

Household Protective Behaviors and Environmental Risk Factors Associated with Malaria Infection in an Endemic Area of Indonesia: A Case-Control Study

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Research Article

Keywords: community behavior, Anopheles, risk factors, malaria elimination

Posted Date: October 1st, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10996348/v1>

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Additional Declarations: No competing interests reported.

Abstract

Background

Malaria remains an important public health challenge in tropical regions, including Indonesia, particularly in endemic areas where environmental conditions support *Anopheles* mosquito transmission.

Sustainable malaria elimination requires not only vector control interventions but also understanding household behaviors and environmental determinants. This study aimed to investigate the association between community behaviors, mosquito breeding-related environmental factors, and malaria infection in the working area of Hanura Primary Health Center, Pesawaran District, Lampung Province, Indonesia.

Methods

A case-control study was conducted involving 180 participants, including 60 microscopically confirmed malaria cases and 120 malaria-negative controls. Data were collected through structured interviews and household environmental observations. Chi-square tests, stratified analysis, and multivariable logistic regression were performed to identify independent risk factors.

Results

Night-time outdoor activities were significantly associated with malaria infection in the bivariate analysis (OR = 2.03; 95%CI:1.035–4.011; $p = 0.025$). After adjustment for potential confounders, household installation of wire mesh on ventilation openings remained significantly associated with malaria risk reduction (OR = 3.15; 95%CI:1.099–9.074; $p = 0.033$). Mosquito repellents, bed net use, mosquito breeding sites, and breeding-site distance were not significantly associated with malaria infection.

Conclusions

Strengthening household-level interventions, particularly improving housing protection and reducing risky night-time exposure, may contribute to malaria control strategies in endemic settings.

BACKGROUND

Malaria remains a major public health concern in tropical and subtropical regions, despite substantial progress in global prevention, diagnosis, and treatment strategies. The disease is transmitted through the bite of infected female *Anopheles* mosquitoes carrying *Plasmodium* parasites. Although malaria control programs have been implemented extensively, persistent transmission continues to occur in several endemic settings due to complex interactions among environmental conditions, vector dynamics, and human behaviors. According to the World Malaria Report, malaria accounted for more than 260 million cases and hundreds of thousands of deaths globally in 2023, with the greatest disease

burden occurring in Africa and Southeast Asia [1, 21]. The achievement of malaria elimination has become increasingly challenging due to climate change, land-use transformation, insecticide resistance, antimalarial drug resistance, and inequities in access to healthcare services [1, 2]

Southeast Asia has demonstrated substantial progress in malaria control; however, several areas continue to experience sustained local transmission. Geographical characteristics, ecological conditions, population mobility, and human–environment interactions remain important determinants in maintaining malaria transmission cycles [2]. Consequently, contemporary malaria elimination strategies require approaches that extend beyond conventional case management and vector control interventions. A comprehensive understanding of the interactions among humans as hosts, *Plasmodium* parasites as agents, and environmental conditions as supporting factors is essential for developing effective and sustainable malaria control strategies.

Indonesia remains one of the countries facing significant challenges in achieving malaria elimination. The distribution of malaria transmission varies considerably across regions due to differences in geographical, socioeconomic, and ecological characteristics. Although several districts and municipalities have achieved elimination status, specific areas, particularly those with favorable ecological conditions for vector survival, continue to experience malaria transmission [3]. The Indonesian government has established a national malaria elimination target by 2030; however, achieving this goal requires strengthening surveillance systems, sustaining vector control programs, and increasing community participation in malaria prevention efforts [4].

Historically, malaria control programs have focused primarily on vector-based interventions, including the distribution of insecticide-treated nets, indoor residual spraying, early diagnosis, and effective antimalarial treatment. Nevertheless, the effectiveness of these interventions is strongly influenced by individual behaviors and household environmental conditions. Human behaviors, such as outdoor activities during mosquito biting hours, utilization of personal protection measures, sleeping under mosquito nets, and housing characteristics, can substantially influence the likelihood of human exposure to *Anopheles* mosquitoes [5]. In addition, environmental conditions, including the presence of mosquito breeding habitats such as wetlands, ponds, stagnant water, and poorly managed drainage systems, may sustain vector populations and increase malaria transmission risk [6].

Pesawaran District, Lampung Province, represents one of the malaria-endemic areas in Indonesia with a history of persistent transmission. The working area of Hanura Primary Health Center has ecological characteristics that support *Anopheles* mosquito breeding, including coastal areas, wetlands, and aquaculture ponds. Previous research reported that malaria incidence in this area increased significantly, with an Annual Parasite Incidence (API) reaching 65.57‰ in 2015 [7]. These conditions indicate that malaria control efforts in Hanura require an integrated approach that considers individual characteristics, household behaviors, and environmental determinants simultaneously.

Previous studies have identified various behavioral and environmental factors associated with malaria risk; however, many investigations have evaluated these determinants independently rather than

considering their interactions within a household context. Malaria transmission is a multifactorial process in which human exposure, vector presence, and environmental conditions interact dynamically. Individuals living near mosquito breeding sites may not necessarily experience the same level of infection risk if they implement effective protective behaviors and maintain safer housing conditions. Conversely, individuals with high-risk behaviors, such as frequent nighttime outdoor activities, may remain vulnerable despite relatively controlled environmental conditions.

Therefore, investigating malaria risk factors through an integrated assessment of household behaviors, housing protection measures, and environmental characteristics is essential to provide a more comprehensive understanding of malaria transmission at the community level. A household-based approach may offer important insights because households represent the primary interface between human populations and malaria vectors. Identifying modifiable household-level risk factors could support targeted interventions and improve the effectiveness of malaria elimination programs, particularly in persistent transmission areas.

This study employed a case-control design to investigate the association between community behaviors, mosquito breeding-related environmental factors, and malaria infection in the working area of Hanura Primary Health Center, Pesawaran District, Lampung Province, Indonesia. The study also considered potential confounding factors and evaluated interactions between household protective measures and individual characteristics. Previous research in the same area demonstrated that wire mesh installation on household ventilation was significantly associated with malaria incidence after adjustment for other variables, whereas several factors, including mosquito net use, mosquito repellents, and breeding sites, showed inconsistent associations [7].

Unlike previous studies that commonly examined behavioral or environmental determinants separately, this study provides a more comprehensive assessment by simultaneously evaluating behavioral practices, household protection measures, and environmental risk factors in an endemic malaria setting. Furthermore, evaluating potential effect modification between mosquito net use and age provides additional insight into variations in intervention effectiveness among different population groups. The findings of this study are expected to contribute evidence for strengthening household-based malaria interventions and supporting more targeted strategies toward malaria elimination in Indonesia.

METHODS

Study Design and Setting

This study employed an observational analytical design using a case-control study approach to investigate the association between household behavioral factors, environmental characteristics, and malaria infection. The case-control design was selected because it enables the identification of potential risk factors associated with disease occurrence by comparing individuals with confirmed malaria infection and individuals without malaria infection from the same source population.

The study was conducted in the working area of Hanura Primary Health Center, Pesawaran District, Lampung Province, Indonesia. The study site was selected due to its historical status as a malaria-endemic area with ecological characteristics that support *Anopheles* mosquito transmission. The geographical characteristics of the study area include coastal environments, wetlands, stagnant water areas, and aquaculture ponds, which potentially serve as breeding habitats for malaria vectors.

The Hanura Primary Health Center area has experienced relatively high malaria transmission compared with other areas in Pesawaran District. Previous surveillance data indicated that the area recorded 2,276 confirmed malaria cases with an Annual Parasite Incidence (API) of 65.57‰ in 2015, highlighting the importance of identifying household and environmental determinants contributing to malaria transmission.

Study Population and Participants

The study population consisted of residents living within the working area of Hanura Primary Health Center, Pesawaran District. A total of 180 participants were included in this study, consisting of malaria cases and controls. The case group included 60 participants diagnosed with malaria based on microscopic blood examination results. The control group consisted of 120 participants from the same population who had negative microscopic examination results for malaria parasites.

Participants were selected based on the following criteria: residents living in the study area and willing to participate in the study. Controls were selected from the same source population as cases to minimize selection bias and improve comparability between groups.

Variables and Measurements

The dependent variable in this study was malaria infection status, categorized based on laboratory confirmation into malaria-positive cases and malaria-negative controls.

The primary independent variables included household behavioral factors and environmental risk factors associated with malaria transmission. Behavioral variables included: night-time outdoor activities, use of mosquito repellents, use of mosquito nets during sleeping, installation of wire mesh on household ventilation openings. Environmental variables included: presence of mosquito breeding sites around the residence, distance between mosquito breeding sites and respondents' houses.

These factors were selected because they represent potential determinants influencing human exposure to *Anopheles* mosquitoes and malaria transmission risk. Several individual characteristics were also assessed as potential confounding variables, including age, sex, educational level, occupation, and malaria-related knowledge. These variables were considered in the analytical model to obtain more accurate estimates of the relationship between exposure factors and malaria infection.

Data Collection

Data collection was conducted through structured interviews and direct household environmental observations. Individual characteristics and behavioral information were collected using a structured questionnaire assessing malaria prevention practices, personal protective behaviors, and activities potentially associated with increased mosquito exposure.

Household environmental assessments were performed through direct observation to identify potential mosquito breeding habitats surrounding participants' residences. Environmental components evaluated included stagnant water bodies, wetlands, ponds, drainage channels, and other locations considered suitable for *Anopheles* mosquito breeding.

Malaria infection status was determined based on microscopic examination of blood samples. Participants with positive microscopic results were categorized as malaria cases, whereas participants with negative results were categorized as controls.

Statistical Analysis

Data analysis was performed using sequential univariate, bivariate, stratified, and multivariable analyses. Univariate analysis was conducted to describe participant characteristics and the distribution of each study variable using frequencies and percentages. Bivariate analysis was performed to assess the association between each independent variable and malaria infection using the Chi-square test. The strength of association between risk factors and malaria infection was estimated using odds ratios (OR) with 95% confidence intervals (CI).

Stratified analysis was conducted to assess potential confounding effects and effect modification among variables. This analysis was particularly performed to evaluate whether the association between protective behaviors and malaria infection varied according to individual characteristics.

Multivariable analysis was conducted using binary logistic regression to identify independent risk factors associated with malaria infection after controlling for potential confounding variables. The final model presented adjusted odds ratios (AOR), 95% confidence intervals, and corresponding p-values.

Ethical Considerations

This study was conducted following ethical principles for research involving human participants, including respect for participant autonomy, confidentiality, and voluntary participation.

Before data collection, participants received information regarding the study objectives, procedures, potential benefits, and their rights to refuse or withdraw from participation at any stage of the study. Written informed consent was obtained from all participants before enrollment.

All collected information was kept confidential and used exclusively for research purposes. The study procedures were conducted while ensuring participant safety, privacy, and comfort throughout the

RESULT

A total of 180 participants were included in this case-control study, consisting of 60 malaria cases and 120 malaria-negative controls. The distribution of demographic characteristics, household protective behaviors, and environmental factors is presented in Table 1.

Among participants in the malaria case group, a higher proportion reported night-time outdoor activities compared with the control group (55.0% vs. 37.5%). Regarding household protective measures, most malaria cases reported not using mosquito nets during sleep (65.0%) and did not have wire mesh installed on household ventilation openings (90.0%). Potential mosquito breeding sites around the residence were identified among 70.0% of malaria cases and 64.2% of controls.

Regarding individual characteristics, malaria cases were predominantly younger than 26 years (55.0%), male (60.0%), had higher educational attainment (58.3%), reported non-risk occupations (80.0%), and demonstrated good malaria-related knowledge (58.3%).

Table 1
Sociodemographic Characteristics, Household Protective Behaviors, Environmental Factors, and Their Association with Malaria Infection

Variabel	Malaria Cases n (%)	Controls n (%)	Odds Ratio (OR)	95% CI	p-value
Night-time outdoor activity					
Yes	33 (55,0)	45 (37,5)	2,03	1,035–4,011	0,025*
No	27 (45,0)	75 (62,5)	Ref		
Mosquito repellent use					
No	44 (73,3)	93 (77,5)	0,79	0,370–1,760	0,536
Yes	16 (26,7)	27 (22,5)	Ref		
Mosquito net use					
No	39 (65,0)	47 (39,2)	2,88	1,445–5,809	0,001*
Yes	21 (35,0)	73 (60,8)	Ref		
Wire mesh on ventilation openings					
No	54 (90,0)	93 (77,5)	2,61	0,970–8,196	0,041*
Yes	6 (10,0)	27 (22,5)	Ref		
Presence of mosquito breeding sites					
Yes	42 (70,0)	77 (64,2)	1,30	0,639–2,700	0,430
No	18 (30,0)	43 (35,8)	Ref		
Distance to mosquito breeding sites					
< 500 m	58 (96,7)	116 (96,7)	1,00	0,138–11,350	1,000
≥ 500 m	2 (3,3)	4 (3,3)	Ref		
Sex					
Male	36 (60,0)	57 (47,5)	1,65	0,845–3,272	0,113
Female	24 (40,0)	63 (52,5)	Ref		

The results of bivariate analysis are presented in Table 1. Several behavioral and household protective factors showed significant associations with malaria infection. Participants who reported night-time outdoor activities had a significantly higher risk of malaria infection compared with those who did not engage in such activities (OR = 2.03; 95%CI: 1.035–4.011; p = 0.025).

The absence of mosquito net use was also significantly associated with malaria infection. Participants who did not use mosquito nets during sleep had a higher likelihood of malaria infection compared with those who used mosquito nets (OR = 2.88; 95%CI: 1.445–5.809; $p = 0.001$). Similarly, the absence of wire mesh on household ventilation openings was associated with increased malaria risk (OR = 2.61; 95%CI: 0.970–8.196; $p = 0.041$).

In contrast, the use of mosquito repellents was not significantly associated with malaria infection (OR = 0.79; 95%CI: 0.370–1.760; $p = 0.536$). Environmental variables, including the presence of mosquito breeding sites (OR = 1.30; 95%CI: 0.639–2.700; $p = 0.430$) and distance between breeding sites and houses (OR = 1.00; 95%CI: 0.138–11.350; $p = 1.000$), also showed no statistically significant associations. Individual characteristics, including sex, age, education, occupation, and malaria knowledge, did not demonstrate statistically significant relationships with malaria infection ($p > 0.05$).

Stratified analysis was conducted to assess potential confounding factors and effect modification among variables associated with malaria infection. The analysis identified a potential interaction between mosquito net use and age. The interaction term between mosquito net use and age showed a statistically significant association with malaria infection (OR = 14.03; 95%CI: 3.292–59.817; $p < 0.001$). This finding indicates that the association between mosquito net use and malaria infection varied according to participant age categories. The protective effect of mosquito nets was therefore not uniform across different age groups.

Multivariable logistic regression analysis was performed to identify independent factors associated with malaria infection after adjusting for potential confounding variables. The final regression model is presented in Table 2. The analysis demonstrated that wire mesh installation on household ventilation openings remained independently associated with malaria infection.

Participants living in houses without wire mesh protection had a significantly higher risk of malaria infection compared with those living in houses with wire mesh installation (adjusted OR = 3.15; 95%CI: 1.099–9.074; $p = 0.033$). Night-time outdoor activity was not statistically significant after adjustment (adjusted OR = 1.87; 95%CI: 0.921–3.809; $p = 0.083$). Similarly, mosquito repellent use (adjusted OR = 1.06; 95%CI: 0.457–2.461; $p = 0.891$) and mosquito net use (adjusted OR = 0.81; 95%CI: 0.311–2.108; $p = 0.666$) were not independently associated with malaria infection in the final model. The interaction between mosquito net use and age remained statistically significant (adjusted OR = 14.03; 95%CI: 3.292–59.817; $p < 0.001$), suggesting that age modified the relationship between mosquito net utilization and malaria infection risk.

Table 2
Final Logistic Regression Model of Factors Associated with Malaria Infection

Variable	Adjusted OR	95% CI	p-value
Night-time outdoor activity	1.87	0.921–3.809	0.083
Mosquito repellent use	1.06	0.457–2.461	0.891
Mosquito net use	0.81	0.311–2.108	0.666
Wire mesh installation	3.15	1.099–9.074	0.033
Age	0.35	0.122–1.049	0.061
Mosquito net × age interaction	14.03	3.292–59.817	< 0.001

DISCUSSION

This study demonstrates that community behavioral factors and household physical characteristics play important roles in malaria transmission in the working area of Hanura Primary Health Center, Pesawaran District. The multivariable analysis showed that the installation of wire mesh on household ventilation openings was an independent factor associated with malaria infection. Respondents living in houses without wire mesh protection had a higher risk of malaria infection compared with those living in houses with this protective measure (OR = 3.15; 95%CI = 1.099–9.074; $p = 0.033$). These findings highlight that malaria transmission is a complex process influenced by interactions between humans, vectors, and environmental conditions. Therefore, malaria control strategies should not rely solely on drug-based interventions and vector control measures but should also incorporate household-level risk modification approaches [1, 3, 4].

Human nighttime activities represent an important determinant of exposure risk to *Anopheles* mosquitoes. Most *Anopheles* species exhibit biting behavior from nighttime to early morning, resulting in increased exposure among individuals who remain outdoors during peak mosquito activity periods. In this study, nighttime outdoor activities were significantly associated with malaria infection in the bivariate analysis (OR = 2.03; 95%CI = 1.035–4.011; $p = 0.025$). This finding indicates that human behavioral patterns may contribute to sustaining malaria transmission, particularly in areas where malaria vectors remain active [5].

Previous studies in Indonesia have demonstrated that human activity patterns are closely related to exposure levels to *Anopheles* vectors. Rozi et al. reported that human activities based on time and location significantly influenced the risk of contact with malaria vectors, particularly when individuals were outdoors during mosquito biting periods. Their study suggested that despite the availability of preventive interventions such as mosquito nets, residual transmission may persist due to outdoor exposure (outdoor exposure) [7]. Similar findings have been reported in malaria-endemic areas of Papua, where protection gaps against *Anopheles* bites remain due to pre-sleep activities, outdoor activities, and limitations of household-based protective measures [9].

This study also found that mosquito net use was significantly associated with malaria infection in the bivariate analysis. Respondents who did not use mosquito nets had nearly three times higher risk of malaria infection compared with those who used mosquito nets (OR = 2.88; 95%CI = 1.445–5.809; $p = 0.001$). This finding is consistent with global evidence indicating that insecticide-treated nets, particularly long-lasting insecticidal nets (LLINs), remain among the most effective malaria prevention interventions, especially in areas with high transmission intensity [17, 18].

However, in the multivariable analysis, the main effect of mosquito net use was no longer statistically significant after adjustment for age and the interaction between mosquito net use and age. This finding suggests that the effectiveness of mosquito nets is not solely determined by ownership but is also influenced by usage patterns, adherence, sleeping behavior, exposure timing, and individual characteristics. Recent studies have demonstrated that protection gaps may persist despite high mosquito net coverage because malaria exposure can occur before individuals enter mosquito nets or through outdoor activities [9, 10, 11].

An important finding of this study was the significant interaction between mosquito net use and age in relation to malaria infection. The interaction term showed a significant association with malaria infection (OR = 14.03; 95%CI = 3.292–59.817; $p < 0.001$). This finding indicates that the protective effect of mosquito nets differs across age groups, suggesting that malaria prevention strategies should consider population-specific characteristics. Age may influence activity patterns, mobility, adherence to mosquito net use, and exposure levels to malaria-risk environments [5, 7]. Biologically, the interaction between mosquito net use and age may be explained by differences in mobility, behavioral patterns, and exposure intensity to *Anopheles* mosquitoes. Younger and economically productive individuals tend to have higher outdoor activities during mosquito biting periods, potentially reducing the protective effectiveness of mosquito nets. Conversely, older individuals with fewer nighttime outdoor activities may obtain greater protection from consistent mosquito net use.

Beyond individual behaviors, this study demonstrates that household physical characteristics represent an important component of malaria prevention. Installation of wire mesh on household ventilation openings was identified as an independent factor associated with malaria infection. Houses without ventilation protection may provide greater opportunities for *Anopheles* mosquitoes to enter indoor environments, thereby increasing human–vector contact. Experimental studies have demonstrated that house screening interventions can reduce mosquito exposure inside households [13].

These findings support previous evidence regarding healthy housing interventions, demonstrating that structural modifications, including installation of wire mesh on doors and ventilation openings, sealing household gaps, and improving housing quality, can reduce malaria risk. Meta-analyses of housing improvement interventions indicate that household-based approaches have substantial potential as complementary malaria control strategies because they provide more sustainable protection compared with interventions that rely solely on individual behavioral compliance [6, 8, 12, 14].

Studies conducted in various endemic regions have also demonstrated that household characteristics are associated with the likelihood of mosquito entry into houses. Houses with open ventilation, poorly sealed walls, and structural gaps may facilitate increased human–vector contact. Therefore, integrating malaria control programs with healthy housing approaches is essential, particularly in areas where local transmission persists [8, 15].

In this study, the presence of mosquito breeding sites was not significantly associated with malaria infection. This finding does not imply that environmental factors are unimportant in malaria transmission; rather, it indicates that the presence of larval habitats alone may not adequately represent transmission risk. Malaria risk is influenced by the interaction between productive breeding habitats, adult vector density, dominant *Anopheles* species, and the intensity of human–mosquito contact [22, 24].

Studies on malaria ecology have demonstrated that environmental characteristics, including rainfall, temperature, land-use patterns, water bodies, and ecosystem changes, influence the distribution and density of *Anopheles* populations. Therefore, surveillance of mosquito breeding sites should be integrated with entomological surveillance to provide a more accurate assessment of habitat contribution to malaria transmission risk [19, 22, 23, 24].

Within the context of malaria elimination in Indonesia, these findings highlight the importance of implementing integrated control strategies. Indonesia has made considerable progress toward malaria elimination; however, several areas continue to face challenges due to geographical conditions, vector habitats, population mobility, and variations in community behavior [1, 2, 3, 16, 20]. Malaria elimination requires not only rapid diagnosis and effective treatment but also strengthened surveillance, vector control, improved housing conditions, and behavioral interventions [4, 18].

Overall, this study indicates that household-based interventions, particularly the installation of ventilation screening, improved mosquito net utilization, and education regarding nighttime activities, represent important components of malaria control strategies in endemic areas. An integrated approach combining environmental management, behavioral modification, and health system strengthening is required to accelerate malaria elimination in Indonesia.

This study has several limitations. The case-control design does not allow direct determination of causal relationships between exposure factors and malaria infection. Furthermore, behavioral data collected through interviews may be subject to recall bias. This study also did not include entomological assessments, such as vector density measurements and *Anopheles* mosquito characteristics, which could provide further understanding of malaria transmission dynamics.

CONCLUSIONS

This study demonstrates that household-level behavioral and environmental factors are associated with malaria infection in an endemic area of Indonesia. Night-time outdoor activities and mosquito net use

were significantly associated with malaria infection in the bivariate analysis, while the absence of wire mesh on household ventilation openings remained an independent risk factor after adjustment for potential confounding variables.

The findings highlight the importance of strengthening household-based malaria prevention strategies. Improving housing protection through the installation of wire mesh, promoting consistent mosquito net utilization, and reducing risky nighttime exposure should be considered important components of malaria control interventions in endemic settings.

A comprehensive malaria elimination approach should integrate household protection measures, behavioral interventions, environmental surveillance, and sustained vector control strategies. Future studies using longitudinal designs and incorporating entomological assessments are recommended to further evaluate the dynamic relationships between human behavior, environmental conditions, vector characteristics, and malaria transmission.

Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the ethical principles for research involving human participants, including the principles outlined in the Declaration of Helsinki. Ethical approval was obtained from the Commission of Research Ethics and Community Health Services, Faculty of Public Health, Universitas Indonesia (Ethical Approval Number: 49/UN2.F10/PPM.00.02/2016).

Consent for publication

Not applicable. This manuscript does not contain individual person's identifiable data, images, or personal information requiring consent for publication.

Competing interests

The authors declare that they have no competing interests.

Funding

The authors received no specific funding, grants, or financial support from any funding agency in the public, commercial, or not-for-profit sectors for this research.

Author Contribution

AAP conceptualized the study, designed the methodology, performed data analysis, interpreted the results, and drafted the manuscript. NMK contributed to the study design, epidemiological interpretation, and critical revision of the manuscript. TYMW supervised the research methodology, contributed to data interpretation, and critically reviewed the manuscript. All authors read and approved the final version of the manuscript.

Data availability

The datasets generated and/or analyzed during the current study are not publicly available due to ethical restrictions and participant confidentiality requirements but may be available from the corresponding author upon reasonable request and with approval from the relevant ethics committee.

Materials availability

Not applicable. This study did not use or generate any unique biological materials or experimental materials.

Code availability

Not applicable. No custom software, algorithms, or computer code were developed for this study.

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