Spring 5-16-2014

Are housing improvements an effective supplemental vector control strategy to reduce malaria transmission? A Systematic Review

Anna Danielle Carter

ABSTRACT

ANNA DANIELLE CARTER

Are housing improvements an effective supplemental vector control strategy to reduce malaria transmission?

A Systematic Review

(Under the direction of Dr. Lisa Casanova, Faculty Member)

Background:

Malaria, a preventable disease caused by a mosquito-transmitted parasitic infection, continues to be a prominent public health problem today. Progress has been made in the last decade demonstrated by malaria mortality reductions primarily attributed to current vector control strategies. However, the continuing threat of resistance, both resistance of mosquitoes to insecticides and parasites to antimalarial medicines, requires the development of new and improved strategies to supplement those already in place. Housing improvements such as screening doors and windows, closing eaves, patching cracks in walls, and installing ceilings are one such intervention that help stop contact between malaria vectors and humans, and therefore, help stop malaria transmission. Historically considered successful in helping fight malaria, housing improvements are being looked to again today.

Objective:

The purpose of this study is to conduct a systematic review of the literature on the relationship between housing improvements and malaria transmission to evaluate if current evidence demonstrates that housing improvements are an effective supplemental vector control strategy to reduce malaria transmission.

Methods:

A literature search was conducted by one author in January 2013 and February 2013 using Medline, PubMed, Global Health, and The Cochrane Library. Abstracts were reviewed and if the studies met the initial criteria for inclusion, they were included for a full review to assess primary outcome measures for this systematic review. There was no restriction on year of study or publication or on region the study occurred. Only studies published in peer review journals and in English were reviewed.

Results:

Nine studies met all criteria and were included in the systematic review. Studies included found reduced odds of malaria incidence, *plasmodium falciparum* infection, and reduced indoor mosquito density when housing improvements were used as an intervention.

Conclusions:

Housing improvements such as screening windows and doors, closing eaves, patching cracks in walls, and installing ceilings can help reduce contact between people and malaria vectors, and therefore help reduce malaria transmission. However, not all housing improvements work effectively in all settings due to differences in local housing. More studies are needed to help understand what housing improvements can be designed to be utilized in a broad array of settings.

Are housing improvements an effective supplemental vector control strategy to reduce malaria transmission?

A Systematic Review

by

Anna Danielle Carter

B.A., GEORGIA STATE UNIVERSITY

A Thesis Submitted to the Graduate Faculty of

Georgia State University in Partial Fulfillment

of the

Requirements for the Degree

MASTER OF PUBLIC HEALTH

ATLANTA, GEORGIA

30303

APPROVAL PAGE

Are housing improvements an effective supplemental vector control strategy to reduce malaria transmission?

A Systematic Review

by

Anna Danielle Carter

Approved:

____
Committee Chair

____
Committee Member

____
Committee Member

____
Date

ACKNOWLEDGEMENTS

I would like to thank my thesis committee, Dr. Lisa Casanova and Dr. Bruce Perry for their support. Mari Stephens, MPH, of Habitat for Humanity International for introducing me to the topic of housing improvements as a vector control strategy, and for being a supportive, guiding presence through my thesis and practicum. Additionally, Dr. Patrick Kachur and David Gittleman, MPH, of CDC's Division of Parasitic Diseases and Malaria.

Author's Statement Page

In presenting this thesis as a partial fulfillment of the requirements for an advanced degree from Georgia State University, I agree that the Library of the University shall make it available for inspection and circulation in accordance with its regulations governing materials of this type. I agree that permission to quote from, to copy from, or to publish this thesis may be granted by the author or, in his/her absence, by the professor under whose direction it was written, or in his/her absence, by the Associate Dean, School of Public Health. Such quoting, copying, or publishing must be solely for scholarly purposes and will not involve potential financial gain. It is understood that any copying from or publication of this dissertation which involves potential financial gain will not be allowed without written permission of the author.

____

Signature of Author

Notice to Borrowers

All theses deposited in the Georgia State University Library must be used in accordance with the stipulations prescribed by the author in the preceding statement.

The author of this thesis is:

Student’s Name: Anna Danielle Carter

Street Address: 300 Arizona Ave NE

City, State, and Zip Code: Atlanta, Georgia 30307

The Chair of the committee for this thesis is:

Professor’s Name: Dr. Lisa Casanova

Department: Environmental Health

College: School of Public Health

Georgia State University
School of Public Health
P.O. Box 3995
Atlanta, Georgia 30302-3995

Users of this thesis who not regularly enrolled as students at Georgia State University are required to attest acceptance of the preceding stipulation by signing below. Libraries borrowing this thesis for the use of their patrons are required to see that each user records here the information requested.

NAME OF USER	ADDRESS	DATE	TYPE OF USE (EXAMINATION ONLY OR COPYING)

TABLE OF CONTENTS

List of Tables:

List of Figures:

Chapter I

Introduction

1.1 Background

Malaria, a preventable disease caused by a mosquito-transmitted parasitic infection, continues to be a prominent public health problem with an estimated 207 million cases and 627,000 deaths in 2012 -483,000 of those in children under five years of age (WHO 2013). Progress has been made in the last decade, demonstrated by malaria mortality reductions, 45% globally and 49% in the WHO African Region, primarily due to scale up of strategies that have successfully distributed long-lasting insecticide treated nets (LLIN) and targeted indoor residual spraying (IRS) to communities in endemic regions, the use of rapid diagnostic tests (RDTs), and antimalarial drugs to prevent and treat infections. However, the continuing threat of resistance, both resistance of mosquitoes to insecticides and parasites to antimalarial medicines, requires the development of new and improved strategies to supplement those already in place (Mendis et al., 2009). An additional problem is securing adequate funding. In 2012, funding to reach universal coverage of current interventions was $2.5 billion, less than half of what is needed to reach these goals in endemic regions (WHO 2013).

Additional supplemental interventions are needed to support the efforts against malaria transmission. Housing improvements such as screening doors and windows, closing eaves, patching cracks in walls, and installing ceilings are all related interventions that help decrease contact between malaria vectors and humans, and therefore help reduce malaria transmission (Hiscox, 2013). Furthermore, they help protect all people in a house and do not contribute to insecticide or antimalarial resistance. Housing improvements have been implemented successfully in the past but were soon replaced when chemicals such as DDT emerged in the 1950s and helped eliminate malaria in the Southern United States cheaply and quickly (Lindsay et al., 2002). Prior to the discovery that mosquitoes transmitted malaria, areas of North America and Europe are thought to have eliminated malaria as a result of better infrastructure and improved housing (Mendis et al., 2009).

If housing improvements are to be considered a potential supplemental vector control strategy, a systematic review of the current literature can help better understand both the relationship between malaria and housing, as well as what type(s) of housing improvements are most effective for malaria control.

1.2 Purpose of the Study

The purpose of this study is to conduct a systematic review of the literature on the relationship between housing improvements and malaria transmission to evaluate if current evidence demonstrates that housing improvements are an effective supplemental vector control strategy to reduce malaria transmission.

Chapter II

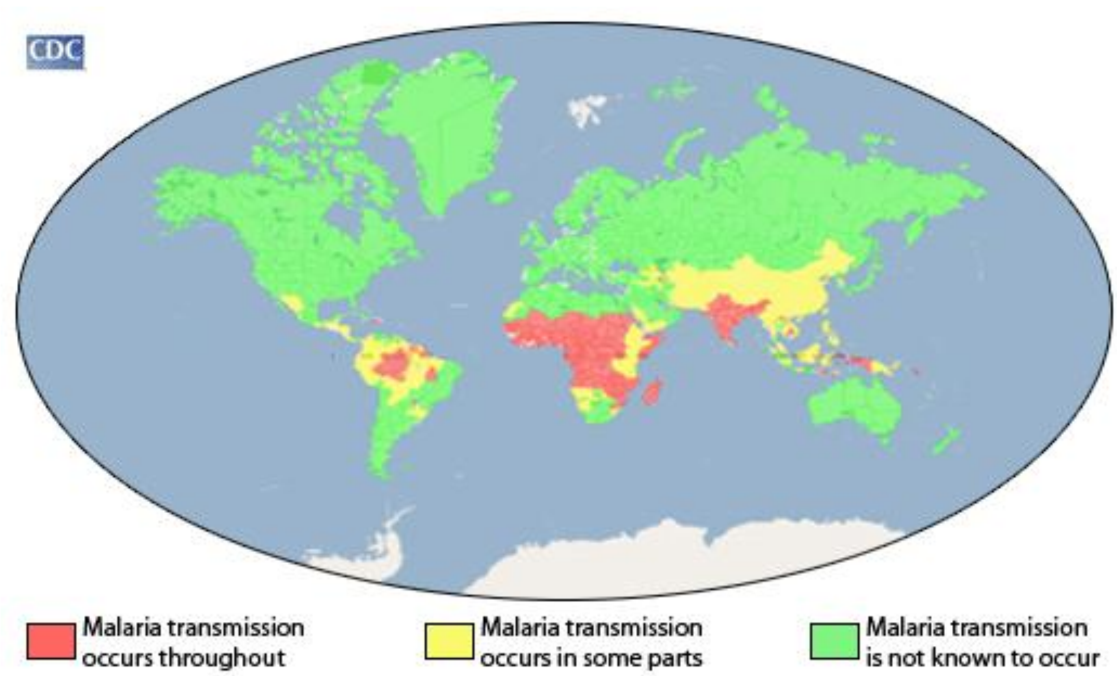
Review of the Literature

2.1 Overview of Malaria

Malaria is a preventable vector-borne disease caused by *plasmodium* parasites that infect *Anopheles* mosquitoes and are then transmitted to humans through bites from these infected mosquitoes, also called "malaria vectors" (WHO). Four types of parasite species can cause malaria in humans including *plasmodium falciparum, plasmodium vivax, plasmodium malariae, and plasmodium ovale. Plasmodium falciparum* is one of the most common species and most deadly (WHO, 2014). There are 430 *Anopheles* mosquito species, however only 30-40 species can transmit malaria to humans, and additionally only female *Anopheles* mosquitoes (CDC, 2014). *Anopheles* mosquitoes are found in all areas of the world, except Antarctica, and those able to transmit malaria are found in regions that have eliminated malaria, thus the risk of re-introduction is a continuing concern (CDC, 2014). *Anopheles* mosquitoes breed in water and different species have varying preferences, including areas such as lakes, agricultural fields, and even in prints left from shoes or animal hoofs (WHO, 2014). The latter breeding preference is an example of the complexity of the relationship between mosquitoes and humans and the difficulty of preventing exposure and transmission. The agricultural revolution contributed to increasing rates of malaria transmission due to humans settling in permanent places and mosquitoes having access to a stable and large population to feed upon. This change in human settlement behavior led some mosquitoes to become anthropophilic (preference for human feeding) and endophilic (lives and rests indoors) making them the most efficient malaria vectors (Carter 2002).

Transmission tends to be seasonal, with the peak during and shortly after rainy seasons, which supports mosquito reproduction. Transmission is dependent upon the conditions of the environment's climate, including rainfall amounts and patterns, temperature, and humidity (WHO, 2014). The geographical distribution of the disease is primarily focused in the tropics, with some subtropical regions included, as a result of favorable temperatures for mosquitoes to reproduce and survive (Sachs et al., 2002). In areas that provide a favorable habitat to mosquitoes, and thus supports longer life spans, transmission is found to be more "intense" (WHO, 2014). This is largely due to the longer life span allowing the parasite to fully develop within the mosquito. "Factors that affect a mosquito's ability to transmit malaria include its innate susceptibility to *Plasmodium*, its host choice, and its longevity" (CDC, 2014).

<u>Figure 1: Distribution of malaria transmission</u>



http://www.cdc.gov/malaria/about/distribution.html

The first symptoms of malaria usually include fever, headache, chills, and vomiting, and appear about a week or more after a person is bitten by a mosquito and infected with the Plasmodium parasite. Infection by Plasmodium *falciparum* can lead to severe illness and a high risk of death if it is not properly diagnosed and treated within twenty-four hours of transmission (WHO, 2014). High-risk groups are those that have a higher chance of contracting malaria and are susceptible to a more severe disease outcome. High-risk groups for malaria include pregnant women, infants, children under five years of age, people infected with HIV/AIDS, and those who do not have any immunity against malaria, such as travelers from areas of the world where malaria is not endemic (WHO, 2014). Individuals can develop partial immunity to malaria after years of exposure, and therefore, asymptomatic infections can occur. In addition, these individuals may have a lower chance of having severe malaria when infected. Severe malaria in children can lead to severe anemia, respiratory distress in relation to metabolic acidosis, or cerebral malaria (WHO, 2014). Data from the World Malaria Report 2013 shows that 77% of all malaria deaths occur in children under five years of age (WHO 2013).

2.2 Burden of Malaria

Today, malaria continues to be a burden for 3.4 billion people in 99 countries around the world (WHO, 2013). In 2012, there were an estimated 207 million cases of malaria and 627,000 deaths, 90% of those deaths occurring in Africa (WHO, 2013). Malaria burden is greatest in the tropical regions of the world, where warmer temperatures have made attempts to eliminate the disease unsuccessful due to the environment creating a favorable habitat for malaria vectors (Sachs et al., 2002). Sub-Saharan Africa and Southeast Asia are the two regions most greatly affected by malaria, and areas of Latin America, the Middle East, and Europe also have populations at risk (WHO). Fifty of the 99 countries with malaria transmission are anticipated to meet targets to reduce malaria case incidence by 75% in 2015, a goal set by the World Health Association (WHA, 2013) and Roll Back Malaria (RBM). However, the remaining 35 countries account for 97% of global malaria burden (RBM/UNDP, 2013). The high malaria burden in the remaining 35 countries can be attributed to resistance to insecticides and antimalarial medications, as well as the absence of socio-economic development (RBM/UNDP, 2013). "The malaria burden is highest in the countries with the lowest human development, within countries in the least developed and poorest areas, and within populations among the most disadvantaged" (RBM/UNDP, 2013). In Africa, malaria is estimated to cost $12 billion annually in lost productivity (RBM/UNDP, 2013).

2.3 Historical Malaria Control Efforts

The discovery of the malaria parasite in 1888, and transmission by mosquito vectors in 1897, allowed targeted efforts of mosquito control, as well as diagnosis and treatment, to almost eliminate malaria from some parts of Western Europe during a time when 90% of the world's population lived in malarious areas (Mendis et al., 2009). Angelo Celli, an Italian hygienist, highlighted the importance of the environment and living conditions of malaria affected populations when he conducted a study in 1900 of malaria cases among railroad workers and their families. His study was the first to show that making changes to housing, such as screening porches and chimneys, resulted in dramatically lowering malaria incidence to 4% in those with the housing intervention, compared with 92% without the intervention (Ferroni et al., 2012). However, Celli's study had possible confounders, including the use of the insecticide pyrethrum and quinine administered to some of the participants (Ferroni et al., 2012). Patrick Munson also conducted a housing study in 1900 in Italy, and recognizing Celli's possible confounders, focused only on screening and bed nets as protection against malaria. Although his study group was small, the five participating individuals never contracted malaria compared to those in the same area without the screening (Ferroni et al., 2012). While these efforts proved to be quite successful, they were largely forgotten when the primary strategies of insecticidal control emerged (Lindsay et al., 2002).

In the United States, malaria was eliminated in the 1950s, after a campaign utilized DDT to spray houses and destroyed outdoor mosquito breeding sites. DDT spraying became the primary strategic tool to eliminate malaria vectors when it was discovered to be both highly effective and cheap (Lindsay et al., 2002). The Global Malaria Eradication Programme, led by the World Health Organization (WHO), began in 1955 with DDT spraying and chloroquine as its primary strategies to reduce malaria transmission in all endemic areas that had low to moderate transmission (Mendis et al., 2009). While the programme was initially successful with many countries eliminating malaria or reducing their burden of disease and death, failure to maintain the programme resulted in numerous resurgences in malaria (Mendis et al., 2009). The efforts of the GMEP were further hampered with "mosquito resistance to DDT, increasing parasite resistance to chloroquine and its replacements, and dwindling investments in malaria control" (Mendis et al., 2009).

Angelo Celli and Patrick Munson's studies, detailed above, illustrate the historical significance that housing improvements, particularly screening, had in reducing malaria at the turn of the century. These studies expanded screening as a malaria control intervention to numerous global locations, including protecting Europeans who lived in the Tropics, and workers building the Panama Canal (Lindsay et al., 2002). In the Southern United States, there was a big push to screen rural homes in malarious areas including in the states of Mississippi, Tennessee, and Alabama. In Northern Alabama, there was "a substantial fall in the incidence of disease compared with control areas" after 700 homes were screened to prevent mosquito entry (Lindsay et al., 2002). These interventions were quite successful and the support for housing interventions and design to reduce disease were recognized (Lindsay et al., 2002). Additionally, armies benefitted from reduced malaria after screening their barracks. The British army stationed in Pakistan reduced the incidence of malaria from 569/1000 in 1925 to 45/1000 in 1927, and in India in 1927 they reduced their malaria incidence from 613/1000 in 1925 to 48/1000. The Spanish army also reduced malaria incidence after screening barracks while stationed in their own country, from 70% to 20% (Carter et al., 2002).

2.4 Current Prevention Strategies/Efforts

Current measures against malaria include preventing transmission with insecticide-based control strategies and the use of antimalarials to prevent and treat infections. Additionally, there has been an increase in access to Rapid Diagnostic Tests (RDTs) which help confirm an infection and provide appropriate treatment (WHO 2013). In the past decade, one million lives have been saved from malaria as a result of successful vector control strategies and treatment with antimalarial medications, and incidence rates have been reduced by 29% globally and 31% in the WHO African Region (RMB/UNDP 2013).

Antimalarials are used in three ways; as prophylactic therapy for those traveling in endemic malaria areas, intermittent preventative therapy for certain high-risk groups in endemic areas (pregnant women, infants, and children in high transmission settings), and treating those who have a confirmed infection (CDC)**.** Combination therapy combines the use of multiple antimalarials and is the most common way antimalarials are administered. Artemisinin-based combination therapies (ACTs) are recommended as first-line treatment for malaria due to *plasmodium falciparum*, the most deadly malaria parasite (WHO). Combination therapies are utilized in an effort to help reduce both parasitic resistance to current medicines and to ensure a low likelihood of treatment failure (WHO). Additionally, many endemic countries now have Rapid Diagnostic Tests (RDTs); the volume of sales in 2012 was at 205 million-117 million more than in 2010-and accordingly, increasing the number of suspected malaria cases that received testing to 64% globally (WHO 2013).

Indoor spraying of insecticides with a residual effect (IRS) and insecticide-treated bed nets (ITNs) or long-lasting insecticide-treated nets (LLIN) are the primary measures to target mosquitoes indoors to protect people from being bitten and contracting malaria. These strategies are a predominant reason for the reduced malaria burden in sub-Saharan Africa as they have immediate results. In the last decade, scale-up efforts have been quite successful with increased distribution of ITNs and LLINs (WHO). According to the World Malaria Report, in 2013, 136 million LLINs were delivered to endemic countries, 66 million more than in 2012, and funding for 2014 should raise the number distributed to 200 million (WHO).

However, even with the success of these interventions and their continued scale-up, insecticide resistance is a major concern and already becoming a reality with surveillance showing over 125 mosquito species actively showing a resistance to one or more insecticides (CDC) in 64 countries around the world (WHO). In large part, this resistance is due to mosquitoes' rapid life cycle and their ability to have many generations each year (CDC).

Resistance can develop after mosquitoes have been exposed to an insecticide over several generations, and resistance to some insecticides has been documented to occur in as little as just a few years (CDC). The resistance to these insecticides threatens the success of malaria prevention and elimination, and historically was experienced as one prominent hindrance to the Global Malaria Eradication Campaign (CDC). Furthermore, there are currently no new insecticides ready to be approved for widespread use (Mendis et al., 2009).

Along with insecticide resistance, parasitic resistance to antimalarials is another concern in the prevention and treatment of malaria. Resistance has been confirmed in a number of endemic countries. Resistance to Artemisinin-based combination therapies (ACTs), one of the recommended first line treatments for malaria caused by *plasmodium falciparum,* has been observed in Cambodia, Thailand, Myanmar, and Vietnam. Chloroquine is recommended to treat malaria caused by *plasmodium vivax*, and resistance has been confirmed in 10 countries and 13 countries are being studied for suspected resistance (WHO). In addition to the absence of new insecticides currently ready to be approved for use, there are also no new antimalarials that are far enough through development to be approved for use (Mendis et al., 2009). Additional supplemental vector control interventions are necessary to address insecticide and antimalarial resistance to ensure that these interventions can continue into the future.

2.5 Malaria and Socioeconomics

Angelo Celli, an Italian hygienist, conducted the first studies on housing and malaria at the turn of the century due to concern about "the impact of economic and social factors on health" (Ferroni et al., 2012). Differences in severity of malaria cases in Italy were apparent between the Northern and Southern regions, with more severe cases being found in Southern regions. As a result, the South struggled with economic and social development due to malaria, while the North did not (Ferroni et al., 2012). Celli's proposal to address malaria broadened the scope beyond the focus of causal factors of transmission by malaria vectors. By calling for combined efforts among various professionals and groups to help address the associative sources of causation, Celli sought interventions that would also target aspects of socioeconomic factors of those affected by malaria (Ferroni et al., 2012). This combined approach is very similar to the multisectoral approach that is recommended today, more than 100 hundred years later, by Roll Back Malaria (RBM) and the United Nations Development Programme (UNDP).

A systematic review and meta-analysis by Tusting et al., (2013) found that children from low socioeconomic status had odds that were doubled for clinical malaria or parasitaemia, compared to children from higher socioeconomic status. Furthermore, those with low socioeconomic status were more greatly affected by the costs of the disease, and the "direction of causality is unable to be established due to the disease itself inducing poverty" (Tusting et al., 2013). Wealth was noted as being protective against malaria as it helps with the affordability of treatments and additional socioeconomic factors such as adequate nutrition and housing quality (Tusting et al., 2013). The authors conclude that development programmes should be an essential component of malaria control and additionally, socioeconomic development could be a sustainable intervention against malaria (Tusting et al., 2013).

Economic development leading to improved socio-environmental conditions in Northeast Tanzania is thought to have contributed to a substantial decline in malaria transmission since 1999. From 2003 to 2008 the "overall prevalence of malaria parasitaemia and the incidence of febrile malaria episodes have dropped by over 80 %"(Liu et al., 2013). While scale-up efforts of primary malaria interventions have increased in the area, they have only done so since the mid 2000s, and do not fully explain the decreasing rates of the previous years. Data from a longitudinal trial study of intermittent preventative therapy in infants (IPTi) in the Tanga Region of Northeast Tanzania, and surveys regarding historical accounts of housing improvements found that children residing in high quality houses had one-third lower malaria incidence, compared to children living in houses of lesser quality, even when controlling for wealth (Liu et al, 2013). Housing quality was indexed into 5 quintiles, ranging from the lowest quality (quintile 1), to the highest quality (quintile 5). The houses that were categorized of highest quality in the study (quintile 5) were more likely to have iron/roof tiles (97.6%), smooth (97.6%) concrete/brick (82.9%) walls, closed eaves (87.8%), finished floors (89.0%), windows that are partially (20.7%) or fully (73.2%) screened, and ceilings (56.1) (Liu eta l., 2013). The incidence of malaria was found to decrease as the housing quality increased due to economic development, with quintile 5 having the most protective effect (Liu et al., 2013). The authors note that there have been "noticeable improvements in the quality of houses in the study area" with almost 80% of houses having iron roofs and 40% having concrete walls built since 2008, both found to be protective housing characteristics against mosquito house entry (Liu et al., 2013).

The Multisectoral Action Framework for Malaria launched by Roll Back Malaria Partnership (RBM) and the United Nations Development Programme (UNDP) in 2013 recognizes the need to extend beyond the health sector and engage many stakeholders to help collaborate in the control and elimination of malaria (RBM/UNDP). Eliminating malaria can only occur if supplemental strategies focused on key areas of socio-economic development are implemented alongside current malaria strategies. "Malaria is both a result and a cause of a lack of development" (RBM/UNDP 2013). A comparison between income in countries with and without malaria transmission shows that the average gross domestic product (GDP) in countries in 1995 without malaria was $8,268 compared to $1,562 in endemic countries (Sachs et al., 2002). Additionally, endemic countries had lower rates of economic growth between 1965-1990 as illustrated by a rate of 1.9% less average growth in per-capita GDP (Sachs et al., 2002).

2.6 Malaria and Housing

Various species of *Anopheles* have become more efficient vectors by developing behaviors that allow them to adapt to be indoor feeders, targeting humans in homes and other built dwellings (Lindsay et al., 2002). An endophilic mosquito is defined as "a mosquito that rests indoors, inside a human dwelling, during the period between the end of blood-feeding and the onset of searching for an oviposition site while an exophilic mosquito spends this period somewhere outside the human dwelling"(Pates, 2005). Indoor feeders, such as *anopheles gambiae*, are able to fly upwards when they reach a wall to find openings in the dwelling, such as windows, cracks, or open eaves, while outdoor feeders have not adapted this behavior for home entry (Anderson et al., 2013). Mosquitoes are attracted to houses by odors that humans emit when they are sleeping (Anderson et al., 2013). Outdoor feeding mosquito species of *Anopheles* can transmit malaria, however, they are less reliant on humans for feeding and are not as effective as vectors (Anderson et al., 2013). In sub-Saharan Africa, 80% of transmission occurs indoors (Huho et al., 2013), primarily at night, with dusk through dawn being the most vulnerable times for humans to be bitten (WHO). Current primary prevention strategies, including indoor residual spraying (IRS), insecticide-treated bed nets (ITNs), and long-lasting insecticide treated nets (LLINs) are targeted in the home due to the high likelihood of transmission indoors (Anderson et al., 2013).

Risk factors for house entry by mosquito vectors have been identified by a number of studies looking into housing design and characteristics that leave inhabitants at a greater risk of high indoor mosquito density and, consequently, exposure to malaria. A multi-factorial risk factor analysis study by Kirby et al. (2008) in The Gambia found that houses with walls made of mud blocks, as opposed to concrete, had an increase of mosquitoes indoors (OR= 1.44, 95% CI= 1.10-1.87), most likely due to more points of entry such as cracks and aging of mud blocks allowing easier mosquito entry. Houses that had closed eaves had a reduced indoor presence of mosquitoes (OR=0.71, 95%CI=0.60-0.85) versus houses with open eaves, a known main route for entry by *An. gambiae s.l* and an important focus for reducing entry. In addition to particular housing characteristics, Kirby et al. (2008), also found that there was an increased risk of malaria transmission in rural areas, in homes with greater density of people, and when horses were not tethered next to homes and churai (a local incense) is not burnt at night.

Modern studies on housing improvements have shown that ceilings, screened windows and doors, and blocked eaves can all reduce malaria transmission by significant amounts (Kirby et al., 2009 and Bradley et al., 2013). Furthermore, these strategies are affordable and have the potential to be implemented locally using local materials and labor (Massebo et al, 2013). The potential of using local materials and labor could help stimulate local economies, an important socio-economic development approach highlighted in the Multisectoral Action Framework for Malaria (RBM/UNDP). Additionally, the current climate for housing improvements as a supplemental vector control strategy is positive as housing improvements are a key area of supplemental strategy implementation of a multi-sector response to malaria detailed in the

“Multisectoral Action Framework for Malaria” 2013 (RMB/UNDP). The framework cites the need for developing norms and standards for malaria safe housing and updating current housing with improvements such as screening and ceilings.

Housing improvements that could help reduce malaria transmission include screening of doors, windows and eaves, closing eaves, installing ceilings, improving roofs, sealing cracks in walls, using higher quality building materials, and creating new housing designs. This systematic review intends to review all studies on these improvements to understand the most effective interventions.

Chapter III

Methodology

3.1 Search Strategy

A literature search was conducted in January 2013 and February 2013 using Medline, PubMed, Global Health, and The Cochrane Library on the following paired search terms:

1. Malaria AND housing
2. Malaria AND housing improvements
3. Malaria AND house screening
4. Malaria AND housing AND risk factor
5. Mosquito house entry AND risk factor

3.2 Types of Outcome Measures

Primary Outcomes

The primary outcomes for this systematic review include the incidence of malaria, prevalence of parasitaemia, and the mosquito density measurement within homes.

Secondary Outcomes

The secondary outcome for this systematic review is anemia prevalence in children as it is a good indicator of malaria infection and a leading cause of malaria mortality in children.

3.3 Initial Selection Criteria

Interventional studies and observational studies were included after confirming that the outcomes of interest were measured and reported. Types of interventions (housing improvements, design, housing features) or observations of these included in the studies for review included types of ceilings, eaves status (open or close), screening (whole house, and/or doors, windows, eaves), types of walls, roof, and newly constructed homes. Studies that also included current primary interventions against malaria, such as Insecticide-treated bed nets, along with housing interventions or observations were included in the review. Studies that focused only on risk factors for house entry without housing improvement interventions were not included. There was no restriction on year of study or publication or on region the study occurred. Only studies published in peer review journals and in English were reviewed.

3.4 Quality Assessment

The following criteria were considered to assure that the selected studies met quality assessment guidelines:

• Was the purpose stated clearly?

• Was relevant background literature reviewed?

• Was the sample described in detail?

• Was there randomization of selection of participants?

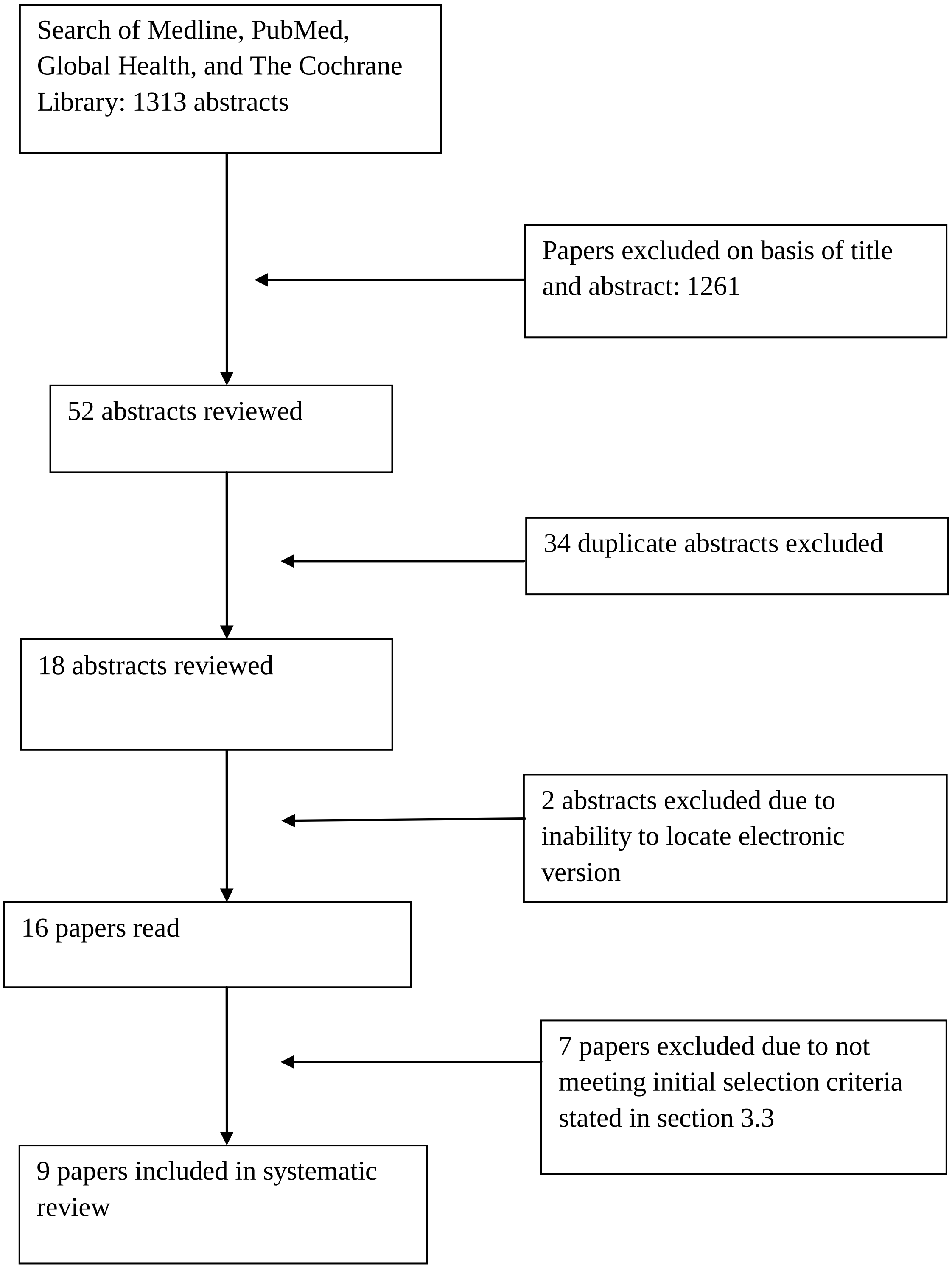
• Were results reported in terms of statistical significance?

• Were the conclusions appropriate considering study methods and results?

3.5 Data Collection

One author conducted the study search in January and February of 2013. Abstracts were reviewed and if the studies met the initial criteria for inclusion stated above, they were included for a full review to assess primary outcome measures for this systematic review.

Figure 2: Flow Chart of Study Selection Process



Chapter IV

Results

4.1 Results of Search

A total of 1,313 studies were generated from the searches conducted using Medline, PubMed, Global Health, and The Cochrane Library in January and February 2013. From this total, 1,262 studies were excluded on the basis of title and abstract leaving 51 abstracts to be reviewed. Duplicates were excluded, 17 abstracts remained to be reviewed for consideration into the systematic review, 2 of which copies were unable to be located. Fifteen studies remained and were read in full. Of these, 3 were excluded for focusing only on risk factors for house entry without housing improvement interventions (Kirby et al., 2008 and Liu et al., 2014 and Lwetoijera et al., 2013), 1 did not randomize its participants (Bradley et al., 2013), and 2 focused on outcomes that were not measured in this review including social acceptability, and usage and expenditures related to housing improvements (Ogoma et al., 2009 and Kirby et al., 2010). Nine papers met selection criteria and were included in the systematic review.

Table 1: Summary of Number of Results Found by Database and Search Term

Database	Search Terms	Number of Results
Medline	malaria AND housing	367
	malaria AND housing improvements	2
	malaria AND house screening	14
	malaria AND housing AND risk factor	11
	mosquito house entry AND risk factor	2
PubMed	malaria AND housing	369
	malaria AND housing improvements	5
	malaria AND house screening	75
	malaria AND housing AND risk factor	78
	mosquito house entry AND risk factor	4
Global Health	malaria AND housing	304
	malaria AND housing improvements	6
	malaria AND house screening	24
	malaria AND housing AND risk factor	38
	mosquito house entry AND risk factor	3
The Cochrane Library	malaria AND housing	2
	malaria AND housing improvements	1
	malaria AND house screening	7
	malaria AND housing AND risk factor	1
	mosquito house entry AND risk factor	0

4.2 Outcome Measure: Malaria Incidence

Newly Constructed Houses by Habitat for Humanity

Wolff et al., (2001) assessed the impact of improved housing construction on children's health in rural Malawi by comparing children living in improved housing with traditional housing. Outcome measures were the prevalence of respiratory, gastrointestinal, and malarial infections in children according to maternal recall, laboratory, or clinical data. Traditional homes in this area are made of mud brick walls, thatch roofing, mud floors, and consist of two to three rooms and sometimes have a pit latrine. Improved houses constructed by Habitat for Humanity programme included fired mud bricks, tile roofing, concrete foundation, a pit latrine, and have three rooms. Households that had participated in the Habitat programme and were living in improved housing were randomly selected for surveys conducted in March and August of 1997 and had samples of water collected, finger pricks for blood screening for malaria from children younger than 5 years of age, and given a medical examination. In March, mothers were surveyed using the illness recall method and reported symptoms for the past month, and in August they reported symptoms for the past two weeks. After this data was collected, the closest traditional house was surveyed and data collected. Habitat and traditional households were compared with bivariate analysis using EpiInfo 6.0, followed by the Genmod procedure.

Results show that while there was no statistically significant reductions in individual illnesses, children living in Habitat for Humanity homes had a 44% reduced odds of respiratory infection, gastrointestinal illness, or malaria compared to children living in traditional homes. There were no identified differences of any significance in socioeconomic demographics, leading to improved housing versus traditional housing being the prominent difference.

4.3 Outcome Measure: Prevalence of Parasitaemia

Intervention: Iron Sheet Roofed Houses

Ye et al., 2006 investigated the protective effect of iron-sheet roofed houses in a cross-sectional design study on *plasmodium falciparum* infection in children below five years old in the North West of Burkina Faso. At the end of the rainy season in November 2003, 661 children aged 6 months-5 years old were randomly selected through cluster sampling of households from four sites; three rural and one semi-urban. The sampling frame was obtained from the Nouna DSS database. All children were screened for fevers using digital axillary thermometers and tested for *plasmodium falciparum* infection using the finger prick method. Parasite density was estimated by counting 100 fields and equating this to 0.25 µl of blood. Data regarding bed net use, if the bed net was treated with insecticide and use of anti-malarials was recorded. Investigators then visited participants at their homes to ask about materials used for walls and roofs. Proc logistic procedure was used to estimate odds ratios for living in house with a mud roof and one with a grass roof compared to living in a house with iron sheets and the multivariate model included potential confounders such as age group, location of house, presence of animals, presence of a well, presence of breeding sites, and use of a mosquito net.

Results of Ye et al., (2006) found that overall *P. falciparum* infection prevalence among participants was 22.8%, with differences between sites. Rural sites had the highest rates of. Children living in iron-sheet roofed houses had 12.7 % *P. falciparum* infection prevalence compared to 25.6 % infection prevalence among children who lived in mud roofed houses. A logistic regression model found that inhabitants of houses with mud roofs had a higher risk (OR 2.6, 95% CI 1.4-4.7) of getting *P. falciparum* compared to those living in iron-sheet roofed houses, after controlling for site of residence, mosquito net use, presence of well, animal enclosure, and potential mosquito breeding sites.

Table 2: Roof Type and *Plasmodium falciparum* Infection- (Ye et al., 2006)

Roof type	N	Cases	Prevalence
Iron-sheet	126	16	12.7
Mud	498	129	25.9
Grass	37	6	16.2
Total	661	151	22.8

Intervention: Full Screening or Screened Ceilings

Kirby et al. (2009), randomized control trial in The Gambia, West Africa, (detailed below in 4.5 Outcome measure: mosquito indoor density), included frequency of parasitaemia as a secondary clinical endpoint in children ages 6 months-10 years by measuring presence of parasites (all parasitaemia) and presence of high parasitaemia (≥5000 parasites per µL). At the end of transmission season in 2006 and 2007 a clinical cross-sectional survey of 755 children was done to evaluate clinical endpoints. Interventions had been present for both groups for more than 6 months prior to collecting clinical data. Finger prick blood samples were obtained for detection of malaria parasites.

Results: Frequency of presence of parasitaemia and frequency of high parasitaemia did not differ enough to be significant.

Table 3: Parasitaemia and Screening-(Kirby et al., 2009)

Clinical Outcomes	Full screening	Screened ceilings	Control
Presence of parasites (all)			
2006	47/164 (29%)	45/140 (32%)	29/89 (33%)
2007	13/151 (9%)	11/137 (8%)	7/74 (9%)

Clinical Outcomes	Full screening	Screened ceilings	Control
Presence of high parasitaemia			
2006	6/164 (4%)	7/140 (5%)	9/89 (10%)
2007	7/151 (5%)	4/137 (3%)	1/74 (1%)

4.4 Outcome Measure: Mosquito Indoor Density

Intervention: Full Screening and Ceiling Screening

Kirby et al. (2009) conducted a randomized control trial in 2006 and 2007 in The Gambia, West Africa, to assess two types of house screening, full screening of houses including windows, doors, and eaves and installing screened ceilings ability to reduce house entry by *An. gambiae* and clinical outcomes including prevalence of parasitemia and anaemia in children (results for clinical outcomes detailed in sections 4.4 and 4.6). 500 houses randomly received full screening, screened ceilings, or no screening. Homes that received full screening had timber framed doors and windows constructed that were then covered with PVD-coated fiberglass netting. Eaves were filled in with a mix of natural materials, per local norms. Houses that received screened ceilings had netting inside below eaves that was attached to the walls and any holes filled. All screening materials used were free of insecticide. CDC light traps placed at the foot of the bed were used to measure the number of mosquitoes and study houses were sampled every two weeks. All beds had untreated bed nets for participants to sleep under.

Results: 462 houses were included in the analysis at the end of the study. Both full screening and screened ceilings reduced indoor exposure to *A. gambiae*. Full screening of homes was found to be more protective against mosquitoes and more desired by participants as it was viewed as improving the appearance of the house and increased privacy.

Table 4: Mosquito Indoor Density and Screening- (Kirby et al., 2009)

Entomological Outcomes	Full screening	Screened ceilings	Control
Mean number of A. gambiae per trap per night	15.2 (12.9-17.4)	19.1(16.122.1)	37.5 (31.6-43.3)

Intervention: Newly Constructed Homes Built to Higher Standards

Hiscox et al. (2013), examined risk factors for mosquito house entry comparing newly built homes in south-central Lao PDR to traditional homes in August and October of 2010. Due to the construction of a hydroelectric project, Nam Theun, 2, 6,300 people were relocated to new homes in 16 different villages. Newly built homes had the following characteristics: high quality hard wood with less gaps in walls and floors than traditional homes, tightly fitting windows and doors, corrugated roofs, and larger in size. Traditional homes were constructed from bamboo, which left many gaps in walls and floors, windows and doors were not tightly fitted, and roofs were made from thatch, wooden tiles, or corrugated roof. Eight villages in the Nakai district along the southern shore of the reservoir were sampled. These villages were primarily populated by resettled residents in newly built homes. An additional 5 villages were also sampled in the Gnommalath district located downstream from the reservoir. These villages were mainly traditional homes, but also had some new construction. Ninety –six traditional homes and 96 newly built homes were sampled one time each, and mosquitoes were collected in bedrooms using CDC light traps that were positioned 50cm from the foot of the bed in which two adults slept underneath at ITN. Risk factor surveys were conducted on each house recording potential risks for mosquito house entry. Variables that were not included in the risk factor analysis that have been common in other studies noted included the presence of a ceiling, closed eaves, screened windows and doors due to less than 1% of houses having these features.

Results: Mosquitoes were pooled into two groups: suspected JE vectors and potential malaria vectors. Only risk factors for malaria vectors are included here. Risk factors for *anophelines* were only recorded for houses in the downstream villages due to very few specimens collected in the Nakai district. Risk of house entry for *anophelines* was greater in houses constructed from bamboo thatch and other non-wooden materials. Burning a fire in the living area or below the house reduced risk, while owning a cow doubled *anophelines* house entry risk. Both types of houses located near rice farm areas had high risks of entry. Results show housing improvements reduce a person's exposure to mosquitoes and strongly recommend housing design be taken into consideration for new builds. Houses should utilize high quality hard wood for building.

Intervention: Plywood Ceiling; Synthetic-Netting Ceiling; Insecticide-Treated Synthetic Netted Ceiling; Plastic Insect-Screen Ceiling; or Eaves Closed with Mud

Randomized control trial by Lindsay et al., (2003) using experimental huts in a rural location in The Gambia to determine if installing ceilings or closing eaves could reduce contact with malaria vectors in the home. Five interventions were tested including plywood ceiling, synthetic-netting ceiling, insecticide-treated synthetic netted ceiling, insect-screen ceiling, or closing eaves with mud. Six square experimental huts, all identical, were made with mud walls, thatched roof, open eaves, a verandah and window on each side and a door opening to the south. All huts were raised off the ground to avoid ants. East and west sides of the huts had fitted screened verandahs and window traps to catch mosquitoes leaving. Each night the huts were occupied by one person sleeping under an untreated bed net. Each hut had the above listed interventions rotated weekly and also had one week of being the control. Nightly exposure to mosquitoes in treatments huts was calculated from the mosquitoes in the room and window traps. In the control hut, mosquitoes from the room, window traps, and double the number from the verandah were counted. Mosquitoes were doubled from the verandah sum to account for the assumption that half of the mosquitoes would have left through the verandah and the other half through the eaves.

Results: Lindsay et al. (2003), found that the addition of simple ceilings greatly reduced exposure to mosquito vectors of malaria. Netting and insect-screen ceilings were found to provide the greatest reduction. The following ceiling interventions provided reduced exposure to *Anopheles gambiae*: plywood (59% reduction), synthetic netting (79%), insecticide-treated synthetic-netting (78%), plastic insect-screen (80%, $P<0.001$ in all cases). Closed eaves reduced exposure by 37%. More mosquitoes were found in huts with netting ceiling than solid, assuming that mosquitoes were not able to smell “host odors” and did not enter huts with solid ceilings. Insecticide treated netting did not appear to repel mosquitoes from entering the windows and door. Interventions were found to be cheap, £0.36-0.59/person/year for locally made ceilings (assuming life of 3-5 years, four people per room) when the study was published in 2003. Cost estimates are for screening only.

Intervention: Papyrus Mat Ceiling Modification with Hanging ITN Net

A randomized control trial by Atieli et al., (2009), in a rice irrigation scheme area in the lowlands of western Kenya was conducted to determine if modifying houses with ceilings made from papyrus mats could reduce indoor resting malaria vector densities. Malaria transmission occurs year round in this region. Homes usually have a stick framework with mud walls and either a thatch or corrugated metal roof. The authors requested that community members and women's groups weave the intervention ceilings from locally available papyrus reed stalks and then purchased them for the intervention homes at market price. Twenty homes were randomly selected and then separated into intervention and control groups. Intervention homes had the papyrus mat ceilings fixed in the entire roof space below the open eaves and a insecticide treated net (ITN) hanging below the papyrus mat ceiling in the sleeping area. From October 2007-February 2008 indoor mosquito densities were determined using the pyrethrum spray collection method in all homes, totaling 80 sampling attempts. Differences in mosquito densities between intervention and control homes was determined by t-test and ANOVA, and the odds of association of house type with the presence of malaria vector was done using Chi-square tests.

Results from papyrus mat ceiling modification found that there was a reduced house entry of *An. gambiae s.l* (78-80%) and *An. funestus* (86%) in intervention homes compared to control homes.

Intervention: Screening of Doors and Windows with Metal Mesh and Closing Openings on Eaves and Walls with Mud

A randomized control trial by Massebo et al., (2013), in Chano, a village in southwest Ethiopia, was conducted to assess if screening doors and windows and closing openings in eaves and walls could reduce mosquito indoor density of *An. arabiensis*. In March and April of 2011, 40 houses were selected and sampled for four consecutive nights biweekly using Centers for Disease Control and Prevention (CDC) light traps to generate baseline data. Houses were then randomized into intervention and control groups using IBM SPSS version 20, with the unit of randomization being an individual house. Intervention houses had all doors and windows screened with metal mesh and openings in the walls and eaves closed with mud. Holes in walls that served ventilation purposes were screened with metal mesh. Screened doors were made out of timber frame and then attached to the main door on the outside of the house using hinges. Windows were permanently fixed on the outside of the home as well with metal mesh. Mosquito collections were then conducted again on the 40 homes every second week in October and November of 2011 with five homes from the intervention group and five homes from the control group sampled per night for four consecutive nights per week. *Anophelines* were identified and classified into categories based on their abdomen, including unfed, freshly fed, half gravid and gravid. Mean ratios of mosquitoes sampled between intervention and control group were used to determine the reduction of entry by mosquitoes.

Results by Massebo et al., (2013), show that screening windows and doors and closing gaps in eaves and walls with mud reduced indoor density of *An. arabiensis* by 40% (ratio of means 0.6, p=0.006) in intervention homes compared to control homes. Additionally, the intervention homes had reduced numbers of indoor density of hunger *An. arabiensis* (42%, ratio of means 0.58, p=0.004) and indoor density of freshly fed *An. arabiensis* (36%).

Intervention: Screening of Eaves, Windows and Doors Using PVC-Coated Fiber Glass Netting Material

Ogoma et al., (2010), evaluated the preferential points of entry of different mosquito species into houses by measuring indoor densities of mosquitoes. The goal of the study was to understand the "optimal method" needed for screening to reduce specific vectors. Only results regarding malaria vectors are included here. The controlled experiment was conducted in south eastern Tanzania in a village with very high malaria transmission (average of 474 and 851 infectious bites per person per year) and high rate of mosquito net coverage above 75%. Local home characteristics include mud walls, thatched roofs with open eaves, and one to two windows. Experimental huts were built to represent local homes and came in kit form. Four local homes and four experimental huts were included in the experiment, all close to each other. Two volunteers slept each night in the same experimental hut. PVC –coated fiberglass netting material was used to screen doors, windows, and eaves. In experimental huts, screens were attached by hook and loop fasteners, while in the local homes screens were nailed into the mud wall. Cotton wool helped seal gaps in the traditional homes between the structure and the intervention. Treatments occurred for all homes so that "four repetitions of four experimental treatment arrangements" occurred. For three nights, three of the four houses would have the same entry point screened and the fourth house would be unscreened. All huts were unscreened the first night, and then for next three nights for each repetition, treatments were changed nightly in each hut beginning with screening the eaves, then windows, and finally doors. Each night one hut had no entry point screened to act as a control. CDC light traps were used to sample mosquito vectors and placed near beds where an individual(s) slept under an untreated bed net.

Results: Malaria vectors were less likely to be found in homes that had screened eaves. Impact of screening eaves upon indoor densities of *An. gambiae sensu lato* 0.91 relative rate (RR), (0.84-0.98, 95% CI).

<u>Intervention: Netting Barriers (Four Year Old Mosquito Nets, Untreated Shade Cloth, and Deltamethrin-Impregnated Shade Cloth) Covering Gable Ends and Eaves</u>

Kampango et al., (2013), pilot tested three different types of netting that differed in their permeability to air on 16 homes in southern Mozambique to evaluate their effectiveness in reducing *Anopheles funestus* and *Anopheles gambiae s.l* house entry. Houses in this area are rectangular, built of reed, and have palm leaf roofs. Few houses have windows, and most have just a single entry door. Estimates of 15 cm spaces between end gables and the roof, providing mosquitoes entry points into the houses. Four year old used Interceptor mosquito bed nets, locally purchased untreated shade cloth, and deltamethrin-impregnated shade cloth were tested in a two-step intervention, first by using each material to cover the gable ends of houses, and then to cover both the gable ends and the eaves. The pilot study was conducted from March to August 2010 and consisted of four experimental rounds lasting three weeks each. Four houses were included in each round with one being the control. Each house had 18 days of sampling during each experimental round by using CDC light traps. Sampling occurred before the first step intervention, during the first step intervention, and then during the second step intervention. The efficacy of each material was determined by the incidence rate ration (IRR) of mosquitoes that entered treated homes compared to the control.

Results: Houses with mosquito netting had 61.3% [IRR=0.39 (0.32-0.46); P<0.0001] and untreated shade cloth 70% [IRR 0.30 (0.25-0.37); P<0.001] fewer *An. funestus* than houses without the interventions. Deltamethrin-impregnated shade cloth had no reduction in houses with the intervention [IRR=0.92 (0.76-1.12); P=0.4] than houses without the intervention.

For *An.gambiae s.l*, mosquito netting reduced entry rates by 84% [IRR=0.16 (0.10-0.25); P<0.001], untreated shade cloth reduced entry rates by 69% [IRR=0.31 (0.19-0.53); P<0.001], and deltamethrin-impregnated shade cloth reduced entry rates by 76% [IRR=0.24 (0.15-0.38); P<0.001].

Covering the whole house instead of just the gable ends reduced entry by *An. gambiae s.l*, but not *An. funestus.* This is most likely due to differing house entry behavior between the two species.

4.5 Outcome Measure: Anemia

Intervention: Full Screening or Screened Ceilings

Kirby et al. (2009) study, (detailed above in 4.5 Outcome measure: mosquito indoor density), also examined the efficacy of house screening in preventing anaemia in children (aged 6 months-10 years) as a secondary endpoint in their randomised controlled trial in The Gambia in 2006 and 2007. The clinical endpoints included haemoglobin concentration, frequency of anaemia (defined as haemoglobin <80 g/L) and severe anaemia (haemoglobin <50 g/L). Children had clinical cross-sectional screenings at the end of each transmission season in 2006 and 2007, both six months or more after screening interventions. A finger prick method was used to obtain a blood sample to measure haemoglobin concentration. Children who were found to be anaemic (<80 g/L) were given iron supplements and those found to be severely anaemic (50< g/L) were taken to a local hospital and given a blood transfusion and further testing. Children with severe anaemia had their haemoglobin retested two weeks after their release from the hospital.

Results: 731 out of 755 children had complete data that was used in the analysis. 30 (19%) of 158 children from control houses had anaemia, compared with 38 (12%) of 309 from houses with full screening (OR 0.53, 95% CI 0.29-0.97; P=0.04) and 31 (12%) of 264 from houses with screened ceilings (OR 0.51, 0.27-0.96; p=0.04). Children in homes that were fully screened or had screened ceilings were less likely to have anaemia than those in the control group.

Chapter V

Discussion and Conclusion

Discussion

5.1 Primary Outcomes

The primary outcomes for this systematic review include the incidence of malaria, prevalence of parasitaemia, and the mosquito density measurement within homes.

One study, a household based cross sectional (Wolff et al., 2001), found improved housing to reduce burden of disease, including malaria, respiratory, and gastrointestinal infections in children under five years of age in Malawi. In a March survey, 19% of children in Habitat constructed houses had malaria compared to 26% in traditional houses. Another survey in August showed 7% of children in Habitat constructed houses had malaria compared to 8% living in traditional houses. Overall, the percentage of children with any of the infections was lower in improved homes.

Two studies examined housing improvements and the prevalence of parasitaemia, Ye et al, (2006), a cross-sectional study design and Kirby et al., (2009), a randomized control trial. Kirby (2009), found no significant difference in parasitaemia between houses with interventions and controls and stated that “such a decline can only be achieved if the infection level in the intervention groups is substantially suppressed” and points to current primary interventions not effectively reducing parasite prevalence. Ye (2006), found iron-sheet roofs to be protective against *plasmodium falciparum* infection when compared to traditional roofs made of mud and grass.

Seven studies (Kirby et al., 2009, is included in three areas: prevalence of parasitaemia, mosquito indoor density, and anaemia in children) examined housing improvements to reduce indoor mosquito density. Two randomized control trials (Atieli, 2009 and Lindsay, 2003) found ceiling interventions to effectively reduce indoor mosquito density. One study (Hiscox, 2013) found newly built housing with improved materials to be effective in reducing mosquito-human contact compared to traditionally built homes. However, Hiscox et al., (2013) had geographical variation between their samples of traditional homes and newly constructed homes. They recommend a larger sample size of houses all in the resettlement area. Four studies focused on various ways screening (Kampango, 2013; Ogoma, 2010; Massebo, 2013; and Kirby, 2009) can reduce indoor mosquito density. A pilot study by Kampango et al., (2013), found various types of netting material covering gables and eaves to be effective in reducing *An. gambiae s.l.*, but not always in *An. funestus* species. A case control study by Ogoma et al., (2010), found that screening eaves protects households against many types of mosquito vectors. Two randomized control studies were conducted focusing on screening interventions. Kirby et al., (2009), found both full screening of homes and only screening ceilings to be effective in reducing indoor mosquito density. Massebo et al., (2013), results show that screening doors and windows can help reduce indoor density of *An. arabiensis* by 40%. The moderate percentage of ability to reduce indoor density was noted by the author as most likely being contributed to doors left open during the day and incompatibility between interventions and traditional homes. Massebo et al., (2013), found that local homes in southwest Ethiopia were not well-matched for screening due to the grass thatched roofs not allowing the doors to open outward making it so they could not be permanently attached and therefore possibly reducing efficacy of the screening intervention.

Additionally, because the doors were not permanently attached, inhabitants might not have used them.

5.2 Secondary Outcome

The secondary outcome for this systematic review is anemia prevalence in children as it is a good indicator of malaria infection and a leading cause of malaria mortality in children.

One study (Kirby et al., 2009), examined the relationship between housing improvements and anaemia in a randomized control trial. Screening interventions were found to reduce anaemia frequency in children living in intervention houses compared to controls.

5.3 Considerations

One important question to consider when examining housing improvements as a supplemental vector control strategy is how we will consider the wide variety of geographical and demographic settings in which these interventions need to be implemented. Differences between housing styles and building techniques can impact the effectiveness of various interventions, leading them to be less effective in some settings compared to others. Additionally, house entry behavior by malaria vectors must be considered depending upon location and species and what types of housing improvements should be recommended. This systematic review shows that the housing interventions tested were successful against reducing *An. gambiae,* the main African malaria vector of concern.

Furthermore, how do we address housing that is poorly built and not easily compatible with recommended housing interventions? Massebo et al., 2013, found local homes in southwest Ethiopia were not well-matched for screening. The grass thatched roofs did not allow the doors to open outward making it so they could not be permanently attached and therefore possibly reducing efficacy of the screening intervention. Kampango et al., 2013, also noted that if houses are not relatively well built, covering gables and eaves might not be enough to sufficiently reduce indoor mosquito density. The authors noted the importance of well constructed doors firmly attached to homes as a key for ensuring that gaps and entry ways are further reduced.

5.4 Reception by Participants

Housing improvements were mostly found favorably by participants. Papyrus mat ceiling modifications were widely accepted by community members in Kenya. According to focus group participants "ceilings were cheap, considered to beautify houses, widely associated with reduced temperatures and less associated disturbance by mosquitoes" (Atieli et al., 2009). In The Gambia (Kirby et al., 2009), participants were allowed to keep their intervention or switch to the other available intervention. Participants largely favored full screening of houses over screened ceilings due to increased privacy, reduction of pests and mosquitoes. 94% of participants with full screening decided to continue their intervention after the study concluded. A common recommendation to close eaves with non-permeable barriers to reduce mosquito house entry was considered to possibly not be acceptable by Kampango et al., 2013. While closing eaves reduces risk of mosquito entry, open eaves provides light and ventilation. Netting should be considered so that favorable aspects of open eaves can continue.

5.5 Costs Associated with Housing Improvements

While housing improvements may be a more costly intervention up front, they might prove to be a sustainable intervention that is cost effective over time. Almost all of the studies in this systematic review found housing improvements to be cheaper than or as affordable as current primary interventions targeting malaria vectors, or proving to be cost effective over time. According to Liu et al. (2013), “Permanent change eliminates the need to continuously distribute LLINs, conduct IRS periodically, or demand consistent use of ITNs, which is particularly difficult to sustain when the perceived risk of malaria decreases.”

Massebo et al., (2013), calculated that the total costs per household for screening windows and doors and closing openings in eaves and walls with mud was $7.34. Furthermore, all materials were locally bought.

Papyrus ceiling mats were locally made in the randomized control trial in Kenya and were purchased for around $1/per mat; assuming a 10 year life and three people per house from local community members (Ateli et al., 2009).

Improved housing constructed by Habitat for Humanity in rural Malawi (Wolff et al., 2001) included fire mud bricks, tile roofing, concrete foundation, pit latrines, and were around 30m and consisted of three rooms, cost about $550 when they were built in the late 1990’s and were offset by a 10 year no interest loan.

The use of used bed nets as screening for eaves and gables, as tested in Kampango et al., 2013, could potentially be a low cost beginning point for housing improvements. In areas with high bed net coverage, old bed nets could be re-used as screening and therefore help reduce waste from this intervention. Additionally, using them as screening takes little effort and no specialization, allowing homeowners the ability to provide an additional intervention.

However, people living in endemic areas may not always be able to afford housing improvements, as Ye et al., 2006, found that corrugated iron-sheets to be used for roofing were expensive and unaffordable for many villagers.

Many of the materials used in the studies were locally made or available, an important aspect that could help to engage community members in endemic malaria areas by supporting the local economy, participation by community members, and implementing the most effective interventions to the type of housing commonly built in communities.

5.6 Conclusion

Housing improvements were found in all studies to be effective supplemental vector control strategies. These interventions should be considered as additional supplemental vector control strategies to compliment current primary interventions. It must be emphasized that current primary interventions, such as ITNs, should continue to be used. What housing improvement interventions should be recommended for widespread use needs to be determined.

5.7 Recommendations for Research

Assessing the efficacy of housing improvements as an effective vector control method must be completed in many different ecological settings for there to be widespread support of its use as a supplemental strategy. Additionally, what specific housing improvements are most beneficial and should be recommended? Additional studies, preferably randomized control studies, need to be conducted to assess effectiveness in various settings and identify the most beneficial housing improvement intervention for a broad implementation to be considered. Studies considering cost and durability as well as the effect on mosquito behavior should also be undertaken.

<u>References</u>

Anderson L., D. Simpson, and M. Stephens (2013).” Durable Housing Improvements to Fight Malaria Transmission: Can we learn new strategies from past experience?” *Healthy Housing Initiative- White Paper No.1*. Habitat for Humanity International- Global Programs Department, Atlanta.

Atieli H., D. Menya, A. Githeko, T. Scott (2009). “House design modifications reduce indoor resting malaria vector densities in rice irrigation scheme area in western Kenya.” *Malaria Journal* 8:108. Doi: 10.1186/1475-2875-8-108.

Bradley J., A.M. Rehman, C. Schwabe, D. Vargas, F. Monti, C. Ela, M. Riloha, I. Kleinschmidt (2013). “ Reduced Prevalence of Malaria Infection in Children Living in Houses with Window Screening or Closed Eaves on Biko Island, Equatorial Guinea.” *PLoS ONE* 8(11): e80626. doi 10.1371/journal.pone.0080626.

Carter R., K. Mendis (2002). “Evolutionary and Historical Aspects of the Burden of Malaria.” *Clinical Microbiology Reviews* 15: 564-594, doi: 10.1128/CMR.15.4.564-594.2002.

Clarke S.E., C. Bogh, R.C. Brown, G. Walraven, C.J. Thomas, S.W. Lindsay (2002). “Risk of malaria attacks in Gambian children increases away from malaria vector breeding sites. *Transactions of the Royal Society of Tropical Medicine and Hygiene.* 96, 499-506.

CDC | About Malaria (n.d.) Centers for Disease Control and Prevention. Retrieved February 4, 2014, from http://www.cdc.gov/malaria/about/index.html

Ferroni E., T. Jefferson (2012). “Angelo Celli and research on the prevention of malaria in Italy a century ago.” *Journal of the Royal Society of Medicine* 105: 35-40. doi 10.1258/jrsm.2011.11k049.

Gimnig, J.E., L. Slutsker (2009). “House screening for malaria control.” *The Lancet* 374:998. doi 10.1016/S0140-6736(09)61078-3.

Hiscox A., P Khammanithong, S Kaul, P Sananikhom, R Luthi, N Hill, P.T. Brey, S.W. Lindsay (2013) “Risk Factors for Mosquito House Entry in the Lao PDR.” PLoS ONE 8(5): e62769. doi: 10.1371/journal.pone.0062769.

Huho B., O. Briet, A. Seyoum, C. Sikaala, N. Bayoh, J. Gimnig, F. Okumu, D. Diallo, S. Abdulla, T. Smith and G. Killeen (2013). “Consistently high estimates for the proportion of human exposure to malaria vector populations occurring indoors in rural Africa.” *International Journal of Epidemiology* 42(1): 235-247.

Kampango A., M. Braganca, B. D. Sousa, J.D. Charlwood (2013). “Netting barriers to prevent mosquito entry into houses in southern Mozambique: a pilot study.” *Malaria Journal* 12:99.

Kirby M.J., D. Ameh, C. Bottomley, C. Green, M. Jawara, P.J. Milligan, P.C. Snell, D. Conway, S.W. Lindsay (2009). "Effect of two different house screening interventions on exposure to malaria vectors and on anaemia in children in The Gambia: a randomised controlled trial." *The Lancet* 374:998-1009.

Kirby M.J., C. Green, P.M. Milligan, C. Sismanidis, M. Jasseh, D. Conway, S.W. Lindsay (2008). "Risk factors for house-entry by malaria vectors in a rural town and satellite villages in The Gambia." *Malaria Journal* 7:2 doi:10.1186/1475-2875-7-2.

Kirby M.J., P. Bah, C.O.H. Jones, A.H. Kelly, M. Jasseh, S.W. Lindsay (2010). "Social Acceptability and Durability of Two Different House Screening Interventions against Exposure to Malaria Vectors, Plasmodium falciparum Infection, and Anemia in Children in The Gambia, West Africa." *Am. J. Trop. Med. Hyg.* 83(5):965-972. doi 10.4269/ajtmh.2010.10-0311.

Liu J.X., T. Bousema, B. Zelman, S. Gesase, R. Hashim, C. Maxwell, D. Chandramohan, R. Gosling (2013). "Is Housing Quality Associated with Malaria Incidence among Young Children and Mosquito Vector Numbers? Evidence from Korogwe, Tanzania." *PLoS ONE* 9(2): e87358. doi: 10.1371/journal.pone.0087358.

Lindsay S.W., P. Emerson, J.D. Charlwood (2002). "Reducing malaria by mosquito-proofing houses." *Trends in Parasitology.* 18:510-514.

Lindsay, S.W., M. Jawara, K. Paine, M. Pinder, G.E.L. Walraven, P.M. Emerson (2003). "Changes in house design reduce exposure to malaria mosquitoes." *Tropical Medicine and International Health* 8(6) 512-517.

Lwetoijera D.W., S.S. Kiware, Z.D. Mageni, S. Dongus, C. Harris, G.J. Devine, S. Majambere (2013). "A need for better housing to further reduce indoor malaria transmission in areas with high bed net coverage." *Parasites and Vectors* 6:57.

Massebo F, B. Lindtjorn (2013). "The effect of screening doors and windows on indoor density of *Anopheles arabiensis* in south-west Ethiopia: a randomized trial." *Malaria Journal* 12:319.

Mendis K, A. Rietveld, M. Warsame, A. Bosman, B. Greenwood, W.H. Wernsdorfer (2009). "From malaria control to eradication: The WHO perspective." *Tropical Medicine and International Health* 14(7) 802-809.

Ogoma S.B., K. Kannady, M. Sikulu, P.P. Chaki, N. J. Govella, W.R. Mukabana, G.F. Killeen (2009). "Window screening, ceilings, and closed eaves as sustainable ways to control malaria in Dar es Salaam, Tanzania." *Malaria Journal* 8:221. doi 10.1186/1475-2875-8-221.

Ogoma S.B., D.W. Lweitoijera, H. Ngonyani, B. Furer, T.L. Russell, W.R. Mukabana, G. Killeen, S.J. Moore (2010). "Screening Mosquito House Entry Points as a Potential Method for

Integrated Control of Endophagic Filariasis, Arbovirus and Malaria Vectors." *PLoS Negl. Trop Dis* 4(8): e773. doi: 10.1371/journal.pntd.0000773.

O'Meara W.P., J.N. Mangeni, R. Steketee, B. Greenwood (2010). "Changes in the burden of malaria in Sub-Saharan Africa." *Lancet Infectious Diseases* 10:545-55.

Pates H, Curtis C (2005). "Mosquito behavior and vector control." *Annu Rev Entomol*, **50:**53-70.

Sachs J., P. Malaney (2002). "The economic and social burden of malaria." *Nature* 415:680-685.

Tusting L.S., B. Willey, H. Lucas, J. Thompson, H.T. Kafy, R. Smith, S.W. Lindsay (2013). "Socioeconomic development as an intervention against malaria: a systematic review and meta-analysis." *Lancet* 382:963-972.

RBM/UNDP (2013). Multisectoral Action Framework for Malaria. Geneva, Roll Back Malaria/United Nations Development Programme.

Walker, N. (2010). "The Hygienic House: Mosquito-Proofing with Screens." *Am. J. Trop. Med. Hyg.*, 83(5):963-964. doi: 10.4269/ajtmh.2010.10-0405.

WHO (2013). World Malaria Report. Geneva, World Health Organization.

WHO | Vector control and insecticide resistance (n.d.) *World Health Organization.* Retrieved January 26. 2014, from http://www.who.int/malaria/areas/vector_control/en/

WHO | Drug resistance and containment (n.d.) *World Health Organization*. Retrieved January 26, 2014, from http://www.who.int/malaria/areas/drug_resistance/en/

Wolff C.G., D.G. Schroeder, M.W. Young (2001) "Effect of improved housing on illness in children under 5-year-old in northern Malawi: cross sectional study. *BMJ* 322: 1209-1212.

Ye Y., M. Hoshen, V. Louis, S. Seraphin, I Traore, R. Sauerborn (2006). "Housing conditions and *Plasmodium falciparum* infection: protective effect of iron-sheet roofed houses." *Malaria Journal* 5:8 doi: 10.1186/1475-2875-5-8.