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Novel paradigm of mosquito-borne disease control based on self-powered strategy

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Introduction

Mosquito is an ancient creature, which can be traced back to the age of dinosaurs (1). There are more than 3,500 species of mosquitoes, in which *Aedes*, *Anopheles* and *Culex* bear primary responsibility for the spread of human diseases (2). Because of their small size and strong adaptability, mosquitoes can transmit bacteria, viruses, or parasites, which threaten >40% of the world's population. Thus mosquitoes are becoming an increasingly serious global public health challenge (3). When mosquitoes carrying pathogens bite people, they inject the pathogens into the human skin through a suction mouthpiece, following which the pathogens attack the subcutaneous immune cells at the bite site (4). The pathogens are amplified in these cells and released into the blood, causing systemic infection, and the symptoms include fever, encephalitis, arthritis, and hemorrhagic fever. However, mosquitoes transmit diseases without being affected. Although recent studies have shown that mosquitoes do not transmit the COVID-19 virus, the COVID-19 global pandemic is hampering mosquito-borne disease control efforts, such as disrupting malaria services (5). This not only increases the risk of mosquito-borne pathogens transmission but also lead to a significant increase in the number of cases and deaths (6, 7). According to the statistics of the World Health Organization, more than 700,000 deaths caused by mosquito-borne diseases annually (8). In fact, not only humans, but most other land mammals are also victims of mosquito bites (9). Therefore, accelerating technical research on the prevention of these mosquito-borne diseases can prevent unnecessary deaths.

Despite the efforts of all countries in preventing mosquito-borne diseases, achieving effective and sustainable mosquito control is still challenging (10, 11). Efficient sterilization and mosquito control are required to significantly reduce the risk of disease transmission and guarantee restrategy of public health problems. Currently, chemical and physical methods of killing mosquitoes are used, although they have obvious shortcomings. Long-term use of chemical methods is harmful to the human body; in addition, chemical reagents pollute the environment (12, 13). In contrast, although the physical methods are reliable, their use is associated with more limitations; for example, high-voltage electricity is dangerous and it relies on a continuous power supply (14–16).

The triboelectric nanogenerator (TENG) is a new technology based on electrification of mechanical interface friction and electrostatic induction coupling effect. The advantages of TENG include a wide selection of materials, simple structure, low cost, high efficiency, and high output voltage (17). It has also been widely used in fields involving motion (18), pressure (19, 20), inertia (21) and vibration (22, 23) to convert mechanical energy to electrical energy; furthermore, it can also be used in conjunction with wind energy (24), water energy (21, 25), and other fields (26, 27). As most mosquito control equipment require external power supply, the limitations of mosquito control and sterilization are manifold, especially in outdoor and remote areas. TENG

technology is effective for integrated self-powered equipment. Therefore, development of an environment-friendly and maintenance-free control equipment for sterilization and infection is necessary.

Here, we envisage a self-powered strategy for sterilization and infection control based on TENG structure, which can be used for mosquito eradication and sterilization to control the number of mosquitoes and the pathogens they transmit, thereby reducing the risk of disease transmission (Figure 1A). This strategy will open up a new avenue for self-powered supply system in infectious disease control and may promote family health care and public health.

Analysis

Epidemic status of mosquito-borne diseases

Mosquito-borne diseases are natural foci diseases transmitted by vector mosquitoes, which mainly include *Aedes*, *Anopheles*, and *Culex* mosquitoes (Figure 1B). *Aedes* is distributed worldwide, especially in the tropics and subtropics. It is the largest genus of mosquitoes, including 38 subgenera and nearly 1,000 species, and is the main vector of urban yellow fever (29), chikungunya virus (30) and dengue fever (31, 32). Experimental infection models have shown that it can also transmit Venezuelan equine encephalitis, western equine encephalitis, eastern equine encephalitis, rift valley fever, zika virus, and other viruses by biting and sucking blood (33, 34). Thus, it is one of the most dangerous mosquitoes. Reports show that the dengue virus transmitted by *Aedes* mosquitoes causes nearly 96 million symptomatic cases and 40,000 deaths every year. At the same time, more than 3.9 billion people in 129 countries are still at risk of contracting dengue fever (35).

The female *Anopheles* mosquito, also known as the malaria mosquito, transmits malaria and filaria to humans. About 450 species of *Anopheles* are known, most of which are distributed in the tropics, mainly in Saharan Africa. Malaria is a life threatening disease caused by the *Plasmodium* parasites, which are transmitted to humans through *Anopheles* bites (36). In early days, the disease caused 0.725 to 1 million deaths every year, which set the Guinness World Record and was also called the deadliest disease on earth. According to the latest World Malaria Report (37), there were 241 million cases of malaria in 2020 and 227 million cases in 2019. Although malaria is preventable and treatable, an increase in the resistance of mosquitoes to insecticides hampers the effectiveness of preventive measures (38).

Culex mosquitoes transmit pathogens causing filaria, Japanese encephalitis, and other diseases. Lymphatic filariasis affects the host's lymphatic system, subcutaneous tissue, abdominal cavity, chest cavity, and other places (39). In total, 863 million people in 47 countries are still threatened by lymphatic filariasis, and preventive chemotherapy is required to prevent the transmission of this parasitic infection (40). However, Japanese encephalitis also poses a threat to public safety.

Today, despite the continuous development of medical technology, pathogens still infect more than one million people every year, posing a growing threat to public health. This is amplified further by the lack of effective treatment methods for most infectious diseases and the accumulation of mutations in viruses, which should be tracked for early prevention and interruption of transmission.

Strategy for mosquito-borne disease prevention based on self-powered supply

Basis of self-powered supply system based on TENG

Currently, TENG is widely used in wearable electronics, the Internet of Things, high-precision sensors, and other fields (41). The main reasons for the large-scale use of TENG are as follows: first, TENG allows extensive material selection and is inexpensive (42). Its performance depends on the materials used to develop them, as the friction charges and electrical properties differ with materials. According to the principle of potential superposition, the output voltage and current are affected by the density of friction charges. Therefore, the materials used to develop TENG must easily generate friction charges and have different friction electrodes. TENG is usually made of polytetrafluoroethylene (PTFE) (43), polyamide, polyvinylidene fluoride (PVDF) (44), and silk (45).

Second, TENG has the advantages of simple structure, high efficiency, and high output voltage. The four basic working modes of TENG are vertical contact separation mode, horizontal sliding mode, single electrode mode, and independent layer mode (46). In the simplest design of TENG, the dielectric films of two different materials are stacked face to face, and their respective back surfaces are coated with metal electrodes in the vertical contact separation mode structure. These two layers of dielectric films contact each other to form opposite charges. An induced potential difference is formed between the two electrodes when the films are separated, which causes the current to flow between the connected metal electrodes. The typical high voltage outputs of TENG can exceed 2 kV for single electrode TENG, 15 kV for independent layer TENG, 7 kV for contact separated TENG and 8 kV for disk TENG, respectively (47).

Third, TENG can be integrated with other systems to realize different types of self-powered microsystems, build a functional and structural integrated microsystem of micro mechanical energy collection management storage utilization, and provide a sustainable power supply for micro-electro-mechanical system (MEMS) devices and micro integrated systems in different environments. TENG not only collects exercise energy, but also powers wearable electronic devices. It is also used to collect the energy generated from life activities, such as heartbeat and breathing, and to provide power for *in vitro* monitoring devices and implanted electronic medical devices for disease treatment and prevention. The realization of self-powered supply based on TENG equipment has more advantages than the existing mosquito-borne disease prevention technologies.

Mosquito killing and sterilization strategy based on self-powered supply

Currently, preventing the spread of infectious diseases at the prevention stage, which will safeguard the public considerably, is the most critical issue that requires attention. The TENG technology can be integrated into sensor devices (48, 49), wearable electronic devices (50) and medical devices (51) to realize self-powered supply function. Therefore, the requirement of external power drives and sterilization after mosquito control should be met.

On the one hand, though the voltage output of TENG is high, the current of TENG is very low (52–54), which is safe for people

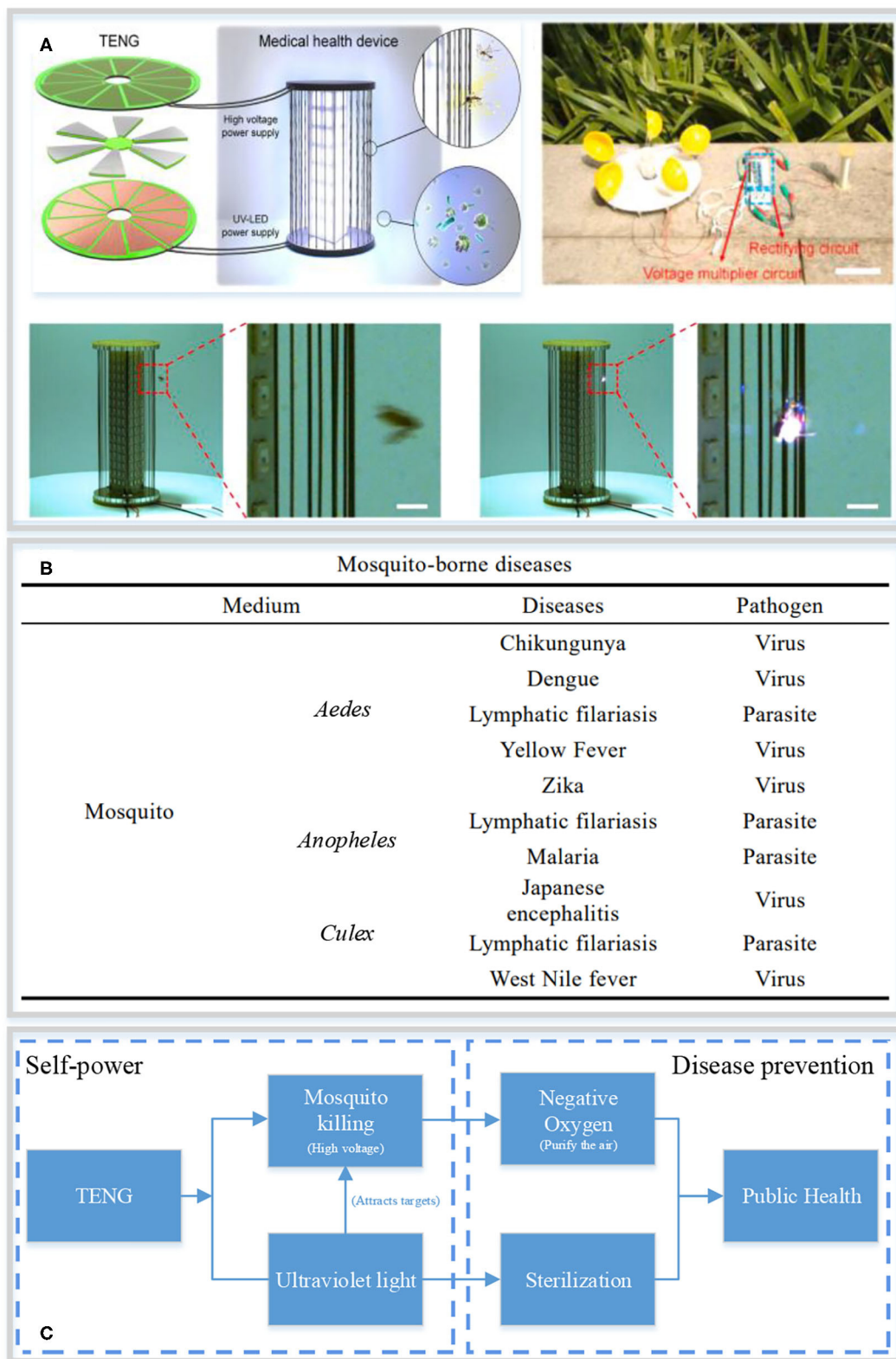


FIGURE 1 The new paradigm of mosquito-borne disease control. (A) Structural design and photographs of the TENG-based self-powered sterilization and infection control system (28). (B) Mosquito-borne diseases. (C) Strategy for mosquito-borne disease prevention based on self-powered supply.

(safe current < 30 mA).¹ On the contrary, as mosquitoes are very

1 <https://www.d.umn.edu/~sburns/EE2212/L-Safe-Levels-of-Current-in-the-Human-Body.pdf>

small, their endurance is considerably much lower than that of human beings, which can be killed by TENG outputs [as has been demonstrated by Luo et al. (28)]. For conventional high-voltage mosquito-killing device, external power sources are indispensable for

driving the relevant devices, which will lead to risk such as power Grid electricity leakage, and fire risk. For instance, electric mosquito swatters are blamed for causing fire.² In comparison, TENG can convert low frequency, distributed, and irregular mechanical energy into electricity, which do not need external power sources. This can reduce the risk of electricity leakage and fire during electricity transmission from the power Grid.

On the other hand, appropriate light sources can be selected to trap mosquitoes according to their phototactic habits. According to a survey, mosquitoes tend to gather near light sources in the ultraviolet and blue ultraviolet wave bands, especially at 365, 405, 420, and 450 nm, among which the sources emitting light at 365 and 420 nm show the most outstanding mosquito-trapping performance, with no significant difference between the effects of the two (16, 55). Therefore, appropriate ultraviolet light source can be selected to trap mosquitoes using electric shock.

Hence, the self-powered tool is harmless and safe for the human body and can be used as a family-level tool. More importantly, the mosquito killing and sterilization system based on TENG can not only present a self-powered working strategy, but can also achieve the goal of purifying air with high-pressure ionized oxygen anion, killing bacteria using ultraviolet radiation and controlling the spread of diseases (Figure 1C).

Discussion

The performance of TENG is the basis for long-term stable operation of a self-powered equipment. However, realizing the stable application of TENG is challenging. Ideally, only when the mosquito-borne disease prevention technology is stable and reliable can these interventions help to control the spread of infections and minimize the damage to society and economy. To promote this, ongoing research should focus on the following areas.

The self-powered equipment should collect micro mechanical energy in various environments, such as wind energy, water energy, and tidal energy. At the same time, efficient mosquito control requires higher output voltage and energy. The output voltage, energy, and charging cycle are the key parameters required to obtain better mosquito control. Therefore, collisions caused by the natural environment should be prevented, and the output performance should be reliable and stable.

The four working modes of TENG depend on the contact friction of different materials. However, the contact friction will lead to heat loss and wear and tear of the friction interface. The surface charge density of TENG will decrease with increase in its service time, affecting its output performance. Therefore, in the future, means of avoiding device wear to achieve more extensive and effective micro energy collection and application should be investigated.

2 <https://asiatimes.com/2018/04/electric-mosquito-swatter-blamed-causing-fire/>

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Enriching the diversity of prevention measures and improving the effectiveness of disease prevention is critical for preventing and controlling the outbreak and transmission of mosquito-borne virus diseases (28). Therefore, assessing the reliability and practicality of new prevention means is extremely important. In this context, a TENG with high durability and high output performance should be developed to realize a self-powered strategy for mosquito-borne disease control.

Conclusion

This paper discusses the epidemic situation and trend in the development of mosquito-borne infectious diseases. It also analyzes the theoretical basis of TENG as a self-powered equipment and discusses its potential as a strategy to mosquito-borne diseases based on TENG structure. In the future, with the continuous development of TENG technology, the self-powered mosquito-borne disease control strategy will also be improved gradually, especially in outdoor and remote areas. The environmental protection and maintenance-free sterilization and infection control strategy are important for public safety.

Author contributions

JW: writing the paper. ZZ: supervised. Both authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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