Published in final edited form as:

Lancet Infect Dis. 2008 September ; 8(9): 564–570. doi:10.1016/S1473-3099(08)70130-0.

Malaria's Indirect Contribution to All-Cause Mortality in the Andaman Islands during the Colonial Era

Prof G. Dennis Shanks, MD^{1,2}, Simon I. Hay, D Phil³, and Prof David J. Bradley, DM^{3,4}

¹Australian Army Malaria Institute, Enoggera, Australia

²Faculty of Health Sciences, University of Queensland, Brisbane, Australia

³Department of Zoology, Oxford University, Oxford, UK

⁴London School of Hygiene and Tropical Medicine, London, UK

Abstract

Malaria appears to have a substantial secondary effect on other causes of mortality. From the 19th century, malaria epidemics in the Andaman Islands Penal Colony were initiated by the brackish swamp breeding malaria vector *Anopheles sundanicus* and fueled by the importation of new prisoners. Malaria was a major determinant of the highly variable all-cause mortality rate (correlation coefficient $r^2=0.60$, $n=68$, $p<0.0001$) from 1872 to 1939. Directly attributed malaria mortality based on postmortem examinations rarely exceeded one fifth of total mortality. Infectious diseases such as pneumonia, tuberculosis, dysentery and diarrhea, which combined with malaria made up a majority of all-cause mortality, were positively correlated to malaria incidence over several decades. Deaths secondary to malaria (indirect malaria mortality) were at least as great as mortality directly attributed to malaria infections.

Keywords

malaria; epidemic; Andaman Islands; mortality

Introduction

Long time-series of health data of reliable quality from sites with major communicable disease problems provide invaluable information for epidemiological study of those infections and their impact on mortality. This paper aims to describe and explain how the records from the Andaman Islands came to have such characteristics and to apply them to explore the magnitude of indirect mortality attributable to malaria.

Acute *Plasmodium falciparum* malaria kills many African children and a substantial number of adults from Asia and Latin America every year.¹⁻³ Malaria can kill directly through recognized syndromes such as cerebral malaria or severe malaria anemia,⁴ but in addition,

Corresponding author: Prof G. Dennis Shanks, Australian Army Malaria Institute, Enoggera, QLD 4051, Australia. Phone: 61 7 3332 4801 fax: 61 7 3332 4800, dennis.shanks@defence.gov.au.

Alternate address: Prof David Bradley, Tinbergen Building, Department of Zoology, South Parks Road, University of Oxford, Oxford, OX1 3PS, UK phone: +44 (0) 207 927 2233 fax: +44 20 7580 9075 david.bradley@lshtm.ac.uk

Author's roles: GDS conceived the epidemiological study, gathered the data, assisted in the analysis and wrote the manuscript. SIH assisted with the data collection, analysis, interpretation and writing of the manuscript. DJB assisted with the epidemiology and the analysis, interpretation and writing of the manuscript.

Part of the data described in this manuscript has been presented at the 54th meeting of the American Society of Tropical Medicine and Hygiene in Washington DC in 2005.

this parasitic infection of the blood might exert a substantial indirect mortality effect which is hard to measure.^{2,5} Quantifying the additional burden of indirect malaria mortality is essential to correctly ranking the importance of malaria intervention and control. Malaria mortality studies are difficult to evaluate due to varying epidemiological situations, differing means of ascertaining cause of death, the large number of subjects required and modification of natural mortality caused by the presence of medically-trained observers.⁶ Search of historical records shows there were few prospective, long-term malaria morbidity and mortality studies prior to the advent of modern chemotherapy. The British colonial Government of India in the 19th and early 20th centuries collected an extensive array of public health indicators in prison and military populations, however, where exact population figures were known.⁷⁻⁹ This study evaluates a particular subset of these historical data in order to determine what can be learned about malaria's indirect effect on all-cause mortality.

Malaria in the Andaman Islands Penal Colony

The Andaman Islands are an isolated archipelago in the Bay of Bengal 200 miles from the Burmese coast which extends approximately from 10-14° N latitude. The Andaman Islands Penal Colony was founded by the British colonial Government of India following the large scale rebellion of Indian soldiers in 1857, known as the Indian Mutiny,¹⁰ despite an earlier attempt to colonize the area in the 18th century had failed due to high mortality of the settlers.¹¹ Britain had a long-standing policy of transporting undesirable criminal or political elements far from their native country to serve out life sentences: both Georgia in the United States and New South Wales in Australia began as penal colonies. Following the suppression of the Indian Mutiny many ex-soldiers implicated in the rebellion were transported to the Andaman Islands to form their own prison on the undeveloped South Andaman Island around a harbor which became known as Port Blair. Conditions were primitive and the Port Blair colony nearly failed like its 18th century predecessor.¹⁰ Gradually conditions became more settled, barracks were built, jungle cleared and various agricultural projects to grow coconuts, tea, coffee, cocoa, sisal and foodstuffs for local consumption were initiated.¹² The administrative headquarters was isolated on Ross Island and consisted of detachments of British and Indian Army regiments, a military police battalion and medical support provided by the officers of the Indian Medical Service.⁸ Indian civilian prisoners sentenced to life imprisonment were later transported to the Andaman Islands Penal Colony, in part to relieve crowding in mainland Indian jails. The total prison population peaked at more than 14,000 early in the 20th century. (See Figure 1.) The majority of these prisoners had been convicted of murder¹¹; since the internment of political prisoners did not become a major function of Port Blair until the 20th century.¹² Although primitive by modern standards, the Andaman Islands Penal Colony aimed to reflect progressive Victorian ideas of penal reform. Well-behaved prisoners could eventually become self-supporting convicts with their own agricultural land and be allowed to raise families after serving in various levels of confinement and forced labor.¹² The small number of indigenous inhabitants were not part of this system nor were data collected on them. The Japanese Imperial Navy captured the Andaman Islands in 1942 without any fighting and the Penal Colony was closed in 1945 following the islands' reoccupation by British Commonwealth / Indian Army forces the same year.¹⁰

Evolution of health data collection in the Andaman Islands

The Andaman Islands Penal Colony had a deservedly notorious reputation for lethal febrile disease. Annual all-cause mortalities as high as 630/1000/year in 1859 were recorded as shown in Figure 2.⁸ Even after the colony was fully established, mortality was routinely in excess of the mean Indian prison population mortality, often twice as great. Several high-level government inquiries were launched to reconcile the stated policy of humane

imprisonment with the huge mortality. The early repercussions of these scandalous prisoner death rates were improved medical care and very detailed collection of medical statistics by officers of the Indian Medical Service.¹⁰ The medical service at Port Blair eventually consisted of five hospitals capable of holding over 1000 inpatients at any one time, staffed by six to ten physicians of varying expertise. They were assisted by ancillary nursing staff and pharmacy practitioners, often trained from the convict population. Low thresholds for hospitalization existed because any sick prisoner had to be removed from his work group or barracks and put in the hospital, as there was no alternative place to confine them. The hospitalization rate for specific diagnoses is used in this review, therefore, as a direct indicator of total disease morbidity. Total and disease specific hospital admissions were all carefully and consistently reported from the Andaman Islands Penal Colony for over fifty years.⁸

Despite the limitations of 19th century medical knowledge and the lack of any effective chemotherapeutic agent other than quinine, mortality reporting within the completely isolated prison population was very complete, since any prisoner dying in the Andaman Islands Penal Colony was legally required to have a post-mortem examination conducted by a medical officer. This law was observed with few exceptions.¹³ Monthly administrative and medical reports forwarded to Calcutta listed twelve diseases; annual reports, which began in 1864, eventually listed >150 diagnostic categories within the prison population. Every death in or outside the hospital was recorded and a cause of death assigned. A few infectious disease categories including malaria, pneumonia, tuberculosis, dysentery, and diarrhea together accounted for the majority of all deaths and are shown in Figure 3. Microscopic diagnoses began from about 1900 when blood films were examined for malaria parasites and sputum smears for tuberculosis were made. Any histological diagnosis required material to be sent to the medical school in Calcutta for examination (by Sir Leonard Rogers for part of the period).¹⁴

The Malaria Situation

Malaria was the leading cause of hospitalization, with rates often in excess of 1000/1000 men recorded annually as shown in Figure 4.8 Malaria was very seasonal in the Penal Colony, peaking at mid-year with the monsoon. As the scientific understanding of malaria increased from the late 19th century, the diagnostic category changed from intermittent fever diagnosed clinically to malaria determined by blood smears. In a series of 1062 blood examinations reported in 1903, 84% were found to contain malaria parasites.¹⁵ *Plasmodium falciparum* (malignant tertian) outnumbered *P vivax* (benign tertian) by approximately 2:1 with relatively few *P malariae* (quartan) parasites recorded.⁸

Large amounts of quinine or the related mixture “cinchona febrifuge” was the only effective therapeutic recourse, so it is unclear how much of the malaria reported may have been due to chronically suppressed cases which repeatedly relapsed or recrudesced. Prophylactic quinine, usually given to most prisoners two sequential days a week, was intermittently used, stopped and reinstituted from the 1870s onwards, reflecting the apparent lack of effectiveness documented in some of the earliest controlled chemoprophylactic trials ever recorded, in 1903.¹⁵ Prophylactic quinine as given in early 20th century India was shown to produce initially negative blood smears in up to 25% of those eventually proven to have malaria parasites.¹⁶ Given the large amounts of quinine used, the presence of blackwater fever is not surprising although there is no known explanation for its peak prevalence occurring after the end of World War I (Figure 4). Annual malaria incidence varied by a factor greater than five and was followed by a malaria attributed mortality of between 2-10/1000 indicating that malaria usually killed less than 1% of prisoners hospitalized with that diagnosis. Although few febrile persons with acute onset of coma consistent with

cerebral malaria were recorded in the Andaman Islands, many malaria deaths indicated chronic disease, severe anemia and a uncertain syndrome listed as “spleen affections”. In retrospect it is possible to see that deaths ascribed to “fever with jaundice” were probably due to leptospirosis and this was substantiated in 1928 when *Leptospira icterohaemorrhagiae* was isolated using guinea pig inoculation.⁸ Although probable cases of severe leptospirosis were diagnosed as Weil’s disease from 1911, it is unclear how much this may have been confused with severe malaria.^{17,18}

There was great variation in both malaria and in mortality from other causes from year to year, the determinants of which are analyzed elsewhere. Administrative factors determining the number and type of new prisoners transported to the Andaman Islands, however, do seem to have contributed to the initiation of malaria epidemics. The size of the previous year’s prisoner intake was loosely associated ($r^2=0.21$, $n=57$, $p<0.01$) with increased malaria, and introduction of prisoners may have contributed both non-immunes and also those infected with new strains of the parasite. The sole malaria vector species was *Anopheles sundanicus*, as shown by Christophers in 1912, whose breeding sites were both created and eliminated by the various types of public works that were undertaken due to changes in prison policy and sometimes in attempts to control malaria.¹³ There was therefore a miscellany of drivers of malaria incidence, superimposed on annual cycles of climatic origin. We use this variation to study the between-year relationships between different causes of mortality.

Indirect Malaria Mortality

Malaria associated mortality is a descriptive term for mortality linked to malaria but not directly attributed to malaria. Searching PubMed using the topics “malaria” and “indirect mortality” one finds that the recent literature has mostly been associated with *P. falciparum* malaria in children^{6,19-23} and pregnant women in Africa.^{24,25} Insecticide impregnated bed net programs are widely reported to result in a larger drop in all-cause mortality than can be accounted for directly by malaria.²⁶⁻²⁹ Cause of death determinations were typically done by verbal autopsy which is known to be problematic.³⁰ Other historical evidence of indirect malaria mortality was seen during malaria eradication residual insecticide spraying programs, when the mortality reduction achieved by this malaria-specific intervention was greater than expected based on mortality attributed to malaria. The best described example of a residual insecticide spraying program decreasing both malaria-specific and all-cause mortality was in Sri Lanka (Ceylon) following World War II.^{31,32} Although the decrease in all-cause mortality was remarkable, it is more difficult to attribute this result only to malaria eradication as other economic and medical improvements occurred simultaneously. In Guyana the elimination of the mosquito vector from the coastal sugar plantations caused a major demographic shift partly attributed to decreased pneumonia and nephritis mortality in addition to malaria.³³ When such indoor spray campaigns were withdrawn, however, a subsequent reversion in mortality could occur, as in the Pare area of Tanzania and the highlands of Madagascar.^{34,35}

There are mathematical arguments based on the prevalence of genes known to protect against mortality due to *P. falciparum* malaria such as sickle cell anemia that indicate that the evolutionary selection for such genes is greater than that caused by malaria attributed mortality alone.^{36,37}

Indirect malaria mortality in adults has been much less studied than in children and deals mainly with epidemic malaria in low transmission areas.³⁸⁻⁴¹ Some circumstantial evidence can be obtained from the historical archives, however. Large mortality rates driven by malaria epidemics, probably due to *An. sundanicus*, have been previously described in

Southeast Asia. In the 18th century during the Dutch colonization of Java, fish pond construction created mosquito habitat similar to that seen in the Andaman Islands which appears to have directly led to mortality rates greater than 500/1000/year in Dutch East Indies Company personnel.⁴² During World War I, severe anemia was commonly described in Serbian soldiers as a consequence of epidemic *P. falciparum* malaria during the Macedonian Campaign.⁴³ During the same campaign, pulmonary manifestations of malaria were reported in many British soldiers.^{44,45} At the end of World War I both Major Philip Manson-Bahr and Lieutenant Colonel Hamilton Fairley encountered epidemic malaria in soldiers in Palestine.^{46,47} Clinical and pathological studies on 80 autopsy cases concluded that uncomplicated *P. falciparum* malaria only accounted for 16% of the deaths, a large majority dying with bronchopneumonia (59%), dysentery (18%) or sepsis (6%) complications of malaria. Fortunately, large scale forced labor schemes such as the Andaman Islands Penal Colony were uncommon. Similar work conditions and diseases, however, were experienced by Allied prisoners of war along the Siam-Burma railway during World War II. A truly remarkable report documented the destruction of “F force” where fewer than half of 7000 prisoner/soldiers survived eight months railway building in the jungles of Southeast Asia.⁴⁸ The authors who were also prisoners state “*Malaria was recorded as the sole cause in 4 per cent of the total deaths, and as one of the two main causes in a further 7 per cent. But several medical officers expressed the opinion that these figures, which are relatively insignificant in comparison with the death roll from other diseases, tend to minimize unduly the importance of malaria as a contributory cause of death*”. Also during World War II, a series of 125 patients with pneumonitis associated with malaria was reported from the William Gorgas Hospital in Panama where pneumonitis was combined with malaria in 3.7% of the soldiers with malaria.⁴⁹ More recent information involving adults previously unexposed to malaria migrating to the intensely malarious island of New Guinea, show that severe malaria is much more common in adults than in their similarly malaria-inexperienced children.^{50,51} Thus multiple associations of malaria morbidity with other infectious disease mortality have been historically observed and this sample is unlikely to be comprehensive.

Malaria's Effect on All-Cause Mortality in the Andaman Islands

One of the opportunities of the half century of malaria and mortality records from the Andaman Islands Penal Colony is that they allow partial insight into malaria associated mortality. In the Andaman Islands it was observed by several Indian Medical Service officers that other infectious disease mortality rose when malaria increased. Christophers noted in 1912 that “*It seemed probable, however, that the real effect of malaria in enhancing the death rate is greater than is indicated by the number of deaths directly due to this disease.*”¹³ He went on to specify that much of this enhanced mortality was due to pneumonia. He further noted in an autopsy series of more than 1100 cases, that pneumonia patients had much heavier spleens than those succumbing to dysentery or tuberculosis and used these data in an effort to link chronic malaria infection to poor outcome in pneumonia patients.¹³ The Chief Medical Officer in the Andaman Islands Penal Colony, Major J H Murray, stated in the annual report of 1915 that “*The increase of the prevalence and virulence of malaria in 1915 was accompanied by an enormous increase in the number of cases of, and deaths from pneumonia*”. These observations on pneumonia were confirmed by Major Gordon Covell of the Central Malaria Bureau in 1927 when he reviewed a further autopsy series of >500 cases.^{52,53} Others also noted a relationship between malaria and other infections as in the 1911 annual medical report noting “*with less malaria in the settlement, there is also less dysentery, and hence a comparatively low mortality*” as well as “*convicts whose health has been undermined by malaria or other disease, appear to be more liable to pulmonary tuberculosis*”. The subsequent 1912 report stated “*there are other considerations which favour the view that the relation between malaria and dysentery is a*

close one".⁸ In summary, the physicians in the Andaman Islands sensed the inter-relationship of malaria and other infections particularly as an additive effect leading to chronic ill-health and death.

The morbidity and mortality records for pneumonia, tuberculosis, dysentery and diarrhea in Figure 5 (A, C, E, G) show a direct relationship between the respective disease's morbidity and mortality as expected. When one plots malaria incidence versus the respective disease mortality (Figure 5 B, D, F, H), positive correlations between malaria and other infectious diseases are observed. No diseases other than the four infections already mentioned had sufficient incidence for analysis and/or could be obtained consistently from the penal colony records.

Malaria is directly responsible for 11% of all deaths over that period, though malaria accounts for 56% of clinical episodes. The annual malaria incidence rate is strongly correlated with annual all-cause mortality (linear regression has correlation coefficients of $r^2 = 0.60$, $n=68$, $p<0.0001$ for the period 1872-1939; $r^2 = 0.40$, 0.54 with a power regression for the period 1875-1929 for which data on other diseases are available), correlated strongly with all non-malaria mortality ($r^2=0.55$), and even more strongly with the total mortality due to the four specific infections other than malaria ($r^2=0.61$, with a power regression). Malaria rates are not correlated with mortality due to other causes than the five infections ($r^2=0.08$). The four named infections have a much weaker correlation with all-cause mortality (pneumonia $r^2=0.05$; tuberculosis $r^2=0.26$; dysentery $r^2=0.25$; diarrhea $r^2=0.23$). Malaria incidence is correlated, but more weakly, with the specific deaths from the other infections as shown in figure 5. The strongest correlation between malaria case rates and other infective morbidity is with tuberculosis, where it is also correlated with an increased case fatality rate. Moreover the relation between malaria incidence and tuberculosis mortality persists at a significant level even when the large direct effect of tuberculosis incidence on tuberculosis death rates is removed.

We interpret these findings as showing the great importance of malaria as an indirect cause of mortality variation over time in the Andaman Islands, even though the direct mortality was limited in this highly malarious and semi-immune population. The large effect on tuberculosis mortality and on the specific case-fatality rate suggests that malaria hastened the death of patients with tuberculosis. The relations of malaria incidence to diarrhoeal disease and dysentery reflect the observations of earlier workers, but there is no such clear relation to pneumonia deaths, even though so careful a worker as Christophers had commented on the malaria association with pneumonia.¹³ That any association might be intermittent or confounded by epidemic influenza is suggested by monthly records for the four years preceding the 1918 influenza epidemic when malaria morbidity vs. two month lagged respiratory mortality showed a substantial correlation ($r^2=0.35$, $n=55$, $p<0.001$).

It is, of course, not possible to infer causality from simple correlations, but the data are supportive of substantial indirect effects of malaria upon overall mortality in this adult population in the Andaman Islands. There are three alternative hypotheses that could explain the findings if malaria is rejected as the main driver of mortality: a combination of sequential and simultaneous infectious diseases causing an eventual exhaustion of the host's ability to cope with a final event determined by an opportunistic infection other than malaria, some unknown infectious agent and environmental changes. The interaction of malaria and other non-parasitic infectious diseases is probably an additive effect of progressive ill-health that eventually kills the weakest individuals. In the Andaman Islands, invalids unable to work died at ten times the rate of ordinary prisoners (data not shown). Nutritional deficiencies would probably have contributed to failure of immune defences. Regarding unknown causes the only described lethal infectious disease endemic to the

Andaman Islands that might qualify is leptospirosis. Leptospirosis presents either in its hepato-renal form as described by Indian Medical Service physicians or as pulmonary haemorrhage.¹⁸ Although some diagnostic confusion may have been caused by leptospirosis, it seems highly unlikely that it would have been a major contributor to mortality. The third possibility, that malaria, tuberculosis, dysentery and diarrhea were all responding independently but in the same manner to an unknown environmental determinate cannot be excluded, but seems highly improbable.

Current Public Health Relevance

That malaria causes massive morbidity and mortality is indisputable. That malaria also causes mortality in excess of that directly assigned to the parasite has been widely suspected from malaria intervention programs such as residual insecticide spraying or the distribution of insecticide treated bed nets. This historical review describes long-term data sets that confirm the huge mortality cost extracted by malaria, even in adults. Quantifying the indirect mortality effect of malaria is difficult; however, the mean annual mortality in the British soldiers (4.7/1000) stationed on the non-malarious Ross Island was considerably lower than that of the Indian police (8.3/1000) stationed throughout the colony. The female prisoners mainly kept on Ross Island also had lower mean annual mortality rates (21/1000) than their male counterparts (33/1000). Noting that all-cause prisoner mortality increased from 12/1000 in 1928 to 51/1000 in 1930 at the trough and peak respectively of a malaria epidemic while the directly attributable malaria mortality changed from 1/1000 to 16/1000 over the same two year period, one could estimate that indirect malaria mortality was at least as large as mortality directly attributed to malaria and could have been greater by a factor of two or three.

What mechanisms might explain malaria's cooperative mortality effect? It could be as simple as anemic persons doing poorly when they develop pneumonia or as complex as malaria induced pulmonary edema.⁴⁵ Antibody is important in the control of pneumococcal pneumonia whereas malaria is known to disorder the function of B lymphocytes.⁵⁴ Pneumonia and severe malaria are difficult to differentiate in African children such that some of the putative disease interactions in the Andaman Islands could have been explained by diagnostic overlap.⁵⁵ The spleen is an important part of the reticuloendothelial system and the spleen's function may be partially paralyzed by removing malaria infected and modified erythrocytes.⁵⁶ Sepsis caused by gram negative bacteria, particularly *Salmonella*, has been described during *P. falciparum* malaria, and it is possible that colonic ulcers of dysentery could increase bacteremia or sepsis from the gut.^{57,58} Although malnutrition may adversely affect any infection, the prisoners were issued a standard food ration by regulation such that frank starvation would seem an unlikely explanation of enhanced mortality in the Andaman Islands.^{59,60}

Practical and ethical reasons make further long-term measurements of indirect mortality unlikely although useful data could continue to be gathered as bed nets are progressively provided to areas with on-going population-based mortality studies. As human genetic polymorphisms selected by malaria become better understood, improved estimates of the evolutionary selection pressure on pre-historic human populations may be possible.^{36,61,62} Malaria is a complex disease causing substantial direct mortality that is considerably augmented by indirect mortality probably by enhancing the case fatality rate of other infectious diseases. It is therefore likely that the anticipated public health gains from adequately executed malaria control programs could exceed expectations due to decreased indirect malaria mortality. While there is good recent empirical evidence for this in paediatric studies in Africa, evidence from adults is scarce, and these historical data can

shed light on the problem. Justification for malaria control programs may not need to be limited to preventing child mortality in Africa.

Acknowledgments

The authors thank the staff members of the India Institute of the Bodleian Library at the University of Oxford and the British Library in London for their assistance in obtaining official records. Professor David Rogers is thanked for his inspiration and encouragement and Professors Karl Rieckmann and Robert Snow for their comments on the manuscript.

Financial Support: The Astor Travel Fund of the University of Oxford funded this study but had no role in its interpretation or publication. SIH is funded by a Senior Research Fellowship from the Wellcome Trust (#079091). DJB holds a Leverhulme Emeritus Fellowship.

References

1. Hay SI, Guerra CA, Tatem AJ, Noor AM, Snow RW. The global distribution and population at risk of malaria: past, present, and future. *Lancet Infect Dis*. 2004; 4(6):327–36. [PubMed: 15172341]
2. Korenromp EL, Williams BG, Gouws E, Dye C, Snow RW. Measurement of trends in childhood malaria mortality in Africa: an assessment of progress toward targets based on verbal autopsy. *Lancet Infect Dis*. 2003; 3(6):349–58. [PubMed: 12781507]
3. Snow RW, Guerra CA, Noor AM, Myint HY, Hay SI. The global distribution of clinical episodes of *Plasmodium falciparum* malaria. *Nature*. 2005; 434(7030):214–7. [PubMed: 15759000]
4. Marsh K, Forster D, Waruiru C, et al. Indicators of life-threatening malaria in African children. *N Engl J Med*. 1995; 332(21):1399–404. [PubMed: 7723795]
5. Snow RW, Korenromp EL, Gouws E. Pediatric mortality in Africa: *plasmodium falciparum* malaria as a cause or risk? *Am J Trop Med Hyg*. 2004; 71(2 Suppl):16–24. [PubMed: 15331815]
6. Snow RW, Craig M, Deichmann U, Marsh K. Estimating mortality, morbidity and disability due to malaria among Africa's non-pregnant population. *Bull World Health Organ*. 1999; 77(8):624–40. [PubMed: 10516785]
7. Annual Reports of the Sanitary Commissioner with the Government of India; Calcutta. 1868-1918;
8. The report on the administration of the Andaman and Nicobar Islands and the penal settlement of Port Blair; Calcutta: Government of India. 1875-1940;
9. Annual Reports of the Public Health Commissioner with the Government of India; imla: Government of India. 1919-1939;
10. Mathur, LP. History of the Andaman and Nicobar Islands (1756-1966). Delhi: Sterling Publishers Ltd; 1970.
11. Majumdar, RC. Penal Settlement in the Andamans. New Delhi: Government of India Press; 1975.
12. Sen, S. Disciplining Punishment: Colonialism and convict society in the Andaman Islands. New Delhi: Oxford University Press; 2000.
13. Christophers, SR. Scientific Memoranda of the Government of India no 46: Malaria in the Andamans. Calcutta: Government of India Press; 1912.
14. Rogers, L. Fevers in the tropics. London: Oxford University Press; 1908.
15. Waters EE. Malaria as seen in the Andamans penal settlement. *Lancet*. 1903; I:1657–1662.
16. Hehir P. Prevention of malaria in the troops of our Indian Empire. *The Indian Medical Gazette*. Aug.1914 :305–309.
17. Roy S, Biswas D, Vijayachari P, Sugunan AP, Sehgal SC. Antigenic and genetic relatedness of *Leptospira* strains isolated from the Andaman Islands in 1929 and 2001. *J Med Microbiol*. 2003; 52(Pt 10):909–11. [PubMed: 12972587]
18. Vijayachari P, Sugunan AP, Sharma S, Roy S, Natarajaseenivasan K, Sehgal SC. Leptospirosis in the Andaman Islands, India. *Trans R Soc Trop Med Hyg*. 2007 in press.
19. Rowe AK, Rowe SY, Snow RW, et al. The burden of malaria mortality among African children in the year 2000. *Int J Epidemiol*. 2006; 35(3):691–704. [PubMed: 16507643]

20. Snow RW, Howard SC, Mung'Ala-Odera V, et al. Paediatric survival and re-admission risks following hospitalization on the Kenyan coast. *Trop Med Int Health*. 2000; 5(5):377–83. [PubMed: 10886803]
21. Snow RW, Marsh K. The consequences of reducing transmission of *Plasmodium falciparum* in Africa. *Adv Parasitol*. 2002; 52:235–64. [PubMed: 12521262]
22. Snow RW, Trape JF, Marsh K. The past, present and future of childhood malaria mortality in Africa. *Trends Parasitol*. 2001; 17(12):593–7. [PubMed: 11756044]
23. O'Dempsey TJ, McArdle TF, Laurence BE, Lamont AC, Todd JE, Greenwood BM. Overlap in the clinical features of pneumonia and malaria in African children. *Trans R Soc Trop Med Hyg*. 1993; 87(6):662–5. [PubMed: 8296367]
24. Guyatt HL, Snow RW. Malaria in pregnancy as an indirect cause of infant mortality in sub-Saharan Africa. *Trans R Soc Trop Med Hyg*. 2001; 95(6):569–76. [PubMed: 11816423]
25. Brabin BJ, Hakimi M, Pelletier D. An analysis of anemia and pregnancy-related maternal mortality. *J Nutr*. 2001; 131(2S-2):604S–614S. discussion 614S–615S. [PubMed: 11160593]
26. Alonso PL, Lindsay SW, Armstrong Schellenberg JR, et al. A malaria control trial using insecticide-treated bed nets and targeted chemoprophylaxis in a rural area of The Gambia, west Africa. 6. The impact of the interventions on mortality and morbidity from malaria. *Trans R Soc Trop Med Hyg*. 1993; 87(Suppl 2):37–44. [PubMed: 8212109]
27. McElroy PD, ter Kuile FO, Hightower AW, et al. All-cause mortality among young children in western Kenya. VI: the Asembo Bay Cohort Project. *Am J Trop Med Hyg*. 2001; 64(1-2 Suppl): 18–27. [PubMed: 11425174]
28. Nevill CG, Some ES, Mung'ala VO, et al. Insecticide-treated bednets reduce mortality and severe morbidity from malaria among children on the Kenyan coast. *Trop Med Int Health*. 1996; 1(2): 139–46. [PubMed: 8665377]
29. D'Alessandro U, Olaleye BO, McGuire W, et al. Mortality and morbidity from malaria in Gambian children after introduction of an impregnated bednet programme. *Lancet*. 1995; 345(8948):479–83. [PubMed: 7861874]
30. Snow RW, Armstrong JR, Forster D, et al. Childhood deaths in Africa: uses and limitations of verbal autopsies. *Lancet*. 1992; 340(8815):351–5. [PubMed: 1353814]
31. Brown PJ. Socioeconomic and demographic effects of malaria eradication: a comparison of Sri Lanka and Sardinia. *Soc Sci Med*. 1986; 22(8):847–59. [PubMed: 3529423]
32. Newman P. Malaria control and population growth. *J Dev Studies*. 1970; 6:133–58.
33. Giglioli G. Changes in the pattern of mortality following the eradication of hyperendemic malaria from a highly susceptible community. *Bull World Health Organ*. 1972; 46(2):181–202. [PubMed: 4624339]
34. Bradley, DJ. Morbidity and mortality at Pare-Taveta, Kenya and Tanzania, 1954–66: the effects of a period of malaria control. In: Feachem, RG.; Jamison, DT., editors. *Disease and Mortality in Sub-Saharan Africa*. London: Oxford University Press; 1992. p. 248–262.
35. Mouchet J. Evolution of malaria in Africa for the past 40 years: impact of climatic and human factors. *Journal of American Mosquito Control Association*. 1998; 14:121–130.
36. Williams TN, Mwangi TW, Wambua S, et al. Sick Cell Trait and the Risk of *Plasmodium falciparum* Malaria and Other Childhood Diseases. *J Infect Dis*. 2005; 192(1):178–186. [PubMed: 15942909]
37. Molineaux L. Malaria and mortality: some epidemiological considerations. *Ann Trop Med Parasitol*. 1997; 91(7):811–25. [PubMed: 9625938]
38. Antony R, Gajraj E, Jacob MS, Mathew T, Anita SR. Rajasthan malaria epidemic--1994--practical problems in prevention, diagnosis and treatment on the field. *J Assoc Physicians India*. 1996; 44(7):508. [PubMed: 9282623]
39. Bouma MJ, van der K. Epidemic malaria in India's Thar desert. *Lancet*. 1995; 346(8984):1232–3. [PubMed: 7475689]
40. Fontaine RE, Najjar AE, Prince JS. The 1958 malaria epidemic in Ethiopia. *Am J Trop Med Hyg*. 1961; 10:795–803. [PubMed: 13893940]
41. Tyagi BK, Chaudhary RC, Yadav SP. Epidemic malaria in Thar desert, India. *Lancet*. 1995; 346(8975):634–5. [PubMed: 7651016]

42. van der Brug PH. Malaria in Batavia in the 18th century. *Trop Med Int Health*. 1997; 2(9):892–902. [PubMed: 9315048]
43. Harrington AW, Whitelaw W. Post-malarial severe anemia. *Glasgow Med J*. 1918; 89(6):321–341.
44. Falconer A, Anderson AQ. Clinical types of subtertian malaria. *Lancet*. 1917; I:607–10.
45. Taylor WR, White NJ. Malaria and the lung. *Clin Chest Med*. 2002; 23(2):457–68. [PubMed: 12092039]
46. Fairley NH, Dew HR. The causes of death from malaria in Palestine - A study in cellular pathology. *Trans R Soc Trop Med Hyg*. 1920; 13(6):121–25.
47. Mason-Bahr P. Experiences of malaria in the Egyptian expeditionary force. *Lancet*. Jan 10.1920 I: 79–85.
48. Wilson T, Reid JA. Malaria among prisoners of war in Siam “F” force. *Trans R Soc Trop Med Hyg*. 1949; 43(3):257–272. [PubMed: 15395876]
49. Applebaum IL, Shrager J. Pneumonitis associated with malaria. *Arch Intern Med*. 1944; 74:155–62.
50. Baird JK, Krisin, Barcus MJ, et al. Onset of clinical immunity to *Plasmodium falciparum* among Javanese migrants to Indonesian Papua. *Ann Trop Med Parasitol*. 2003; 97(6):557–64. [PubMed: 14511553]
51. Baird JK, Masbar S, Basri H, Tirtokusumo S, Subianto B, Hoffman SL. Age-dependent susceptibility to severe disease with primary exposure to *Plasmodium falciparum*. *J Infect Dis*. 1998; 178(2):592–5. [PubMed: 9697752]
52. Covell, G. Report of an inquiry into malarial conditions in the Andamans; Delhi: Government of India Press. 1927;
53. Covell G, Baily JD. Observations on malaria in the Andamans; with special reference to the enlarged spleen in adults. *Ind Jour Med Res*. 1927; 15:309–25.
54. Whittle HC, Brown J, Marsh K, Blackman M, Jobe O, Shenton F. The effects of *Plasmodium falciparum* malaria on immune control of B lymphocytes in Gambian children. *Clin Exp Immunol*. 1990; 80(2):213–8. [PubMed: 1972671]
55. English M, Punt J, Mwangi I, McHugh K, Marsh K. Clinical overlap between malaria and severe pneumonia in Africa children in hospital. *Trans R Soc Trop Med Hyg*. 1996; 90(6):658–62. [PubMed: 9015508]
56. Engwerda CR, Beattie L, Amante FH. The importance of the spleen in malaria. *Trends Parasitol*. 2005; 21(2):75–80. [PubMed: 15664530]
57. Berkley J, Mwarumba S, Bramham K, Lowe B, Marsh K. Bacteraemia complicating severe malaria in children. *Trans R Soc Trop Med Hyg*. 1999; 93(3):283–6. [PubMed: 10492760]
58. Mabey DC, Brown A, Greenwood BM. *Plasmodium falciparum* malaria and *Salmonella* infections in Gambian children. *J Infect Dis*. 1987; 155(6):1319–21. [PubMed: 3553352]
59. Maharatna, A. Famines and epidemics: an Indian historical perspective. In: Dyson, T.; Grada, CO., editors. *Famine Demography: Perspectives from the Past and Present*. London: Oxford University Press; 2002. p. 113–141.
60. Nyakeriga AM, Troye-Blomberg M, Chemtai AK, Marsh K, Williams TN. Malaria and nutritional status in children living on the coast of Kenya. *Am J Clin Nutr*. 2004; 80(6):1604–10. [PubMed: 15585775]
61. Fairhurst RM, Baruch DI, Brittain NJ, et al. Abnormal display of PfEMP-1 on erythrocytes carrying haemoglobin C may protect against malaria. *Nature*. 2005; 435(7045):1117–21. [PubMed: 15973412]
62. Williams TN, Wambua S, Uyoga S, et al. Both heterozygous and homozygous {alpha}+ thalassemias protect against severe and fatal *Plasmodium falciparum* malaria on the coast of Kenya. *Blood*. 2005; 106(1):368–71. [PubMed: 15769889]

Figure 1. Work party of Andaman Island Penal Colony prisoners being fed by the sea shore circa 1880s. Men with canes and sashes are convict warders. Photo is from a collection presented to India Record Office by Sir Richard C. Temple in 1922. Reproduced by permission of The British Library with shelfmark 125/2(1)

Figure 2.

Annual all-cause mortality per 1000 prisoners in the Andaman Islands Penal Colony from 1858-1939 with the same data shown on two scales varying by a factor of ten.

Figure 3.
Annual mortality by number of deaths attributed to the five major infectious diseases (50-80% of total mortality) in the Andaman Islands Penal Colony from 1875-1929.

Figure 4.

Annual malaria morbidity (as defined by malaria hospital admissions) and malaria attributed mortality per 1000 prisoners in the Andaman Islands Penal Colony 1875-1939. Also shown are malaria deaths per 1000 malaria hospitalizations and blackwater fever cases.

Figure 5.

Annual morbidity and disease-specific attributed mortality per 1000 prisoners 1875-1929 in the Andaman Islands Penal Colony for A pneumonia, C tuberculosis, E dysentery, G diarrhea with regression curves of malaria morbidity versus disease-specific attributed mortality for B pneumonia, D tuberculosis, F dysentery, H diarrhea.