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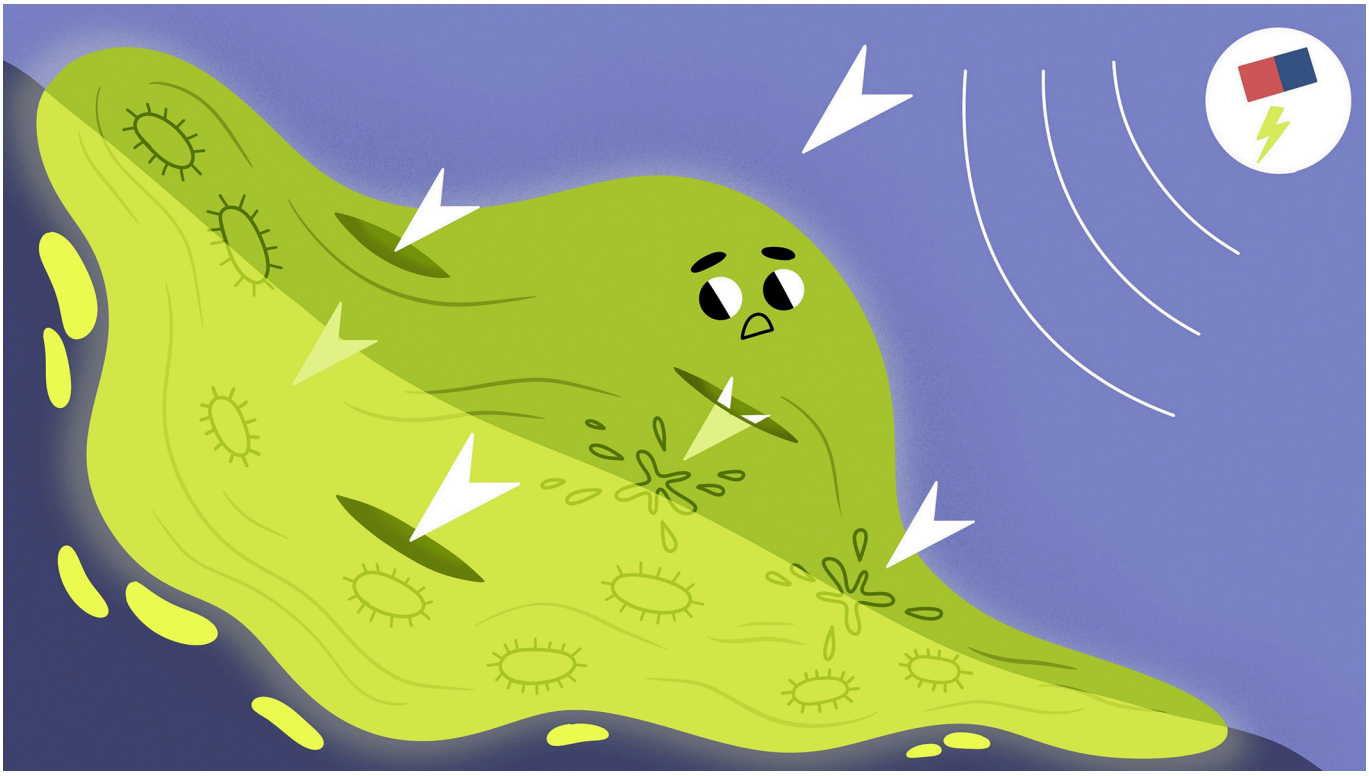

SHAPESHIFTING LIQUID METAL DROPLETS VERSUS SUPERBUGS

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YOUNG REVIEWERS:


ALI
AGE: 13


BILAL
AGE: 15


ELLOUISE
AGE: 12


HAMZAH
AGE: 13


KAJ
AGE: 10


LAURENT
AGE: 10

Scientists have found an exciting new way to fight a big problem called bacterial biofilms. Biofilms are made up of billions of bacteria living inside a sticky substance, a bit like a slime monster. Within biofilms, bacteria are protected from medical treatments and the human immune system. To make matters worse, biofilms are an ideal place for the emergence of new forms of bacteria with improved defenses, which are often called superbugs. Biofilms and superbugs make people very sick, and they are increasingly more difficult to treat. However, scientists may have come up with a new solution—a special liquid metal that can change shape with the help of magnets. It turns into tiny ninja-stars and spears that can pierce through the cell walls of bacteria. When this special liquid metal is exposed to a rotating magnet, the tiny stars whizz around like a whirlwind, destroying bacterial biofilm and killing the superbugs inside.

SAMAR

AGE: 8

YA'EL

AGE: 11

MEDICAL IMPLANT

A device that is inserted into the body of a sick or injured patient for a long period, to restore or improve the function of a body part.

BACTERIA

Tiny single-celled creatures that can either promote health or disease depending on their type and what part of the body they colonize.

BIOFILM

A slimy layer of microorganisms, like bacteria, that stick to surfaces and each other, often found in places like your teeth (as plaque) or on medical devices.

IMMUNE SYSTEM

A collection of cell types and proteins that recognize disease-causing invaders and mount a response to eliminate them.

Figure 1

A hip replacement implant has been colonized by a slime monster! In this scenario, unwanted bacteria that contacted the metal implant before or during the surgery quickly attach to the implant and began to multiply. Eventually, these bacteria form a biofilm, which contains sticky substances that shield the bacteria from medicines and the human immune system.

INFECTIONS OF MEDICAL IMPLANTS

Maybe you know someone, perhaps an elderly family member, who has had some kind of **medical implant**. Medical implants are incredible modern inventions that can often restore the functions of damaged body parts, improving the lives of ill or injured patients. For example, titanium rods can be inserted into badly broken bones to guide the healing process. Sometimes elderly patients require knee or hip replacements due to failing joints. In patients with narrow or weakened blood vessels, a small metal tube called a stent can be implanted into the blood vessel, to keep blood flowing through the body. These are just some examples of devices that are implanted into the human body for medical purposes.

While medical implants are incredibly useful, they are not perfect. This is because they are an attractive home for **bacteria**—tiny single-celled creatures 100 times smaller than the width of a human hair. If bacteria are given the chance, they will quickly attach to medical implants and multiply until there are billions of cells. They coat themselves in a sticky, slimy substance that strengthens their attachment to the implant. This colony of cells is called a **biofilm**, but you can think of it as a slime monster made of bacteria and their sticky substances (Figure 1). From the outside, the slime monster might only look like a blob of goo, but within the slime, bacteria are superpowered. Inside the biofilm, bacteria can communicate using chemical signals, enabling them to work together to adapt to their environment and obtain food. The sticky substance covering the slime monster protects the bacteria from drug treatments and the human **immune system**, so they are very difficult to kill. Scariest of all, different types of bacteria inside the slime monster teach each other how to build new weapons and defenses, by sharing genes. Bacteria that have acquired new defensive abilities in this way are called **superbugs**, and they are one of the toughest challenges in medicine. So how do we vanquish the monster? Well, scientists are swiftly finding new solutions.

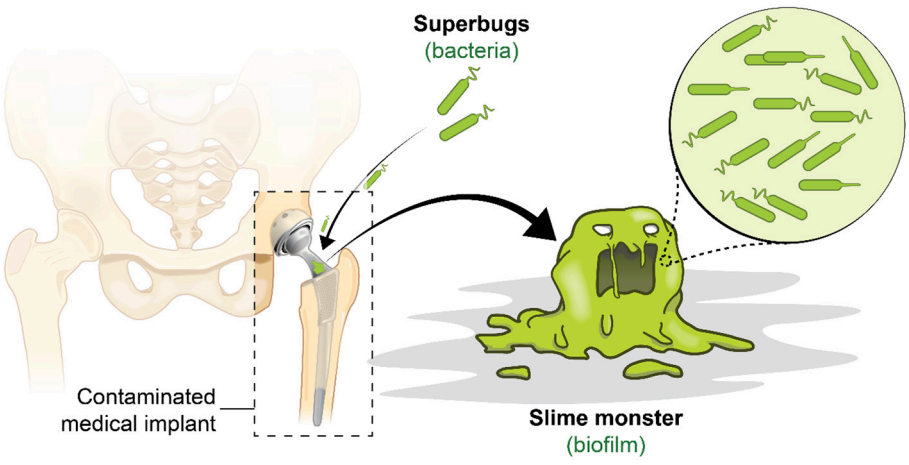

Figure 1

MEET GALLIUM, A SOLUTION TO THE BIOFILM PROBLEM

SUPERBUGS

Bacteria that have become harder to kill with antibiotics, making them a serious threat to health.

ALLOY

A mix of multiple metals, that creates a new material with unique properties, like mechanical strength or resistance to rust.

Gallium is a metal, but it is unlike most other metals you have probably heard of. Gallium has a very low melting temperature (only 30°C), meaning it melts in your hands! Unlike other metals, gallium can cleverly wrap itself around complex structures or combine itself with other materials. You might have heard the term **alloy**, which means two or more metals that are mixed together to make a new material with useful properties. Scientists have combined gallium with other metals, such as silver or copper, to make various alloys with unique properties and purposes. Gallium-iron alloys are particularly interesting. Iron is one of the most commonly used metals in the production of many useful products, and it is highly magnetic. Can you guess what happens when you mix gallium with iron? You get a new material that is both magnetic *and* liquid at body temperature. The solid iron particles become embedded in the liquid gallium, and when they are exposed to a magnet, the iron particles move within the liquid metal and cause it to change shape. Imagine that... a magnetic puddle of metal!

At this point you might be thinking, "that is interesting, but what is useful about a magnetic liquid metal?" Well, an intelligent group of scientists discovered that this exciting material can be used to kill superbugs in biofilms [1]. They combined gallium and iron, and then used high-energy soundwaves to break up the new alloy into tiny droplets that are smaller than bacteria. When the researchers placed the liquid metal on a dish with a magnet underneath the dish, they saw the droplets morph into new shapes, including rods and stars (Figure 2). Much like ninja-stars, these objects can cause some serious damage to unsuspecting foes.

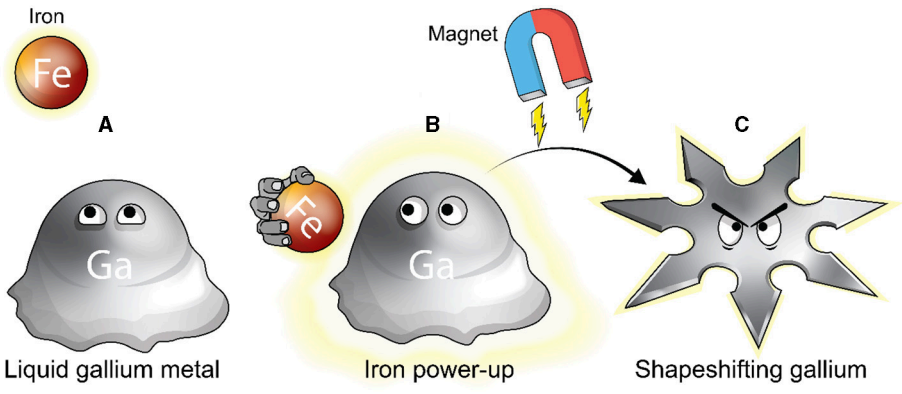

Figure 2

(A) A liquid metal gallium (Ga) droplet finds an iron (Fe) power-up. **(B)** Gallium grabs the power-up, which gives it the power of magnetism. **(C)** With the help of magnets and its iron power-up, gallium shapeshifts into a more fearsome form!

Even better, the researchers realized they could create a whirlwind of shapeshifting gallium droplets by rotating the magnetic field. To test their invention, the researchers grew biofilms in a plastic dish

and dropped the magnetic liquid metal droplets on top. They then placed a rotating magnet under the dish to activate the liquid metal. The biofilms did not stand a chance against a whirlwind of ninja stars (Figure 3). After performing this spectacular attack against the slime monster, the researchers used a microscope to visualize the destruction. What they saw was nothing short of amazing, as the biofilm was nowhere to be seen—all that remained was a small number of bacterial cells, and most of them had serious damage. Without the protection of the biofilm, bacteria are much easier to fight using medicines or by the immune system.

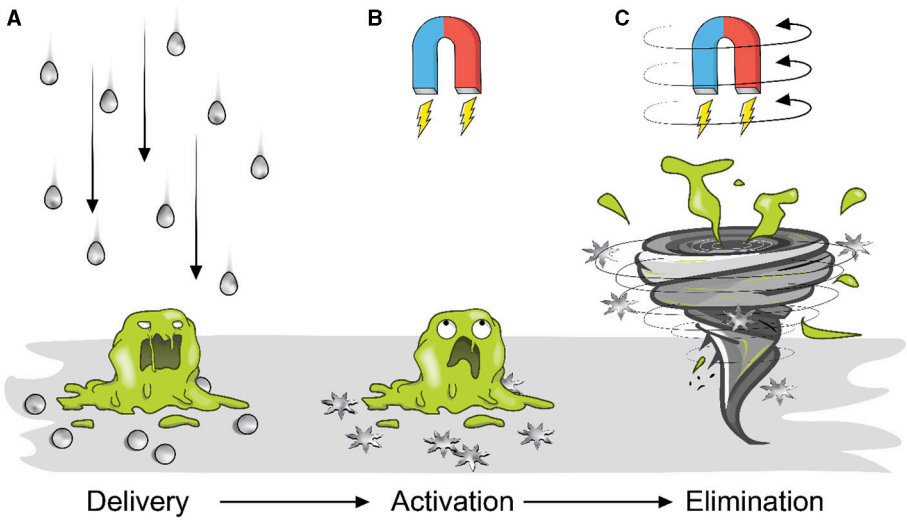

Figure 3

Figure 3

A slime monster is shredded to pieces by a whirlwind of shapeshifting gallium alloy particles. **(A)** Iron-gallium droplets are delivered to the site of infection, either by injection, or as a surface-coating prior to implantation. **(B)** A magnetic field is applied to the droplets, causing them to morph into sharp-edged stars. **(C)** The magnetic field is rotated at a high speed to create a whirlwind effect, causing the sharp stars to break up the biofilm and eliminate the bacteria within.

IS GALLIUM TREATMENT SAFE?

While the iron-gallium alloy is an impressively effective way to kill bacteria and remove biofilms from surfaces, it is still very important to consider the safety of using such a strategy inside the human body. You may be familiar with another liquid metal, mercury, which is used in thermometers and is known to be toxic to humans. To settle this concern, scientists must consider safety from two perspectives. First, is gallium toxic to human cells? And second, would a whirlwind of shapeshifting gallium droplets destroy the human cells surrounding the medical implant?

To address the first point, researchers grew human cells in a laboratory and exposed them to gallium to see if the metal affected the health of the cells. In many cases, human cells were shown to function normally in the presence of small amounts of gallium [2]. In fact, the safety of liquid gallium has prompted some researchers to use this metal to create new cancer treatments [3]. This safety result is extremely important, because it suggests that, in small amounts, gallium does not cause any serious harm to the human body, unlike mercury.

Furthermore, gallium has been shown to be effectively eliminated from the body through the kidneys [4]. In contrast, mercury builds up in the body and causes damage to the nervous system. But how about magnetically activated gallium whirlwinds? It might seem like a gallium whirlwind would be as harmful to human cells as it is to bacteria. However, human cells are typically 10–50 times larger than bacteria. So, the large size of human cells might enable them to withstand the forces of a magnetically activated gallium whirlwind. Researchers tested this in the lab using human cells and observed no harmful effects of the liquid metal, either with or without magnetic activation [5].

SUMMARY

Overall, this exciting research may one day be used to fight real infections in real patients. The work that we presented shows that magnetic particles of a gallium-iron alloy can kill biofilms grown in a plastic dish—but more research is needed to determine the best and safest way to use this treatment in people. It may be possible to use shapeshifting gallium as a coating on the surfaces of medical implants. This coating could act as a trap for invading bacteria that could otherwise produce dangerous biofilms. However, scientists are still a long way away from using this technology in real medical implants, as further safety testing is required.

ACKNOWLEDGMENTS

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ORIGINAL SOURCE ARTICLE

Cheeseman, S., Elbourne, A., Kariuki, R., Ramarao, A. V., Zavabeti, A., Syed, N., et al. 2020. Broad-spectrum treatment of bacterial biofilms using magneto-responsive liquid metal particles. *J. Mater. Chem. B* 8:10776–10787. doi: 10.1039/D0TB01655A

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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.

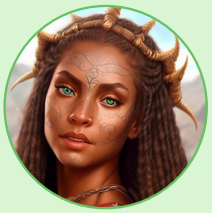
YOUNG REVIEWERS

ALI, AGE: 13

I am Ali, I am 13 years old, and I like playing video games and having fun with my friends and family. I am in a Gifted and Talented track in middle school. I am deeply interested in Science and Engineering, and I plan to pursue a doctorate in Chemical Engineering as my career inspiration and then teach kids through much simpler ways, may be through new innovations and tools and may be only using video games to do math and science. I also think that the current system of educating digital age kids is not efficient and parents and teachers are using age old methods for my generation of kids. I think in school everything should be oriented around video games.

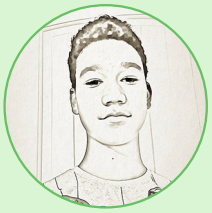
BILAL, AGE: 15

My name is Bilal, I am a 15-year-old high school sophomore. I am on a Gifted and Talented Track. I am deeply interested in medicine and engineering, and I love research, I am fascinated by how stem cells can repair certain cells, tissues, and diseases. I am currently working on stem cell model systems. As my lifelong goal I plan to pursue medicine but with deep insights and expertise in mathematics and engineering.



ELLOUISE, AGE: 12

Ellouise plays volleyball, and chess and is an avid reader & writer. Conversations are also very important to her. She loves music a lot and appreciates different genres. She particularly enjoys lasagna, despite being lactose intolerant.



HAMZAH, AGE: 13

Hamzah just turned 13 and loves anything science. He wants to be an astrophysicist when he grows up. He us currently into gaming and Anime.

KAJ, AGE: 10

Kaj is a black playful boy who plays chess and football. He loves video games and his favorite actor is Kevin Hart. He also enjoys food quite a lot and cooks.

LAURENT, AGE: 10

My name is Laurent. I love spending time with friends from my neighborhood and with classmates. I love reading and writing, and I have already won prices for poems I wrote! French is my mother tongue and I also speak English. I play basketball and before I played Judo and Football. I like reading fiction-stories, manga's, "Enquettes Policières" horror stories, myths, and histories, and I like watching scientific documentaries. My favorite season is spring when I can play outdoor and ride my bicycle.

SAMAR, AGE: 8

I am Samar, and I like playing with my friends and making friendship clubs. I am the president of a friendship forever club at my elementary school. I love going to my school library and looking at books. On weekends I always push my mom to take me to our neighborhood libraries as for me it is fun to just look at pictures in nice books about sea creatures and oceans. I am fascinated by living systems, particularly how life came into being in oceans and researching on Sharks and Whales. I love asking lots of questions to my teachers and parents. I also love Disney world and hope to continue visiting it every year, its lot of fun and inspires me to dream.

YA'EL, AGE: 11

I like Minetest, computer programming, maths, science, running, playing with dolls, drawing, baking, reading, playing with Lego, watching videos, arts and crafts, and thinking.

AUTHORS

ANDREW HAYLES

I am an early career researcher within the Biomedical Nanoengineering Laboratory at Flinders University, South Australia. I am interested in the interactions between microbial pathogens, biomaterials, and antimicrobial treatments. I recognize that microbial infections represent one of the quickest-growing threats in medicine, due to the rise of antibiotic resistance, and I aim to help fight against this threat by studying new antimicrobial treatments, technologies, and strategies. *andrew.hayles@flinders.edu.au

VI KHANH TRUONG

Dr. Vi Khanh Truong is currently a lecturer in medical biotechnology at Flinders University. He is an accomplished researcher who has developed several revolutionary approaches to protect medical devices and other surfaces from bacterial colorization. He was a key player in the team that developed surfaces containing tiny sharp structures that can kill bacteria upon contact. More recently, he has pioneered the field of liquid metal-based antibacterial technologies. This is now a growing and very promising research direction, with a high probability of an impact.

KRASIMIR VASILEV

Krasimir Vasilev is a Matthew Flinders Professor, a professor in biomedical nanotechnology, and a NHMRC leadership fellow. His work sits at the intersection between materials, biology, and medicine, focusing on engineering and tailoring at a molecular level, where living things interact with biomaterials and devices. Prof. Vasilev's work has been important in advancing cutting-edge research across a range of subjects and has led to the creation of new technologies, devices, and research tools that are being used to overcome many pressing medical and biological challenges.