Cost-effectiveness of dengue control using copper ions in Indonesia

Hisaya Doi,1 Eiji Konishi,2 Hiroya Matsuo3
Medical researcher, Division of Anesthesiology, Department of Surgery Related, Kobe University Graduate School of Medicine; Doctoral Program, Kobe University Graduate School of Health Sciences1
Research Institute for Microbial Diseases, Osaka University2
Kobe University Graduate School of Health Sciences3

Abstract

Japan’s climate has rapidly become more tropical in recent years due to the effect of global warming. Such climate change raises concerns about the outbreak of tropical infectious diseases in Japan. In taking measures against infectious diseases, prevention of such diseases is beneficial from a health care economics viewpoint. Thus, we focused on dengue fever, and estimated how much Indonesia’s health care expenditures will be reduced by using the insecticidal property of copper ions to prevent eclosion of the dengue vector Aedes aegypti. As a result of using 5-yen coins, 10-yen coins, brass fiber and copper fiber as copper ion sources, copper fiber was found to produce the largest economic effect. The cost of illness associated with dengue fever in Indonesia is about 1.4 billion dollars, whereas the cost for preventing eclosion of Aedes aegypti by using copper fiber was low at about 45 million dollars. We consider measures to eradicate Aedes aegypti by using copper ions to be a useful and economical approach.

Keywords: Dengue fever, copper ions, Aedes aegypti, cost-effectiveness

Introduction

Japan’s climate has rapidly become more tropical in recent years due to the effect of global warming. Such climate change raises concerns about the outbreak of tropical infectious diseases in Japan. In the tropical zone where a large number of developing countries exist, various health damages caused by such diseases have been a problem. Therefore, measures against tropical infectious diseases are important, and prevention of such diseases is also beneficial for reducing health care expenditures (from a health care economics viewpoint).1 Indeed, the Indonesian Ministry of Health
has rolled out a basic policy to shift from the conventional passive health care policy focusing on treatment and rehabilitation to a more proactive policy focusing on disease prevention and health promotion, giving high priority to disease prevention. It has selected specific diseases to prioritize under the term MADAT (M: malaria; A: avian influenza; D: dengue fever; A: AIDS; and T: tuberculosis) as specific diseases, and positions dengue fever as the disease to be addressed with the highest priority.

Dengue fever is an infectious disease caused by the dengue virus, and its key vector mosquito is *Aedes aegypti*. It is one of the most important tropical diseases along with malaria. The World Health Organization (WHO) reports that the disease is now endemic in more than 100 countries. More than half of the world’s population lives in areas with a risk of dengue infection, and the annual number of dengue cases around the world is estimated at 50 million to 100 million. After an incubation period of four to seven days, dengue presents a condition of acute febrile illness, and it is relatively difficult to make a definitive diagnosis. A few percent of dengue patients further develop dengue hemorrhagic fever (DHF), accompanied by hemorrhagic tendency and disseminated intravascular coagulation (DIC), with a fatality rate of 0.2%. Moreover, 20–30% of DHF patients go into shock and develop dengue shock syndrome (DSS) with a high fatality rate of 12–44%. These DHF and DSS patients need to be hospitalized, and the treatment cost is enormous.

Indonesia has recently been categorized as an emerging economy as defined by the World Bank. However, the country’s sanitation is still in the developing stage. Indonesia has a population of 230 million, of which 50 million are without access to clean water and 71 million without access to sanitation. Most Indonesian houses have a water container for a toilet called “Storage in WC” (WC), and a large number of *Aedes aegypti* pupae are found in these containers, triggering the onset of dengue fever.

Given that no effective vaccine has been approved against the dengue virus at present, *Aedes aegypti* control is considered to be an important means for preventing dengue fever, also from a health care economics viewpoint. Thus, we took note of several reports indicating that copper and copper alloy inhibit the growth of *Aedes aegypti* larvae. In Japan as well, it has been known from experience that leaving some 10-yen coins in a bucket of water in the garden controls mosquito larvae, suggesting that copper ions are discharged from the 10-yen coins. That is to say, copper ions are considered to have an insecticidal property against mosquito larvae.

In this study, we focused on dengue fever, and estimated how much Indonesia’s health care expenditures will be reduced by using the insecticidal property of copper ions to prevent eclosion of the dengue vector *Aedes aegypti*, and examined the
usefulness of this approach. Note that in expressing expenditures in this article, international dollars and U.S. dollars are uniformly expressed as “dollars” having the same value.

**Materials and Methods**

(1) Materials for copper ion discharge

As copper ion sources, we used 5-yen coins, 10-yen coins, brass fiber and copper fiber, and dissolved them in distilled water. A copper sulfate solution was used as a positive control. Copper ions were measured by using the Copper Test Kit (Japan Ion Corporation, Tokyo) every 24 hours.

(i) Experiments using 10-yen coins
   (a) Inserting five 10-yen coins in 20 ml of distilled water
   (b) Inserting one 10-yen coin in 20 ml of distilled water
   (c) Inserting one 10-yen coin in 200 ml of distilled water
(ii) Experiment using 5-yen coins
   (d) Inserting five 5-yen coins in 20 ml of distilled water
(iii) Experiment using brass fiber
   (e) Inserting 2.75 g of brass fiber in 25 ml of distilled water
(iv) Experiment using copper fiber
   (f) Inserting 4.5 g of copper fiber in 200 ml of distilled water

(2) Method of determining the type and amount of copper ion sources and the amount of distilled water

First, the solubility of copper ions was unknown at the time of conducting the experiments using 5-yen coins and 10-yen coins. Thus, we used five coins and 20 ml of distilled water in experiments (a) and (d). The results of these experiments revealed that the copper ion concentration was sufficiently high when using a 10-yen coin, so we used one 10-yen coin in experiment (b), and considering that the WC capacity is about 20 l, we used 200 ml of distilled water in experiment (c). Further, in experiment (e), we used a lump of brass fiber that weighs 2.75 g, and 25 ml of distilled water to fully soak the lump. In experiment (f), we used 4.5 g of copper fiber, which is the same weight as a 10-yen coin.

(3) Literature search method used for philological consideration

We searched and cited literature from PubMed and meeting minutes of
economic research groups, academic societies and other study groups.

**Results and Discussion**

(1) Expenditures for treatment of dengue fever in Indonesia

(i) Dengue fever

The earliest record of dengue fever dates back to 265–420 B.C. in China, which states that water-related insects are involved in the disease. In recent years, the disease is regarded as a mosquito-borne viral disease with high incidence and fatality rates.

The incubation period of this disease is basically four to seven days, but it can range from three to 14 days. The disease presents a condition of acute febrile illness. Its symptoms include headache, pain behind the eyes, pain in the bones, muscles and joints, nausea, vomiting, rash and fatigue, but it lacks specific symptoms, and it is difficult to make a definitive diagnosis. Dengue fever is characterized by a biphasic or saddleback biphasic fever curve that lasts for two to seven days. Dengue is suspected when the fever accompanies the abovementioned symptoms, and a definitive diagnosis is given by using polymerase chain reaction (PCR). It is difficult to give a differential diagnosis from other febrile illnesses (chikungunya, measles, leptospirosis, typhoid, malaria, etc.) based on clinical symptoms alone. However, it has been reported that a significantly large number of dengue patients in Indonesia exhibit nausea as one of the symptoms. Also in the case identified in Kobe City last year where a patient who frequently visited Southeast Asia developed a fever of unknown origin, nausea was a chief complaint on the patient’s initial visit. In this case, the patient developed abdominal tenderness and leg pain at the onset of the fever, and a rash on the fifth day of the fever.

A few percent of dengue patients further develop DHF. Diagnosis of DHF requires a sudden high fever (38–40°C) that lasts for two to seven days, hemorrhagic tendency (the tourniquet test is positive for more than 50% of the cases), a decrease in platelets, and plasma leakage. Some cases additionally accompany an enlarged liver, circulatory failure and DIC. The annual number of DHF patients around the world is estimated at 250,000 to 500,000. Dengue fever and DHF are caused by any of four serotypes (serotypes 1 to 4) with similar immunogenicity, and the disease is considered to become severe if a patient is secondarily infected by another serotype.

Moreover, 20–30% of DHF patients go into shock and exhibit dengue shock syndrome (DSS). The DSS accompanies DHF as well as circulatory failure. Warning signs of shock include persistent strong abdominal pain, persistent nausea, restlessness, lethargy and a sudden shift from fever to hypothermia accompanying sweating and
prostration, and if a patient develops these symptoms, treatment of shock should be started promptly.\textsuperscript{7} At hospitals well-experienced in treating DSS, the fatality rate of DHF is low at 0.2%.\textsuperscript{7} However, the rate rises to 12–44% for cases of DSS that have not received appropriate treatment.\textsuperscript{7}

As for susceptible ages, it had been reported that 90% of DHF patients around the world are children less than 15 years of age,\textsuperscript{20} but reports of adult cases have grown in recent years.\textsuperscript{21} By age group, the percentage of patients aged 5–15 significantly dropped from 60% in 1993 to 30% in 2001.\textsuperscript{21} On the other hand, the percentage of patients aged 15 or older significantly increased from 20.5% in 1993 to 54.5% in 2001.\textsuperscript{21} Recently, patients aged 65 or older rarely develop DHF, but the disease often becomes severe and the aggravation rate is high.\textsuperscript{22} While the decline of incidence among younger age groups has led to securing the country’s future production capacity, the increase of severe cases and death cases among the elderly has led to higher health care expenditures. Table 1 shows the number of dengue patients, the incidence per 100,000 population and the fatality rate in Indonesia.\textsuperscript{23,24} The population, number of patients and incidence have risen, but the fatality rate dropped in 2009 to a level below the country’s target of 1%. However, a large number of patients are considered to lack access to diagnosis and treatment among the poor, and the actual number of patients is expected to be substantially higher than the statistics.\textsuperscript{8}

(ii) Indonesia

The Republic of Indonesia is a country in Southeast Asia consisting of about 17,000 islands and having an area five times larger than Japan. It has the fourth largest population in the world at about 230 million. By age group, the population aged 0 to 14 and the population aged 15 to 29 respectively constitute about 30% of the total population, suggesting that the country is expected to achieve further economic growth with its large future labor population and consumer population. Indeed, Indonesia’s economic growth rate in 2011 was 6.6%, surpassing the 2.2% average economic growth rate of developed countries (the United States, the Euro zone, the United Kingdom and Japan), and is predicted to rise to the third highest in the world by 2013.\textsuperscript{25,26} However, 56% of Indonesian people live on 2 dollars per day or less. For this poor segment with limited income, excessive health costs will restrain education and threaten family life. For the past few years, health cost in Indonesia has been 1.6–2% of the gross domestic product (GDP), considerably lower than the 4.5% in other developing countries such as Bangladesh and Nepal. In addition, only 16% of Indonesia’s total population have health insurance, which is a lower percentage compared to other Southeast Asian
In terms of resources, Indonesia is the world’s largest producer of palm oil, the world’s second largest producer of tin, nickel and natural rubber, and the world’s sixth largest producer of copper. However, Indonesian workers’ average monthly income is 148 dollars, which is lower than the levels in other Asian countries such as India, Thailand and China. The approach to control *Aedes aegypti* by using copper ions, discussed in this study, suits Indonesia’s situation also from the viewpoint of resources.

(iii) Problems concerning treatment of dengue fever

Since dengue fever is a viral disease, its treatment is centered on symptomatic therapy. Given that most Indonesian people do not have health insurance, they will have to fully bear the cost of such treatment.

Even if dengue patients unfortunately further develop DHF, their fatality rate can reportedly be restrained to below 1% through appropriate treatment and nursing care. The average cost of nursing care is about 38 dollars per day in Asia. One of the complications of DHF, gastrointestinal bleeding, is found in 80% of the DHF patients, and 30% of them go into shock and die. Since gastrointestinal bleeding develops suddenly, careful observation, that is, nursing care is required. Other complications that require attention include cardiomyopathy and encephalitis. Further, patients with long-standing DHF/DSS can develop disorders of consciousness, spasms or fall into a coma. Acute renal failure (ARF) is a relatively rare but serious complication of DHF because it could lead to death if it accompanies septicemia. In actuality, while ARF was found in 3.3% of DHF patients at the time of hospitalization, and 60% of them died, all DHF patients without ARF survived. Among DHF patients with ARF, complication with DSS serves as a risk factor for death. Therefore, early diagnosis of ARF complication in DHF patients contributes to lowering the fatality rate. Furthermore, if a patient with DHF complicated by ARF survives but develops chronic renal failure, maintenance dialysis will be needed, and the health care expenditures become a problem. Incidentally, an annual expenditure of about five million yen is required per patient for maintenance dialysis in Japan. The same level of expensive health care will also be required in Indonesia. Therefore, under limited health care expenditures, dengue fever needs to be definitively diagnosed at an early timing, and be treated intensively so as to prevent the transition to DHF/DSS, but from the viewpoint of health care economics, the best approach would be to prevent dengue fever. In addition, while Indonesia aims to lower the fatality rate per 100,000 population of dengue fever to a level below 1.0, various problems including uneven distribution of
doctors, delay in the development of medical care systems such as health insurance, poverty of the people and delay in infrastructure development have caused delay in diagnosis and treatment, and have hindered attainment of this target.

(iv) Costs related to dengue fever treatment

First of all, one of the methods to economically identify the social impact of a disease is the “cost of illness.” The cost of illness is largely divided into direct cost and indirect cost. Direct cost is the cost that directly occurs through intervention of health care, such as the labor cost of doctors and nurses, medical testing cost and medication cost. Indirect cost is the loss associated with declined productivity caused by the disease and any resulting disabilities or death, and it is also referred to as productivity cost. Indirect cost can be further divided into mortality cost, which is the loss associated with early death including suicide, and morbidity cost, which is the loss associated with the disease, such as leaving a job, being absent from work and lower work efficiency. The morbidity cost can be further divided into absenteeism, which is the loss from being absent from work, leaving a job or being unable to find work, and presenteeism, which is the loss from being able to work but suffering from declined work efficiency. For example, depression has recently been characterized by the high amount of indirect cost, particularly morbidity cost, and its high proportion in the total indirect cost. With regard to dengue fever as well, if the disease is aggravated into DHF or DSS, the treatment cost will become high and will affect the household budget. In the case of DHF, about nine days of disease duration will be needed including hospitalization, and an adult patient will incur loss from absence from work, and a child patient will also face increased indirect cost, including the cost of care by family members or a carer. 

Health care expenditures in Indonesia are restrained at present. The following part discusses the health care expenditures for dengue fever. The cost required for diagnosis of dengue fever is said to be 22 dollars, which is ten times the daily living cost for about half of Indonesian people.

Since reports on the treatment cost for dengue fever in Indonesia are scarce, we made a comparative study based on other countries’ data. First, we examined the number of dengue patients in light of the health care situation in Indonesia. We made comparison with Thailand, Cambodia and Vietnam, which are Indonesia’s neighboring countries. Thailand has a population of about 63 million with GDP per capita of about 5,000 dollars. As of 2011, the country is achieving high economic growth following Indonesia. The economy is centered on external demand, and its foreign currency reserve is twice as high as that of Indonesia. Cambodia has a population of 13 million
with GDP per capita of 600 dollars. Vietnam has a population of 89 million with GDP per capita of 1,200 dollars. Meanwhile, Indonesia has a population of 230 million with GDP per capita of about 3,015 dollars. The per capita health care spending to public institutions in 2003 was 11 dollars in Indonesia and 63 dollars in Thailand, indicating that the level of health care spending in Indonesia is low, even taking into account the difference in per capita GDP. Furthermore, Thailand has relatively substantial social security, such as a scheme that exempts a covered patient who has registered with a hospital in advance from a certain amount of treatment fees at that hospital by paying 5% of the patient’s wage as a premium. Meanwhile, the rate of out-of-pocket health care expenditures is 90% in Cambodia and 50% in Indonesia. Cambodia has public health care institutions, but the poor segment often select private health care providers at the final stage. Since the treatment cost at private health care providers is three to four times higher than that at public institutions, 63% of the patients become indebted. The reasons for selecting private providers include uneven distribution of and lack of trust in public institutions. Moreover, a more costly choice of “home care” is often selected as well. Due to the high interest (2.5–15%) on debts, many households have to sell their property. If these economic issues worsen poverty, and further cause such disease as depression, they are likely to cause loss of indirect cost as mentioned above. In Indonesia, one public health care institution exists per 10,000 population, with only 0.6 beds per capita provided by public and private health care providers, and the bed occupancy rate is merely about 50%. This is assumed to be due to the uneven distribution of public institutions attributable to the country being made up of a large number of islands and due to the high out-of-pocket health care expenditures. This phenomenon is considered to also apply to dengue fever patients. There is also a report that the actual number of dengue patients requiring treatment is underrecognized by about 10-fold in Thailand and Vietnam. Given that the tendency of the changes in the number of patients is similar in Indonesia and Thailand, that the annual number of patients in Thailand is about four times the number in Indonesia and the number of patients correlates with the population size, that the susceptible ages for dengue had been less than 15 years of age in both countries until 2000, and that both countries are humid, which is considered to be a regional characteristic related to the occurrence of dengue, we consider it possible to assume that the actual number of patients in Indonesia is also underrecognized by about 10-fold. Since the dengue incidence in Indonesia reported for 2010 was 70 per 100,000 population, the number of dengue patients in the 230 million population should be 160,000. However, following the examples of Thailand and Vietnam, we could estimate the actual number of dengue
patients in Indonesia to be 10 times larger than that at 1.6 million.

Next, we examine the treatment cost for dengue fever. According to an article on the epidemic outbreak of DHF in Cuba in 1981, $44 103$ million dollars was required for the countermeasures. The breakdown was $41$ million dollars as health care expenditures, five million dollars as benefits for patients who cannot pay the health care expenditures, $14$ million dollars to compensate for losses in production costs and $43$ million dollars for vector mosquito control.

Furthermore, Shepard et al. $45$ reported that, in a total of eight countries in the Americas (Brazil, El Salvador, Guatemala, Panama and Venezuela) and Asia (Cambodia, Malaysia and Thailand), the average treatment cost for dengue fever per patient was $500$ dollars for an ambulatory case and $1,000$ dollars for a hospitalized case. In this study, we applied these figures to Indonesia. A report on Paraguay states that $1,000$ dollars are required for treating DHF, $46$ and considering that hospitalization is required for treating DHF, the figure matches the abovementioned average dengue treatment cost for a hospitalized case in the cited countries.

According to a report on the cost for vector mosquito control, the cost for controlling vector mosquitoes by using insecticides in two locations in Vietnam was $393$ dollars and $553$ dollars, respectively. $47$ The cost for the control using insecticides in Cambodia was $500,000$ dollars, $36$ and the total cost for preventing dengue fever and controlling vector mosquitoes in Thailand was $4.87$ million dollars. $48$ In this manner, the cost varies by country at present.

Here, we sum up the citations from articles about costs related to dengue fever. As the direct cost, the medical testing cost for diagnosis in Indonesia is $22$ dollars. $39$ As the cost for hospitalization, nursing cost in Asia is $38$ dollars per day, $29$ the treatment cost in Vietnam is $5–198$ dollars, $37$ and because the GDP of Indonesia is about $2.5$ times that of Vietnam, the treatment cost in Indonesia is estimated to be $12.5–495$ ($5 \times 2.5–198 \times 2.5$) dollars. Further, the hospitalization cost per day, including the meal cost, in Indonesia is $26–47$ dollars. $49$ Since the average hospitalization period in Indonesia is $4.8$ days, the nursing cost will be $190$ dollars ($38$ dollars/day $\times$ five days), and the hospitalization cost including the meal cost will be $130–235$ dollars ($26$ dollars/day $\times$ five days to $47$ dollars/day $\times$ five days). In other words, the direct cost will be $354.5–942$ ($(22+12.5+190+130)$ to $(22+495+190+235)$) dollars, which matches the abovementioned assumption of $500$ dollars for an ambulatory case and $1,000$ dollars for a hospitalized case. With regard to the indirect health care cost, the minimum monthly wage in Indonesia is $55$ dollars, $50$ and the average hospitalization period is $4.8$ days, so the income loss from not being able to work will be about $10$ dollars. Accordingly, the
total health care cost involved with the disease will be about 364.5–952 ((354.5+10) to (942+10)) dollars.

Here, we estimate the cost of illness associated with dengue fever in Indonesia. Assuming that the estimated 1.6 million dengue patients need to receive ambulatory treatment, 1.60 million patients × 500 dollars = 800 million dollars will be required, and since about 10% of them need to be hospitalized, 1.6 million patients × 0.1 × 1,000 dollars = 160 million dollars will be required, and the total health care expenditures are estimated at 960 million dollars. In addition, as indirect loss, the WHO reports that when one dengue patient in Thailand dies, the predicted lost wage when supposing that the patient worked for 50 years would be 120,000 dollars. Therefore, given that the minimum monthly wage in Indonesia is 55 dollars and the fatality rate of dengue fever in the country is 0.89%, the indirect loss will be 1.6 million patients × 0.89% × 55 dollars × 12 months × 50 years = 470 million dollars. In sum, the total cost of illness associated with dengue fever in Indonesia is estimated at 1.43 billion dollars.

(2) Effect of copper ions against *Aedes aegypti*

O’Meara et al. reported that vases with copper liners significantly restrained maturation of mosquitos compared to those with aluminum liners. Also, Bellini et al. reported that use of copper ions (electric cable) could restrain larval development of the vector mosquito *Aedes albopictus*.

An article by A. Rayms-Keller et al. on the effect of heavy metals on *Aedes aegypti* larvae makes a comparative study on the period from egg hatching to eclosion of *Aedes aegypti*. In tap water, eclosion was first observed in seven days from hatching, 40% had eclosed by eight days, and 80% by 16 days from hatching. On the other hand, in water with 0.32 ppm of dissolved copper ions, eclosion was first observed in eight days from hatching, but the eclosion rate was restrained to below 10% until the 11th day. However, the rate surged thereafter, exceeding 80% by 15 days from hatching. Further, in water dissolving 3.2 ppm of copper ions, no eclosion was observed until 15 days from hatching, and the eclosion rate remained at 20% even on the 24th day after hatching.

Since WCs in Indonesia are the principal habitat of *Aedes aegypti*, we examined the effectiveness of copper ions for preventing eclosion of *Aedes aegypti* within WCs. The copper ion concentration within the WC required for preventing eclosion of *Aedes aegypti* was set at 0.32 ppm because the eclosion rate was sufficiently restrained until the 11th day at that concentration level. This concentration was also considered to be appropriate in comparison to the guideline level of allowable copper
ion concentration in drinking water, set by the Joint Food and Agriculture Organization of the United Nations (FAO)/WHO Expert Committee on Food Additives, which is 2 ppm.51

(3) Discharged copper ion results

(i) Experiments using 10-yen coins

(a) Measurement was stopped due to high concentration at 2 ppm after 24 hours.
(b) Concentration was 0.8 ppm after 24 hours, chronologically rising thereafter in a linear fashion to come to equilibrium after 192 hours (eight days) at 3.5 ppm (Figure 1).
(c) Concentration was 0 ppm after 24 hours, and 0.15 ppm after 48 hours, chronologically rising thereafter almost in a linear fashion to reach 1.9 ppm after 888 hours (37 days) (Figure 2).

(ii) Experiment using 5-yen coins

(d) Concentration first became measurable after 336 hours (14 days) at 0.15 ppm. Measurement was stopped due to low concentration of the dissolved copper ions.

(iii) Experiment using brass fiber

(e) Concentration was 0.05 ppm after 24 hours, 0.2 ppm after 48 hours, 0.1 ppm after 72 hours, 0.15 ppm after 96 hours, 0.1 ppm after 120 hours, 0.25 ppm after 144 hours, and 0.15 ppm after 168 hours. Measurement was stopped due to unstable copper ion concentration.

(iv) Experiment using copper fiber

(f) Three measurements were made each time. Concentration was 1.2–1.4 ppm after 24 hours, 1.5–1.9ppm after 48 hours, 1.7–2.1 ppm after 72 hours, 2.0–2.5 ppm after 96 hours, 2.1–2.7 ppm after 120 hours (the third measurement was stopped hereafter), 2.2 and 2.7 ppm after 144 hours (six days), and 2.6 and 2.8 ppm after 168 hours (seven days) (Figure 3).

(4) Cost-effectiveness of copper ions

The above results revealed that when 4.5 g of copper fiber is soaked in 200 ml of water, the copper ion concentration will be 1.3 ppm in one day and 2.7 ppm in seven days. Copper ion concentration of 0.32 ppm significantly restrains the eclosion rate during the seventh to 11th days after hatching. Therefore, it is sufficient to bring the copper ion concentration within a WC with a capacity of 200 l to 0.32 ppm by the seventh day. To this end, 533 g of copper fiber is needed. Meanwhile, when 4.5 g of copper fiber is soaked in 200 ml of water, 0.26 mg of copper ions are released in one
day. Copper fiber of 533 g can achieve 0.32 ppm copper ion concentration in 96.2 l of water every day. In other words, if the daily use of the WC water is 96.2 l or less, the copper ion concentration can constantly be maintained at 0.32 ppm or more. Also, if the daily use of the WC water is 96.2 l or more, the number of larvae will be almost zero within about seven days according to the water intake sheet graph (Figure 4). Moreover, assuming that a household has five members on average and that each member uses about 4 l of WC water per day, each household is estimated to use about 20 l of WC water per day. According to the water intake sheet graph, when the daily use of WC water is 20 l, the number of larvae within the WC will be half in seven days, and if the copper ion concentration within the WC can be maintained at 0.32 ppm thereafter, mosquito development will significantly be restrained. Due to the above results, 533 g of copper fiber will be required per household to prevent eclosion of *Aedes aegypti* within the WC. The total number of houses in Indonesia is 45,000,000, and the price of copper fiber sold in Japan is 30,000 yen for 5 kg (6 yen/g). Given that 30.8 mg of copper ions will be released per day from 533 g of copper fiber, 533 g / 30.8 mg = 17305 days = 47.4 years; in other words, 533 g of copper fiber can be used for about 40 years. If so, the estimated price of the copper needed per year will be 533 g × 45,000,000 houses × 6 yen / 40 years = 3,597,750,000 yen, or, about 45 million dollars if 1 dollar = 80 yen. This amount is extremely low compared to the abovementioned estimated cost of illness associated with dengue fever, which is about 1.4 billion dollars. In addition, this estimated price for acquiring copper is based on the price in Japan. Since Indonesia is the world’s sixth largest producer of copper, it is considered possible to acquire copper easily at a lower price.

The 10-yen coins used in the experiments in this study can be expected to dissolve copper ions in water, but use of coins will not be practical due to legal restrictions.

(5) Vector mosquito control against dengue fever

The principal vector mosquitoes, *Aedes aegypti*, mostly grow within artificial collections of water including containers (such as pots, flower vases and bottles), and have domestic and diurnal habits even in the way they attack. When the number of *Aedes aegypti* within containers indoors and outdoors were investigated in Indonesia, the number was significantly large within WCs.

Today when no safe and effective vaccine has been approved, the only way to prevent dengue fever infection is to control the vector mosquito, that is, *Aedes aegypti*. Conventional approaches to control vector mosquitoes were to use insecticides against
adult mosquitoes or to use insect-controlling agents to inhibit mosquito development in water. Recently, however, the approach to control vector mosquito has gradually shifted from the use of insecticides to removal of breeding places of *Aedes aegypti* or to exterminate the larvae in water. Therefore, we consider that the most effective approach to control the vector mosquito against dengue fever is to prevent the eclosion of *Aedes aegypti* within WCs.

Will the number of dengue patients truly decrease if the absolute number of *Aedes aegypti* is reduced as a result of preventing the eclosion of *Aedes aegypti*? The life cycle of *Aedes aegypti* is 18–20 days, and a pupa becomes an adult mosquito in two days.\(^{13}\) If pupae are made subject to vector mosquito control, the number of adult mosquitoes will decrease, and further, the ovulation number will decrease. As a result, the number of adult *Aedes aegypti* is expected to be effectively reduced. On the other hand, a decrease in the number of dengue patients will lower the collective immunity, so people could become more susceptible to dengue fever infection. Thus, Reiter et al.\(^{28}\) has reported on the incidence of dengue fever based on collective immunity and the number of mosquitoes per capita. Even if the collective immunity is zero, if the number of mosquitoes per capital falls from five to two, the incidence of dengue fever moderately declines to 80%, and if the number of mosquitoes per capita falls further, the number of patients sharply decreases, with the incidence restrained to almost zero when the number of mosquitos per capita is one. On the other hand, when the collective immunity is 80% and the number of mosquitoes per capita is five, the incidence of dengue fever is restrained to about one-tenth of that in the case where the collective immunity is zero under the same conditions. Also, the incidence will be almost zero when the number of mosquitoes per capita is 3.5. Accordingly, we can conclude that the number of dengue patients can be restrained if we can reduce the number of mosquitoes per capita, but it is desirable to also maintain a high level of collective immunity. Meanwhile, there is a report on areas where dengue antibody prevalence is low in spite of a large number of mosquito habitats.\(^{53}\) These are areas where GDP per capita is about 10 times higher than in other areas. Collective immunity is also affected by the possibility of individuals’ contact with infection sources, and restraining the possibility of contact requires costs. For example, dengue antibody prevalence is lower in areas with a large number of air-conditioning facilities than in areas with a small number of such facilities.\(^{53}\) In other words, areas where an appropriate environment such as air-conditioning can be arranged are areas with high GDP per capita, and this suggests a relation between vector mosquito control and the economy.
**Conclusion**

In this study, we reported on the effectiveness of using copper fiber to control dengue vector mosquitoes in Indonesia from a health care economics viewpoint. When patients develop dengue fever, the cost of illness including the indirect cost will be high, so dengue prevention should be prioritized. In addition, the vector control by using copper ions discussed in this study will be an easy and low-cost approach for Indonesia, which possesses copper. Accordingly, we expect this approach to be considered in Indonesia.

**Acknowledgments**

We would like to sincerely thank Dr. Nobuhiro Maekawa, Professor, Division of Anesthesiology, Department of Surgery Related, Kobe University Graduate School of Medicine, Dr. Takako Miyazaki, Department of Pediatric Cardiovascular Surgery, Children's Research Hospital, Kyoto Prefectural University of Medicine, and others who took time out of their busy schedule to provide helpful support in writing this article.

**References**


Singapore. World Health Organization Western Pacific Region.

23. www.searo.who.int/LinkFiles/Dengue_dengue_updated_tables_06.pdf
25. IMF (World Economic Outlook Update, October 2010)
26. IMF (World Economic Outlook, April 2010)
34. Wiwanitkit V. Acute renal failure in the fatal cases of dengue hemorrhagic fever, a summary in Thai death cases. Ren Fail. 27:647,2005.
46. www.med.oita-u.ac.jp/infectnet/oitav5n4.pdf
51. JECFA; Toxicological evaluation of certain food additives, 1982
Cost effectiveness of dengue control by using copper ions: an estimation for Indonesia

Hisaya Doi, 1 Eiji Konishi, 2 Hiroya Matsuo 3
Medical researcher, Division of Anesthesiology, Department of Surgery Related, Kobe University Graduate School of Medicine; Doctoral Program, Kobe University Graduate School of Health Sciences 1
Research Institute for Microbial Diseases, Osaka University 2
Kobe University Graduate School of Health Sciences 3

Abstract

Japan’s climate has rapidly become more tropical in recent years due to the effect of global warming. Such climate change raises concerns about the outbreak of tropical infectious diseases in Japan. In taking measures against infectious diseases, prevention of such diseases is beneficial from a health care economics viewpoint. Thus, we focused on dengue fever, and estimated how much Indonesia’s health care expenditures will be reduced by using the insecticidal property of copper ions to prevent eclosion of the dengue vector Aedes aegypti. As a result of using 5-yen coins, 10-yen coins, brass fiber and copper fiber as copper ion sources, copper fiber was found to produce the largest economic effect. The cost of illness associated with dengue fever in Indonesia is about 1.4 billion dollars, whereas the cost for preventing eclosion of Aedes aegypti by using copper fiber was low at about 45 million dollars. We consider measures to eradicate Aedes aegypti by using copper ions to be a useful and economical approach.

Keywords: Dengue fever, copper ions, Aedes aegypti, cost-effectiveness
Cost-effectiveness of dengue control using copper ions in Indonesia

Hisaya Doi¹, Eiji Konishi² and Hiroya Matsuo³

Department of Anesthesiology and Perioperative Medicine, Kobe University Graduate School of Medicine,
Division of Infectious Diseases, Department of International Health, Kobe University Graduate School of Health Sciences¹,
Research Institute for Microbial Diseases, Osaka University²
Kobe University Graduate School of Health Sciences³

Abstract

Dengue fever is one of the most serious tropical infectious diseases in Indonesia, because of its morbidity and mortality rate. The vector of dengue is Aedes aegypti and treatment of dengue requires a relatively huge amount of money. Therefore, prevention of the disease, that is, control of Ae. aegypti, is the most essential. Vector control using copper ions as an insecticide is regarded as a safe and economical choice. Japanese copper coins, copper fibersiber and brass fibersiber were dissolved into distilled water. DischargeExtraction levels of the copper ions were measured using a copper test kit. Copper fiber produced copper ions most effectively. The cost for treatment and loss of income associated with dengue fever was estimated to be approximately one-point-four 1.4 billion dollars in Indonesia. On the other hand, vector control using copper fiber was estimated to be approximately 45 million dollars. According to these estimates, the vector control using copper ions can save have a great economic effect.

Treatment for dengue management and costs depends on the severity of the disease and health facilities.

Even today, no vaccine is available against dengue, so cost effective vector control is the most essential.

Key-words: Dengue fever, Copper ion, Vector control, Ae. Aegypti, Cost effectiveness
Table 1) National population, number of dengue patients, incidence per 100,000 population, and fatality rate in Indonesia for each year

(Figure 1) Chronological changes in copper ion concentration when soaking one 10-yen coin in 20 ml of distilled water

(Figure 2) Chronological changes in copper ion concentration when soaking one 10-yen coin in 200 ml of distilled water

(Figure 3) Chronological changes in copper ion concentration when soaking 4.5 g of copper fiber in 200 ml of distilled water

(Figure 4) Assumed changes in the number of mosquito larvae according to intake of water within the container

The figure shows changes in the number of larvae by amount of daily water intake, assuming that the container holds 200 l of water, the initial number of larvae is 1,000, the period until eclosion is 10 days, and larvae are distributed evenly within the container.