SYSTEMATIC REVIEW

Is diabetes associated with malaria and malaria severity? A systematic review of observational studies [version 1; peer review: 2 approved with reservations]

Rodrigo M. Carrillo-Larco 1-3, Carlos Altez-Fernandez 4, Cesar Ugarte-Gil 4-7

1 Department of Epidemiology and Biostatistics, School of Public Health, Imperial College London, London, UK
2 CRONICAS Centre of Excellence in Chronic Diseases, Universidad Peruana Cayetano Heredia, Lima, Peru
3 Centro de Estudios de Poblacion, Universidad Catolica los Ángeles de Chimbote (ULADECH Catolica), Chimbote, Peru
4 Facultad de Medicina Alberto Hurtado, Universidad Peruana Cayetano Heredia, Lima, Peru
5 Instituto de Medicina Tropical Alexander von Humboldt, Universidad Peruana Cayetano Heredia, Lima, Peru
6 Department of Clinical Research, London School of Hygiene and Tropical Medicine, London, UK
7 Department of International Health, Johns Hopkins Bloomberg School of Public Health, Baltimore, USA

Abstract

Background: We conducted a systematic review to study the association between diabetes as a risk factor for malaria.

Methods: The search was conducted in Embase, Global Health, MEDLINE, Scopus and Web of Science. Titles and abstracts were screened, full-text studied and information extracted for qualitative synthesis. Risk of bias was assessed with ROBINS-I criteria. The exposure was diabetes and the outcome malaria or malaria severity.

Results: Of 1992 results, three studies were included (n=7,226). Two studies found strong associations: people with diabetes had higher odds of malaria (adjusted odds ratio (aOR): 1.46 (95% CI: 1.06-2.03)) and severe malaria (aOR: 2.98 (95% CI: 1.25-7.09)). One study did not find conclusive evidence: aOR for severe malaria was 0.95 (95% CI: 0.71-1.28). Risk of bias was high in all the studies.

Conclusions: Although the available evidence on the association between diabetes and malaria is limited, the results may suggest there is a non-trivial positive relationship between these conditions.

Keywords

malaria, diabetes, multi-morbidity, co-morbidity, syndemics, Peru
Introduction

In a global context where non-communicable diseases lead the ranking of mortality and disease burden, malaria is a tropical disease still accountable for thousands of years of life lost and years lived with disability disproportionally affecting low- and middle-income countries (LMICs)\(^1\,^2\). The current multi-morbidity and syndemics paradigm calls to study diseases as clusters rather than isolate entities\(^3\,^4\), and new links between diseases could signal innovative prevention paths, e.g., adequate control of socio-demographic determinants for both conditions. Moreover, this knowledge could also provide relevant evidence on treatment and management, e.g., medications and their interactions for subjects with both illnesses. Therefore, looking at unknown associations between non-communicable diseases and malaria seems relevant, particularly for diseases for which incidence has swiftly risen in the last decades such as diabetes\(^5\,^7\).

Even though there is evidence about the increasing co-morbidity between diabetes and infectious diseases\(^7\,^3\), the concept that diabetes could be a “risk factor” for malaria is relatively new\(^9\). Although relevant, available evidence is still sparse, including letters, brief reviews and animal models\(^10\,^12\). To the best of our knowledge, no systematic review has yet summarised the evidence on the association between diabetes and malaria. In so doing, the magnitude of this association could be explored and research gaps identified. Consequently, we aimed to conduct a systematic review of observational studies addressing the association between diabetes and malaria.

Methods

Study design

This is a systematic review of the literature following the PRISMA guidelines\(^13\); the checklist is available on Figshare\(^14\). This work was registered at PROSPERO (ID CRD42018105771).

Search strategy

The search was conducted in Ovid, including Embase, Global Health and MEDLINE, as well as in Scopus and Web of Science; for specific terms used in these search engines please refer to Extended data (pp. 4–7). The search was conducted from inception to July 31\(^t\) 2018, and no language restrictions were set. However, the search in Ovid was restricted to human subjects; the search in Scopus was restricted to articles and medicine as subject area; and the search in Web of Science was restricted to articles.

Selection criteria

We sought studies that included human subjects, had a comparator group (e.g., healthy individuals or subjects without diabetes), and the outcome was malaria diagnosis or severity. In detail, studies were selected if they included human subjects regardless of where they had been enrolled, i.e., these could have been population-based/community studies or hospital-based samples; no age restrictions were set. The study followed an observational design, e.g., cross-sectional, case-control or cohort study. Case reports and non-comparative studies were excluded. The exposure variable was diabetes defined as either a laboratory test (e.g., fasting plasma glucose ≥126 mg/dL), self-reporter diagnosis or currently receiving medication for diabetes; these variables could have been actively collected or retrieved from medical records. The exposure of interest could have been any kind of diabetes (e.g., type 1 or type 2). The outcome was either malaria diagnosis or malaria severity regardless of the species; cases should have had laboratory confirmation (e.g., blood smears, rapid diagnostic tests or polymerase chain reactions (PCR)).

Data collection

Using the Rayyan online tool\(^15\), two reviewers (RMC-L and CA-F) screened titles and abstracts retrieved from the search strategy. The full text of the studies that both reviewers agreed met selection criteria were sought; in addition, studies on which both reviewers had a discrepant opinion were also retrieved in full text. These full texts were studied by two reviewers (RMC-L and CA-F) to select those for final inclusion. The authors agreed on items that needed to be extracted from each study and RMC-L sought these pieces of information; all the authors reviewed the extraction process.

Risk of bias was assessed using the ROBINS-I criteria\(^16\); nevertheless, the “Bias due to deviations from intended interventions” criterion was not considered because it did not apply to the studies herein included. RMC-L conducted the risk of bias assessment and all the authors reviewed the results.

The results are presented as a qualitative synthesis. No meta-analysis was planned because very few studies were expected, with high variability among them. Therefore, summary measured (e.g., odds ratio) are summarized and presented as they were reported by each original study.

Results

Search strategy

The search strategy retrieved 2108 results, 1992 were screened and 10 selected for in-depth scrutiny; finally, three studies were included for qualitative synthesis. Figure 1 depicts the number of studies at each stage of the screening process.

Study characteristics

Table 1 shows the overall characteristics of the selected studies. Of the three studies, two were conducted in high-income countries: USA\(^17\) and Sweden\(^18\); whereas one was in Africa (Ghana)\(^19\). All of them were published in the last 8 years and followed a retrospective design. There was heterogeneity in diabetes definition, including blood tests (e.g., fasting glucose) and history based on clinical records. In all the studies the malaria diagnosis was confirmed with blood tests, including PCR.

Diabetes and malaria susceptibility

One of the three selected reports showed a strong positive association between diabetes and malaria susceptibility. People with type 2 diabetes had higher odds of malaria: adjusted odds ratios (aOR) = 1.46; 95% CI: 1.06-2.03 (Table 1)\(^19\).

Diabetes and malaria severity

Of the three selected reports, two provided\(^17,18\) evidence that people with diabetes (including type 1 and 2) had higher odds
of severe malaria, aOR = 2.98; 95% CI: 1.25-7.09. One study did not find a strong association, reporting that type 2 diabetes and severe malaria had an aOR = 0.95; 95% CI: 0.71-1.28 (Table 1).

Risk of bias
The risk of bias assessment showed that the three retrieved studies had critical risk of bias, particularly in selection of participants into the study. They all had low bias in classification of the intervention, and they presented poor information to assess bias due to missing data. Table 2 summarizes all criteria for risk of bias assessment, and specific items within each criterion are shown in Extended data (pp. 9–11).

Discussion
Summary of evidence
There were three reports addressing the association between diabetes and malaria, one studied malaria diagnosis whereas two malaria severity or complications. There was a strong positive association between diabetes and malaria diagnosis, and only one study found compelling evidence of an association between diabetes and malaria severity. Across these three studies, risk of bias was high.

Limitations
The study designs followed by the reviewed studies were case-control and retrospective analyses. Although these methodologies provide relevant evidence and have a number of strengths, regarding the topic at hand the evidence they offer still needs further verification with stronger observational approaches. These could include prospective cohorts or thoroughly conceived analysis following a casual-inference methodology. On the other hand, we acknowledge that the reviewed studies ascertained both the exposure and outcome following strong methodologies, which in turn suggests that addressing the association of interest is feasible and supports our call for further studies in this field.

This review has some strengths and limitations. First, we searched five international search engines, which allowed us to cover thousands of published materials. Therefore, our results show
<table>
<thead>
<tr>
<th>Study</th>
<th>Country</th>
<th>Design</th>
<th>Setting</th>
<th>Study population</th>
<th>Sample size</th>
<th>% diabetes/ % malaria</th>
<th>Exposure</th>
<th>Outcome</th>
<th>Main result</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Malaria Susceptibility</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Danquah I, et al.</td>
<td>Ghana</td>
<td>Case-control study</td>
<td>Health centre</td>
<td>Men and women aged ≥18 years</td>
<td>1,466</td>
<td>46% / by PCR 14.1% had Plasmodium spp. infection (91.8% P. falciparum)</td>
<td>Type 2 diabetes: treatment or fasting plasma glucose ≥7 mmol/L</td>
<td>Malaria: PCR was used to identify Plasmodium infection and species</td>
<td>Type 2 diabetes was associated with higher odds of Plasmodium falciparum infection: aOR = 1.46 (95% CI: 1.06-2.03)</td>
</tr>
<tr>
<td><strong>Malaria Severity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wyss K, et al.</td>
<td>Sweden</td>
<td>Retrospective observational study</td>
<td>National surveillance data (Public Health Agency)</td>
<td>All adults (≥18 years) with Plasmodium falciparum microbiologically confirmed</td>
<td>937 individuals with P. falciparum, of which 9.8% were severe</td>
<td>In severe cases 9.8% had diabetes</td>
<td>Diabetes: as per the ICD-10 codes registered, including type 1, type 2 and unspecified</td>
<td>Severe malaria: 2012 WHO criteria (modified by the authors)</td>
<td>Regardless of hyperparasitemia, diabetes was associated with higher odds of severe malaria: aOR = 2.98 (95% CI: 1.25-7.09)</td>
</tr>
<tr>
<td>Khuu D, et al.</td>
<td>USA</td>
<td>Retrospective observational study</td>
<td>Based on hospital records from State Inpatient Database</td>
<td>Men and women whose discharge records had malaria (ICD-9 codes) as the primary or secondary diagnoses</td>
<td>4,823 severe malaria hospitalizations</td>
<td>Among severe malaria inpatients, 10.4% type 2 diabetes</td>
<td>Based on the hospital records; no further details</td>
<td>Severe malaria: CDC criteria (modified by the authors). Malaria complications: where the discharge record noted malaria plus one or more complications (e.g., neurological symptoms)</td>
<td>Type 2 diabetes was not associated with severe malaria or malaria plus complications: aOR = 0.95 (95% CI: 0.71-1.28) [severe malaria]; aOR = 1.06 (95% CI: 0.60-1.88) [malaria with ARDS]; aOR = 0.93 (95% CI: 0.55-1.57) [cerebral malaria]; aOR = 1.16 (95% CI: 0.75-1.80) [malaria with severe anaemia]; aOR = 1.20 (95% CI: 0.82-1.74) [malaria with renal failure]; aOR = 0.83 (95% CI: 0.36-1.92) [malaria with jaundice]</td>
</tr>
</tbody>
</table>
what there is available at a global scale and thus signal a dearth of strong evidence on the association between diabetes and malaria. Second, there are a number of tools to assess risk of bias. The one we followed, ROBINS-I, is a domain-based approach which seems to be a better approach in comparison to tools without domains; nevertheless, it has also been suggested that ROBINS-I labels more studies as of high risk of bias. Regardless of the assessed domains and other properties of the ROBINS-I, the study design (e.g., case-control) followed by the reviewed reports already suggest high risk of bias. This is not a critique on the available evidence, but rather a call to build on the available literature and conduct more comprehensive research.

Implications for research
This systematic review found three studies following a case-control and retrospective analysis approach. Although they did a great effort to ascertain the exposure and outcome with precision, e.g., using biomarkers for diabetes or PCR for malaria, they lacked of generalizability because their study populations were based on (small) patients samples instead of general population samples. A relevant research approach, as suggested by Broz et al., would be how to improve diabetes control in people with malaria. Because malaria would imply haemolysis, this could impair the accuracy of HbA1c to inform about diabetes control; potential solutions could include daily glucose monitor or fructosamine. We believe that a population-based cohort study that has assessed diabetes would be a key asset in further elucidating the (true) association between diabetes and malaria. We are confident that these studies are available somewhere, with particular interest in LMICs, and that soon they will produce evidence in order to identify whether addressing diabetes could reduce malaria burden.

Implications for public health and clinical practice
At this this time we believe it is premature to draw any strong conclusions for clinical practice or public health. Nevertheless, we could suggest strengthening malaria prevention strategies for people with diabetes, particularly in highly endemic areas or among travellers to these settings. In accordance to international guidelines suggesting prophylactic treatment for travels to highly-endemic areas, these recommendations could be stronger for people with diabetes.

Diabetes and malaria: the epidemiological context
Global estimates inform that Africa is the region with the largest number of Malaria cases, where Nigeria, followed by the Democratic Republic of Congo, accounts for most of these. Although there has been a decrease since 1990, West and Central Africa exhibit the highest malaria death rates, with Mali, Burkina Faso and Niger leading the ranking. On the other hand, epidemiological evidence shows that from 1980 to 2014, diabetes prevalence has doubled in most sub-Saharan nations. Regarding the above highlighted countries, diabetes prevalence in Nigeria and the Democratic Republic of Congo has increased by 2- and 2.5-fold, respectively; these estimates for Mali, Burkina Faso and Niger were 2.6-, 2.8- and 2.3-fold. These country-level estimates have several implications. First, countries with high malaria prevalence have experienced a dramatic increase in diabetes prevalence. This could imply that the rising diabetes burden makes it difficult to lessen malaria burden despite large efforts on this matter. Second, Burkina Faso, one of the countries with high malaria death rates have also had an utterly increase in diabetes prevalence. This could suggest that diabetes is behind more severe cases that unfortunately have a fatal outcome. Third, as diabetes prevalence keeps rising in these areas, larger populations could be at high risk of malaria. This could lead to call to strengthen diabetes prevention and early diagnosis programs, not only to stop non-communicable diseases but also because of a potential positive impact on malaria control. These ecological arguments, along with the evidence summarized in this review, suggest of a possible co-morbidity (if not synergism) between diabetes and malaria that deserves further and comprehensive scrutiny.

Diabetes and malaria: pathways
The aim of this review was to synthesize the evidence about diabetes as an associated factor with higher malaria prevalence, incidence or severity. Even though we could not assess diabetes as a ‘risk factor’ in the strict definition of the term because of the lack of prospective studies, we summarized preliminary
evidence that suggest diabetes could be associated with malaria. In addition to this finding, biological pathways have been proposed to explain this association.

Olivier and colleagues summarized key aspects of immune response in malaria, highlighting features of early infection including that phagocytes such as monocytes, macrophages and neutrophils lead the immunological response; this role of monocytes and macrophages during erythrocyte infection has been studied before, particularly in response to Plasmodium falciparum and Glycosylphosphatidylinositol. However, macrophage phagocytic activity seems to be reduced in diabetics, and this is paramount in the association between diabetes and tuberculosis. This impaired immunity, particularly regarding those cells with responsibilities against malaria, could explain the association between diabetes and malaria. These arguments suggest a biologically plausible pathway between these illnesses.

Other possible pathways between diabetes and malaria include hyperinsulinemia, which has been suggested to affect mosquitoes in a way that they have a reduced immune response against Plasmodium falciparum. This implies there would be more mosquitoes to spread malaria. Although we are unaware of robust evidence to support this potential explanation, Raghunath hypothesized that diabetics who take metformin would attract more mosquitoes because this medication increases the concentration of lactic acid in their sweat, a compound that attracts mosquitoes. These additional arguments to support the association between diabetes and malaria render further importance to the study of this co-morbidity; not only because this would enrich science, but because it could also provide innovative prevention or treatment strategies.

Conclusions
Despite conducting a comprehensive systematic review, the results showed there is paucity in the evidence about the association between diabetes and malaria. Of the three reviewed studies, one found a strong association between diabetes and malaria diagnosis, and one between diabetes and malaria severity; one study did not find strong evidence of association between diabetes and malaria severity. The three studies had high risk of bias, with one following a case-control design while the other two conducted a retrospective analysis. This limited evidence precludes drawing a strong conclusion on the association of interest. Although there is evidence signalling biologically plausible pathways between diabetes and malaria, at this time it is still premature to make clinical or public health recommendations to address the (possible) synergism between these diseases. On the other hand, this review signals the dearth of evidence on this association, both in terms of quantity and quality of available research; this calls to further study this association and others between communicable and non-communicable diseases particularly in places with high or raising burden of both of them.

Data availability
Underlying data
All data underlying the results are available as part of the article and no additional source data are required.

Extended data
Figschedule: IS DIABETES ASSOCIATED WITH MALARIA AND MALARIA SEVERITY? A SYSTEMATIC REVIEW OF OBSERVATIONAL STUDIES - SUPPLEMENTARY MATERIAL. https://doi.org/10.6084/m9.figshare.9789740.v1

Reporting guidelines

Data are available under the terms of the Creative Commons Attribution 4.0 International license (CC-BY 4.0).

Author contributions
RMC-L conceived the idea with support from CU-G. RMC-L conducted the search. RMC-L and CA-F screened titles and abstracts and studied full texts. RMC-L extracted information and conducted the risk of bias assessment with support from CA-F and CU-G. RMC-L drafted the first version of manuscript and all authors provided critical insights. All authors approved the final version of the manuscript.

References
This study is a systematic review to find an association between diabetes and Malaria. Study is highly relevant because diabetes patients are susceptible to various infections because of dysregulation of immune response. Authors have finally selected only three articles addressing the association between diabetes and malaria. One of those articles focused on malaria diagnosis and two others studied malaria severity or complications. Only one study found compelling evidence of an association between diabetes and malaria severity. Authors need to clarify why they have finally selected only three studies for qualitative synthesis from 1992 studies. Ten articles that were selected for in-depth scrutiny should be considered for synthesizing the data. I recommend that they should also include those seven full-text articles for analysis and submit the results as supplementary materials.

Though it is a systemic review, after analysis of the selected articles, authors should be able to form good hypotheses to explain the reasons for high susceptibility of diabetics to malaria infection. They should also be able to explain the reasons for high severity and complications of malaria in diabetics. This study is well designed and deserves indexing after incorporating results from more studies.

Are the rationale for, and objectives of, the Systematic Review clearly stated?
Yes

Are sufficient details of the methods and analysis provided to allow replication by others?
Yes

Is the statistical analysis and its interpretation appropriate?
Not applicable

Are the conclusions drawn adequately supported by the results presented in the review?
Yes

**Competing Interests:** No competing interests were disclosed.
**Reviewer Expertise:** My research interest is in the field of microbial pathogenesis and molecular genetics of bacterial pathogens especially enteric pathogens. Currently in Guyana, I am interested in studying the incidence of various infections in patients with type 1 and type 2 diabetes with special reference to respiratory infections and candidiasis.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

---

**Author Response 19 Nov 2019**

Rodrigo Carrillo-Larco, School of Public Health, Imperial College London, London, UK

Q1: Authors need to clarify why they have finally selected only three studies for qualitative synthesis from 1992 studies. Ten articles that were selected for in-depth scrutiny should be considered for synthesizing the data. I recommend that they should also include those seven full-text articles for analysis and submit the results as supplementary materials.

A1: The three studies finally included in the review were those which met the inclusion criteria detailed in the methodology. Of the ten studies that were selected after the titles/abstract screening, seven were excluded because these did not meet the inclusion criteria. To be consistent with our methodology, and inclusion/exclusion criteria as in any thorough systematic review, we cannot include more results in the review because these do not answer the research question. However, as suggested, we have listed the seven excluded reports in supplementary material (table below).


Q2: Though it is a systemic review, after analysis of the selected articles, authors should be able to form good hypotheses to explain the reasons for high susceptibility of diabetics to malaria infection. They should also be able to explain the reasons for high severity and complications of malaria in diabetics.

A2: We have made it clear what pathophysiological hypothesis could explain the associations of interest (page 10 updated manuscript).

**Competing Interests:** None.
supplementary materials) a list of the seven full-text articles that were excluded.

Study characteristics: The authors state that “In all the studies the malaria diagnosis was confirmed with blood tests, including PCR.” This is however not correct; the malaria cases in the study by Khuu et al were identified by ICD-9 discharge diagnoses since laboratory results were not included in the NIS (Nationwide Inpatient Sample). This is an important difference and limits the comparison with the study by Wyss et al. In addition, this implies either that the authors need to exclude this study since the case definition does not fit with the one specified under methods, or they need to redo the literature search using a broader definition of malaria, including any additional studies with parasitological un-confirmed cases.

Diabetes and malaria susceptibility: It is important to point out to the readers that the increased risk in this group of diabetics concerned asymptomatic parasitaemia, none of the included subjects presented with fever.

Diabetes and malaria severity: The sentence “Of the selected reports, two provided evidence that people with diabetes had higher odds of severe malaria” should be rephrased. Only one of the papers presented a significantly higher odds of severe malaria for diabetics. However, one could mention that in both studies there was a higher proportion of diabetics among severe cases compared to non-severe. Also, it is important to point out that assessment of severe malaria was based on different methods in the two retrospective studies.

Risk of bias: I do not quite agree concerning the assessment of bias. Could the authors explain why there would be a selection bias in the study by Wyss et al. where all malaria cases reported to the national surveillance system were included? In contrast, including only hospital treated malaria patients could result in a selection bias. Also, concerning missing values, there is information about how missing values are handled in relevant tables and discussion for both the study by Khuu et al. and Wyss et al.

Discussion:
Considering that only three articles were reviewed, it would be appropriate to provide a more thorough analysis concerning the diverging results of the two studies assessing risk factors for severe malaria. Any suggestions to why these studies showed different results? Both reported 10% diabetes among severe cases, however a lower proportion of diabetics among non-severe cases in the study by Wyss et al. The authors should consider if the difference could be associated with the selection of malaria cases and definition of severe malaria.

Implications for research: Concerning generalizability, it is important to mention that the studies were done in different types of populations; while the cross-sectional studies were carried out in a non-endemic setting the case-control study was performed in a malaria endemic area where asymptomatic infections are common and severe manifestations of malaria seldom seen among immunocompetent, non-pregnant adults. Different study designs are required depending on setting and which research question one intends to answer, which also should be pointed out in the discussion. Using a general population sample of diabetics or a population based cohort study as the authors suggested would not be a reasonable approach in a non-endemic setting where the incidence of malaria is extremely low. In an endemic setting the challenge is instead lack of reliable health and recording systems as well as difficulty in the diagnostics of clinical malaria due to both frequent reinfections and asymptomatic parasitaemia.

Epidemiological context: As the authors emphasize, the prevalence of diabetes is increasing in many countries with high malaria transmission. However, I would suggest the authors to be a bit more careful in drawing conclusions concerning malaria mortality based on country estimates of diabetes and malaria prevalence.
Pathways: The possible association of diabetes and risk of malaria infection, and risk of severe disease in an ongoing infection, implies completely different pathobiological mechanisms, which the authors should consider elaborating more on. As an example, there are several studies demonstrating that glucose levels affect parasite growth in vitro, which could have implications for malaria severity. Concerning the hypothesis that metformin use could attract mosquitoes it would be reasonable to mention that the same drug also has antimalarial effect (Jones et al 2002).

Conclusions:
Again, important to clarify that there were two different objectives in this review, and the included studies analysed two distinct outcomes, thus it is not justified to simply conclude that there is an association between diabetes and malaria.

References

Are the rationale for, and objectives of, the Systematic Review clearly stated?
Yes

Are sufficient details of the methods and analysis provided to allow replication by others?
Partly

Is the statistical analysis and its interpretation appropriate?
Not applicable

Are the conclusions drawn adequately supported by the results presented in the review?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Epidemiology of imported malaria and risk factors for severe malaria

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.
a systematic review to study the association between diabetes and … or to We conducted a systematic review to study if diabetes is a risk factor for…

A1: The ‘background’ section of the abstract, as well as the last sentence of the introduction, have been modified as suggested to reflect that the review focused on both outcomes: malaria and malaria severity.

Q2: Selection criteria: Concerning definition of outcome the authors need to specify how severe malaria was defined and revise the definition of malaria cases as laboratory confirmed, see below under results.

A2: Unlike malaria infection, for which we defined there should have been laboratory confirmation, we did not have a specific definition for malaria severity. We made the first decision to avoid bias or misclassification of malaria cases. However, we strongly believe that severe cases would be treated (and studied) in hospitals or other highly-specialized health facilities. Therefore, they are most likely to rely on laboratory tests to define severity, thus less likely to be subject of bias or misclassification. We have discussed these arguments in the ‘limitations’ section.

Q3: Data collection: Suggest that the authors specify in the methods section if screening of articles were done independently by the two reviewers and also include the proportion of agreement between reviewers in the screening process (not only as supplement).

A3: We have specified that both review stages (screening and full-text) were conducted by two reviewers independently. Also, as suggested, we have reported the agreement and Kappa metrics. Please refer to ‘data collection’ section for details.

Q4: Ten articles were selected and assessed for eligibility, it would be recommended to add (as supplementary materials) a list of the seven full-text articles that were excluded.

A4: We have included a list of the seven reports excluded at the second selection stage (full-text). The table below is in the updated supplementary material.


Q5: Study characteristics: The authors state that “In all the studies the malaria diagnosis was confirmed with blood tests, including PCR.” This is however not correct; the malaria cases in the study by Khuu et al were identified by ICD-9 discharge diagnoses since laboratory results were not included in the NIS (Nationwide Inpatient Sample). This is an important difference and limits the comparison with the study by Wyss et al. In addition, this implies either that the authors need to exclude this study since the case definition does not fit with the one specified under methods, or they need to redo the literature search using a broader definition of malaria, including any additional studies with parasitological un-confirmed cases.

A5: We were aware of the point highlighted by the reviewer, and we agree there may be differences that are now pinpointed in the ‘limitations’ section. Nevertheless, because the work by Khuu and colleagues was based on hospital discharge records from a high-income country, we strongly believe these cases were based on laboratory tests hence the inclusion on the review. In fact, because they based the cases selection on ICD codes, these should have been based on laboratory tests to confirm the diagnostic.

Q6: Diabetes and malaria severity: The sentence “Of the selected reports, two provided evidence that people with diabetes had higher odds of severe malaria” should be rephrased. Only one of the papers presented a significantly higher odds of severe malaria for diabetics. However, one could mention that in both studies there was a higher proportion of diabetics among severe cases compared to non-severe. Also, it is important to point out that assessment of severe malaria was based on different methods in the two retrospective studies.

A6: We have rephased the corresponding lines in the ‘results’ section to signal that only one study showed strong association. In addition, as pointed out before (Q5), the ‘limitations’ section now includes a few lines about the differences in ascertainment methods.

Q7: Risk of bias: I do not quite agree concerning the assessment of bias. Could the authors explain why there would be a selection bias in the study by Wyss et al. where all malaria cases reported to the national surveillance system were included? In contrast, including only hospital treated malaria patients could result in a selection bias. Also, concerning missing values, there is information about how missing values are handled in relevant tables and discussion for both the study by Khuu et al. and Wyss et al.
A7: We considered there was high risk of bias because these were cases reported to the national surveillance system. However, after further consideration and studying, we believe the surveillance system in Sweden should be good enough to register all malaria cases, especially severe cases as studied by Wyss and colleagues. Therefore, we re-classified this study as “low risk of bias” in the “Bias in selection of participants into the study” domain (also updated in supplementary material).

We considered “no information” on bias due to missing data because:

1. Wyss et al conducted multiple imputation for missing values in BMI: “To account for missing BMI, a multiple imputation model with chained equations was performed based on variables related to sever malaria, obesity status, and missing BMI”. However, we could not find similar information for diabetes (exposure of interest).

2. Khuu et al reported that multiple imputation was not possible because of limited computational power: “Imputation of missing variables was not feasible due to the large size of the NIS and limited computing power”. We still considered this as “no information” because there were no further details about proportion of missing observations.

Q8: Considering that only three articles were reviewed, it would be appropriate to provide a more thorough analysis concerning the diverging results of the two studies assessing risk factors for severe malaria. Any suggestions to why these studies showed different results? Both reported 10% diabetes among severe cases, however a lower proportion of diabetics among non-severe cases in the study by Wyss et al. The authors should consider if the difference could be associated with the selection of malaria cases and definition of severe malaria.

A8: As pinpointed before, we have discussed in the ‘limitations’ section that a potential driver for the different results between these studies could be the definitions of severe malaria.

Q9: Implications for research: Concerning generalizability, it is important to mention that the studies were done in different types of populations; while the cross-sectional studies were carried out in a non-endemic setting the case-control study was performed in a malaria endemic area where asymptomatic infections are common and severe manifestations of malaria seldom seen among immunocompetent, non-pregnant adults. Different study designs are required depending on setting and which research question one intends to answer, which also should be pointed out in the discussion. Using a general population sample of diabetics or a population-based cohort study as the authors suggested would not be a reasonable approach in a non-endemic setting where the incidence of malaria is extremely low. In an endemic setting the challenge is instead lack of reliable health and recording systems as well as difficulty in the diagnostics of clinical malaria due to both frequent reinfections and asymptomatic parasitaemia.

A9: As suggested, in the ‘implications for research’ section we have included a few lines highlighting the differences and strengths of study designs. We agree that a population-based cohort in a non-endemic area would not be reasonable. However, experience has shown us that population-based cohorts in endemic settings where resources are not abundant as in high-income countries, are feasible and provide strong local evidence.
Q10: Epidemiological context: As the authors emphasize, the prevalence of diabetes is increasing in many countries with high malaria transmission. However, I would suggest the authors to be a bit more careful in drawing conclusions concerning malaria mortality based on country estimates of diabetes and malaria prevalence.

A10: We have toned down these lines to be more careful in drawing conclusions concerning malaria mortality based on country estimates.

Q11: Pathways: The possible association of diabetes and risk of malaria infection, and risk of severe disease in an ongoing infection, implies completely different pathobiological mechanisms, which the authors should consider elaborating more on. As an example, there are several studies demonstrating that glucose levels affect parasite growth in vitro, which could have implications for malaria severity. Concerning the hypothesis that metformin use could attract mosquitos it would be reasonable to mention that the same drug also has antimalarial effect (Jones et al 2002).

A11: We would rather not further elaborate on the mechanisms behind the associations of interest. This work intended to give an epidemiological overview, instead of a comprehensive pathophysiological explanation. Concerning the hypothesis that metformin could attract mosquitos, we have now mentioned the antimalarial effects and included the suggested reference.

Q12: Again, important to clarify that there were two different objectives in this review, and the included studies analysed two distinct outcomes, thus it is not justified to simply conclude that there is an association between diabetes and malaria.

A12: As we did in the abstract and introduction, we have also clarified in the conclusion that there were two aims (diabetes-malaria and diabetes-malaria severity).

**Competing Interests:** None.