinea-Bissau, a single category was used to represent Guinea and Guinea-Bissau.
- Because of the small no. of events in 1989 and 1990, a single category was used to represent these 2 years.
Table 4. Risk of blindness attributable to onchocerciasis in the Onchocerciasis Control Programme in Western Africa, in the entire data set (1971–2001) and in data taken from the period after ivermectin treatment was introduced (1988–2001).

<table>
<thead>
<tr>
<th>Sex</th>
<th>Risk of blindness attributable to onchocerciasis, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>32.7</td>
</tr>
<tr>
<td>Female</td>
<td>22.8</td>
</tr>
<tr>
<td>Total</td>
<td>29.7</td>
</tr>
</tbody>
</table>

The results of these calculations are given in table 4.

RESULTS

Table 2 illustrates the effect of assuming a time delay of 0, 2, or 4 years, for analyses of the relationship between the incidence of blindness and microfilarial load. It can be seen that the microfilarial-load coefficient was largest when a 2-year lag was assumed, although the difference between assuming no latency and assuming a 4-year lag was modest. The sex coefficient became progressively less negative as the lag was increased from 0 to 4 years. In a separate analysis of the same data set [25], in which host mortality was the outcome variable, regression coefficients were also largest for a 2-year delay. All subsequent results in the regression analyses were obtained under the assumption of a 2-year lag. Table 2 also shows that analyses for the period before ivermectin therapy was introduced (1971–1987) exhibited essentially the same findings.

Table 3 indicates a highly statistically significant variation of the incidence of blindness, with age group, country, calendar...
Figure 3. Underlying incidence of blindness, plotted against calendar year of observation, adjusted for age (adjusted to age 55–59 years), country of residence (adjusted to Burkina Faso), calendar year of first survey (adjusted to 1975–1980), sex (adjusted to male subjects), and *Onchocerca volvulus* microfilarial load (adjusted to 0 load). Error bars denote 95% confidence intervals. The graph is based on fitting of equation (1) to data from the Onchocerciasis Control Programme in western Africa.

Figure 4. Incidence of blindness, by sex, plotted against *Onchocerca volvulus* microfilarial count, adjusted for age (adjusted to age 55–59 years), country of residence (adjusted to Burkina Faso), calendar year of follow-up (adjusted to 1994), and calendar year of first survey (adjusted to 1975–1980). Error bars denote 95% confidence intervals. The graph is based on fitting of equation (1) to data from the Onchocerciasis Control Programme in western Africa.

Figure 2 shows the underlying rate of blindness (adjusted for microfilarial load and the other covariates) as a function of age and sex. As can be seen, the incidence of blindness increases progressively with the age of the host. The effect that sex has...
on the underlying incidence of blindness was highly statistically significant ($P < .001$; table 3), as illustrated by figure 2, which demonstrates markedly lower rates of blindness in female subjects than in male subjects. Female subjects have an $\sim40\%$ lower risk of blindness overall (table 2). The divergence, between the sexes, of the rates of blindness in the last age group ($\geqslant 75$ years) is particularly noteworthy. Although the number of blindness events in this age group was small (31 men and 2 women), the difference in crude rates ($22.5 \times 10^{-3}$ vs. $4.7 \times 10^{-3}$) is statistically significant ($P = .02$).

Figure 3 shows that, after an initially high incidence of blindness at the beginning of the OCP, the rate of blindness from causes other than onchocerciasis remained more or less constant throughout the duration of the program, with perhaps a slight increase during later years, from 1990 onward. Testing of the trend in underlying incidence during 1989–2001, by use of a modified form of equation (1), revealed a statistically significant (2-sided $P = .023$) increasing trend in incidence. The magnitude of this trend showed a heterogeneity by country that was highly statistically significant ($P < .001$). However, because these tests were not conducted a priori (i.e., they were not hypothesis driven), their nominal statistical significance (i.e., $P$ values) is misleading.

Table 4 shows that, overall, 29.7% of cases of blindness were caused by onchocerciasis, and this percentage was higher for male subjects (32.7%) than for female subjects (22.8%). If the data are restricted to the period after the introduction of ivermectin (1988–2001), the percentage of cases of blindness caused by onchocerciasis decreases to 19.6% and is still higher for male subjects (21.9%) than for female subjects (14.4%). The incidence of blindness increases with increasing microfilarial load (tables 2 and 3), as shown in figure 4. This figure also shows that, in terms of the effect that increasing microfilarial load has on the incidence of blindness, there is little difference between the sexes ($P = .722$ for significance of difference in trends, by sex).

Figure 5A shows the microfilarial load in the 0–19- and $\geqslant 20$-year age groups, by sex, throughout the duration of the program. The microfilarial loads in these groups peaked during the late 1970s as OCP teams targeted communities at high risk, and loads have been progressively decreasing since then. Mi-
Microfilarial loads are consistently higher in the male subjects, in both age groups. Microfilarial loads in men ≥20 years old remained >20 microfilariae/snip (a suggested threshold above which there is severe ocular morbidity [14]) until the introduction of ivermectin in the late 1980s, and loads exhibited a sharper decline after 1989, although there are indications that the trend increased during the last 4 years of the OCP (1998–2001). The results in figure 5A all relate to the analysis using the instantaneous (observed) microfilarial counts for each calendar year, by calendar year of follow-up. Qualitatively similar findings were obtained when, instead, microfilarial load was plotted against years since the start of control, as shown in figure 5B. Similar findings were also obtained when the piecewise linear exposure model was used to derive microfilarial loads between individual measurements (as used in the regression analysis in tables 2 and 3), plotted against either calendar year or year since the start of control (figure 5C and 5D, respectively). On the whole, the picture of what was going on in the OCP cohort should be more reliable in the piecewise linear exposure model used to generate figure 5C and 5D than that in the instantaneous measures depicted in figure 5A and 5B, because the microfilarial surveys during any year may well not be representative of the distribution of infection in the total population. However, during the last few years of follow-up, when surveys became less frequent, it is possible that the model-based calculations of figure 5C and 5D may have overestimated the current microfilarial status of the surviving cohort.

**DISCUSSION**

In the present article, we have documented that, during the OCP follow-up period, the incidence of blindness was significantly and positively associated with increasing microfilarial burden (P < .001). Approximately 30% of the blindness incidence in this area of western Africa can be attributed to the effects of onchocerciasis. These findings are similar to those reported for an area of Nigeria where onchocerciasis is hyperendemic [26]—the prevalence of blindness was >60% among those with skin loads ≥100 microfilariae/snip. On the basis of data from Burkina Faso [27], it has been estimated that, in the same country, the lifetime risk of becoming blind is more than twice as high in areas of hyperendemicity of onchocerciasis than in areas of mesoendemicity of onchocerciasis [13]. Endemicity levels of onchocerciasis were defined so as to reflect increasing values of microfilarial prevalence and the intensity of infection in the community [28]. The annual rates of blindness incidence—5.7 cases/1000 population in areas of hyperendemicity and of 1.3 cases/1000 in areas of mesoendemicity—are in line with our overall estimated average of ≈1.8 cases/1000 (table 1), which, as mentioned above, did not vary a great deal during the 28 years of the program.

A weakness of the data is that the recorded blindness was due to all causes; therefore, it is difficult to ascertain whether the incidence of onchocerical blindness actually decreased during the OCP. However, the fact that the overall rate of blindness was lower in female subjects than in male subjects suggests that onchocerciasis may, indeed, have been the principal cause of blindness initially [12, 29]. Throughout the program, both young and adult male subjects consistently had higher microfilarial loads than did female subjects, which indicates an intense exposure to microfilariae early in life [30]. (In African countries where cataract and trachoma are the main causes of blindness, female subjects are more frequently affected than male subjects [2, 31].) In addition, the blindness end point was ascertained only during surveys. If a person became blind between surveys, the blindness event was deemed to have occurred midway between them. Because intervals ≥10 years could elapse between surveys, the times imputed for the occurrence of blindness may be significantly in error. However, because these events were relatively infrequent, it is not to be expected that there would be significant bias occasioned by the use of such midinterval estimates.

Another possible weakness is that, although the analysis was based on individual data, the start and duration of control measures were recorded mainly on a community or regional basis. The OCP recorded the geographical (percentage of communities) and therapeutic (percentage of eligible individuals in a community) coverage of ivermectin treatments but not the number of treatments received by each individual in the cohort. Although vector control would have affected the overall prevalence of onchocerciasis, it would not be expected to affect the relationship between microfilarial load and blindness, which is the main topic of the analysis given here. In contrast, ivermectin may affect this relationship—ivermectin treatment would rapidly result in the microfilarial load falling to near zero, thereby reducing ocular morbidity and eventually preventing new cases of blindness, although with some lag. For this reason, we analyzed separately the total data set and a subset for the period before ivermectin was administered. The results of these analyses were very similar (table 2). Further analyses are under way that take into account more-detailed information on the start and duration of ivermectin treatment and of vector-control measures (authors’ unpublished data).

Ocular morbidity and, ultimately, blindness have been thought to be mediated by cumulative inflammatory processes that occur around dead or moribund microfilariae that have found their way into the eyes of the infected individual [3, 4]. This causal pathway, which links microfilariae in the cornea to snowflake opacities (punctate keratitis) and, eventually, to irreversible opacities (sclerosing keratitis) and visual impairment, seems to apply more readily to savannah areas than to forest areas, which may explain why the microfilarial load is such a
strong predictor of the incidence of blindness in the OCP data. More generally, it is thought that the type and severity of ocular pathology in different areas of western Africa is partly due to infections with different strains of the parasite [32–34], which in turn are differentially transmitted by distinct members of the S. damnosum complex [35]. Anterior segment lesions (sclerosing keratitis) are both more prevalent and more likely to cause onchocercal blindness in the savannah, whereas posterior segment lesions (chorioretinitis) are more common and a more frequent cause of blindness in the forest [36]. However, the pathogenesis of some disease manifestations in onchocerciasis, in particular of posterior-segment onchocercal eye lesions, is largely unknown. A novel mechanism has recently been proposed that suggests that inflammatory responses are elicited not so much by (somatic) microfilarial antigens as by the endosymbiotic Wolbachia bacteria released from (dying) microfilariae [5].

Regardless of the mechanism underlying the relationship between the intensity of infection and morbidity in human onchocerciasis, the direct effects of O. volvulus may be more severe than has previously been thought. The infection has commonly been regarded as a chronic and debilitating process that affects the host indirectly rather than directly. Onchocercal blindness has been linked to increased mortality of the human host [12, 13, 27, 37], but a direct relationship between increased mortality and the intensity of infection has proved elusive [12, 37]. The results of another study, which examined mortality in relation to microfilarial load and blindness prevalence in the same OCP cohort [25], suggest that increased mortality not only may be the result of blindness (which may lead to poorer nutrition, more trauma, and fatal accidents) but also may be caused, more directly, by the parasitic infection.

To determine the microfilarial load at any time, we linearly interpolated between measurements, and the microfilarial load was assumed to be constant after the last measurement in an individual. Given the very short average length of follow-up (1.2 years; table 1), it is unlikely that using assumptions other than these to interpolate between measurements and between the last measurement and the end of follow-up would have made an appreciable difference.

Our model assumes that blindness was correlated with suitably lagged (by 2 years) microfilarial load. It is possible that blindness at a given age may be related to a weighted cumulative microfilarial load—for example, the integrated microfilarial load up to 2 years before. This might explain part of the strongly increasing incidence of blindness with age (figure 2), although this phenomenon is known to also occur in several nononchocercal causes of blindness. This might also partially explain the increase in underlying blindness during the 1990s (figure 3), which could have been a result of the continuing excess risk introduced by such a cumulative load when rates of infection decrease, as is shown in figure 5A. However, other explanations of this latter phenomenon are also possible, as we discuss below. There were no indications of a lack of fit of our model, although it is possible that such an alternative model might fit as well or better.

Figure 3 shows that underlying rates of blindness not caused by onchocerciasis (adjusted for a microfilarial burden of 0 and other covariates) were fairly constant during the follow-up period, after a sharp (and probably artificial) initial decline. These rates generally decreased until 1990 [38] and increased slightly from 1990 onward. This may appear to be somewhat surprising, given that ivermectin was introduced into the OCP, solely or in combination with vector control, during the late 1980s [10, 11]. Ivermectin reduces the microfilarial load (as illustrated in figure 5C and 5D) and, hence, lowers morbidity [39]. The exclusion of the 4 additional countries that were incorporated into the OCP from 1986 onward (and that could have caused a peak in the incidence of blindness, because of the inclusion of areas not previously considered in the study) did not produce a different pattern (data not shown). More likely, because mortality rates decreased in the OCP area during the program [25], this increase in the incidence of blindness may reflect nononchocercal blindness (e.g., caused by cataract or trachoma). Of some concern, however, are the indications (figure 5A) that the intensity of infection slightly increased during the last 4 years of the program (1998–2001), which implies that the future risk of blindness may also increase in this population. This trend should be monitored.

Acknowledgments

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