Mosquito-resistant clothing prevents bites in trials

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Mosquitoes landing on bite-resistant fabric during an in vivo bioassay in which they fail to probe through the fabric due to its small pore size. The proboscis bends when mosquitoes try to push through the fabric. Credit: Matt Bertone.

North Carolina State University researchers have created insecticide-free, mosquito-resistant clothing using textile materials they confirmed to be bite-proof in experiments with live mosquitoes. They developed the materials using a computational model of their own design, which

describes the biting behavior of *Aedes aegypti*, the mosquito that carries viruses that cause human diseases like Zika, Dengue fever and yellow fever.

Ultimately, the researchers reported in the journal *Insects* that they were able to prevent 100 percent of bites when a volunteer wore their clothing—a base layer undergarment and a combat shirt initially designed for the military—in a cage with 200 live, disease-free mosquitoes. Vector Textiles, an NC State startup company, has licensed the related patent rights and intends to make clothing for commercial sale in the United States.

The researchers think their computational model could be used more widely to develop clothing to reduce transmission of diseases.

"The fabric is proven to work—that's the great thing we discovered," said study co-author Andre West, associate professor of fashion and textile design at NC State and director of Zeis Textiles Extension for Economic Development. "To me, that's revolutionary. We found we can prevent the mosquito from pushing through the fabric, while others were thick enough to prevent it from reaching the skin."

To develop the computational model to design textile materials that could prevent A. aegypti bites, researchers investigated the dimensions of the head, antenna and mouth of A. aegypti, and the mechanics of how it bites. Then, they used the model to predict textile materials that would prevent bites, depending on their thickness and pore size. Researchers said they believe the materials could be effective against other mosquito species in addition to A. aegypti because of similarities in biology and biting behavior.

"There are different uses for clothing," said the study's first author Kun Luan, postdoctoral research scholar of forest biomaterials at NC State.

"The idea is to have a model that will cover all possible garments that a person would ever want."

To test the accuracy of their model, the researchers tested the materials predicted to be bite-proof. In experiments with live, disease-free mosquitoes, the researchers surrounded a blood reservoir with plastic materials made according to parameters predicted by the model. They then counted how many mosquitoes became engorged with blood.

One material they initially tested was very thin—less than one millimeter thick—but had a very small pore size to prevent the mosquito from sticking its mouth parts, or proboscis, through the material. Another material had a medium pore size to prevent the mosquito from inserting its head through the textile far enough to reach the skin; and a third material had larger pores, but was sufficiently thick that the mosquito's mouth still couldn't reach the skin.

In a subsequent test, the researchers chose a series of knitted and woven fabrics that met the bite-proof parameters determined by the model, and validated they worked in experiments using both the blood reservoir and human volunteers. The researchers tested the number of bites received by volunteers when study participants inserted an arm covered by a protective sleeve into a mosquito cage. The researchers also compared the fabrics' ability to prevent bites and repel mosquitoes to fabrics treated with an insecticide.

From what they learned in early experiments, researchers developed the bite-resistant, form-fitting undergarment made with a thin material, as well as a long-sleeved shirt, which was initially envisioned as a combat shirt for the military.

When a volunteer wore the garments sitting for 10 minutes and standing for 10 minutes in a walk-in cage with 200 hungry mosquitos, the

volunteer found the combat shirt was 100 percent effective at preventing bites. In the first trial testing the base layer, the volunteer received bites on the back and shoulders—seven bites for 200 mosquitoes. The researchers attributed the bites to the fabric stretching and deforming, so they doubled the material layer around the shoulders, and were ultimately able to prevent 100 percent of bites. They also tested the clothing for comfort, and to see how well it trapped heat and released moisture.

"The final garments that were produced were 100 percent bite-resistant," said Michael Roe, William Neal Reynolds Distinguished Professor of Entomology at NC State. "Everyday clothing you wear in the summer is not bite-resistant to mosquitoes. Our work has shown that it doesn't have to be that way. Clothes that you wear every day can be made bite-resistant. Ultimately, the idea is to have a model that will cover all possible garments that person would ever want—both for the military as well as for private use."

More information: Kun Luan et al, Mosquito-Textile Physics: A Mathematical Roadmap to Insecticide-Free, Bite-Proof Clothing for Everyday Life, *Insects* (2021). DOI: 10.3390/insects12070636

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