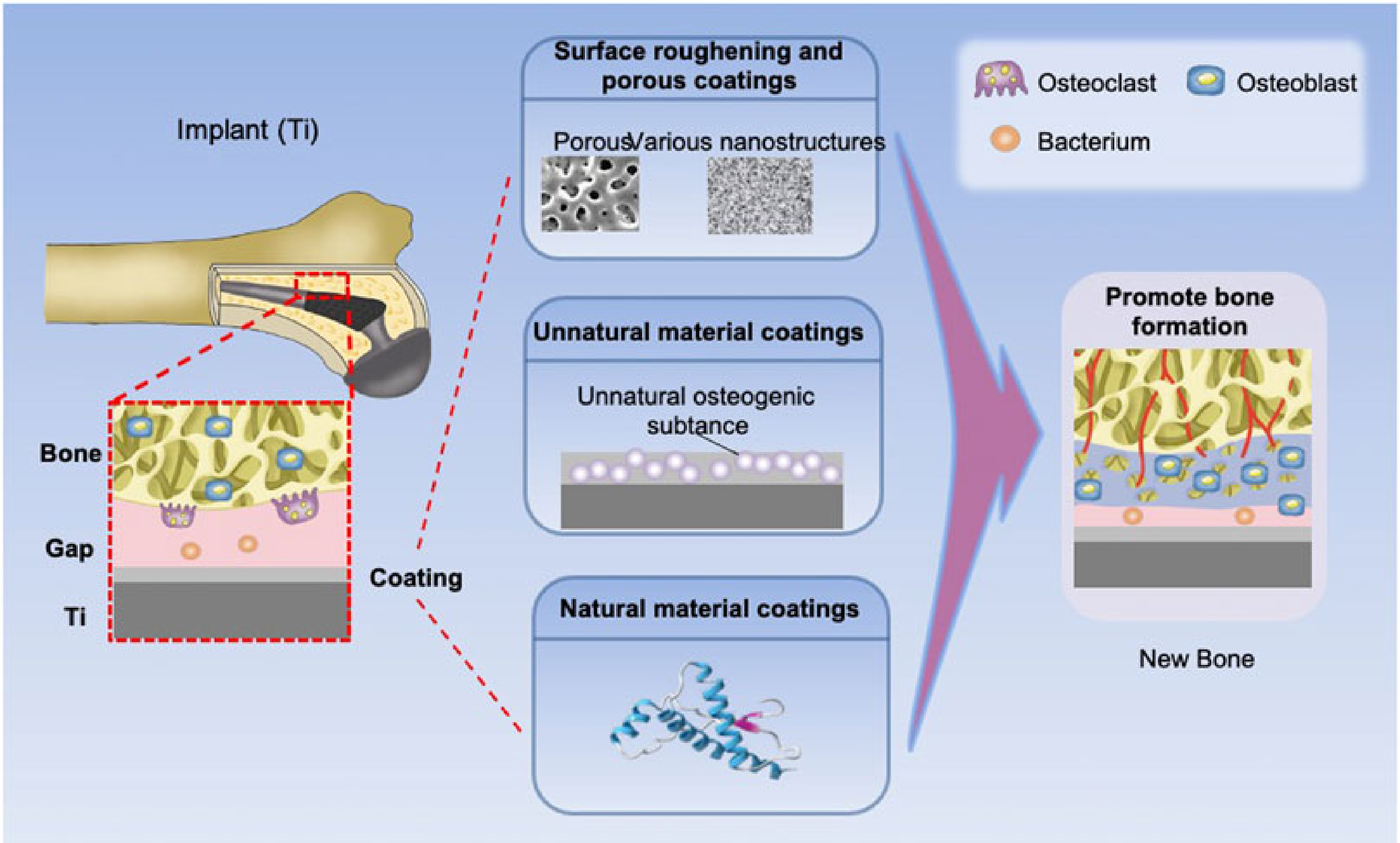
Smart Implant Coatings Revolutionise Modern Medicine

Surgical implants such as joint replacements, pacemakers, and artificial heart valves have revolutionized modern medicine / iStock.

Newly developed “smart” coatings for surgical orthopedic implants can monitor strain on the devices to provide early warning of implant failures while killing infection-causing bacteria, the University of Illinois Urbana-Champaign researchers report. The coatings integrate flexible sensors with a nanostructured antibacterial surface inspired by the wings of dragonflies and cicadas.

Surgical implants such as joint replacements, pacemakers, and artificial heart valves have revolutionized modern medicine, improving the quality of life for millions of people around the world. However, like any medical intervention, surgical implants come with risks, including the risk of infection, and bacteria infusion on the materials. To address these issues, researchers have been developing new technologies that prevent infection.

One promising approach involves the use of smart implant coatings that integrate flexible sensors with a nanostructured antibacterial surface inspired by the wings of dragonflies and cicadas. These coatings are designed to detect early signs of implant failure, such as changes in temperature, pressure, or pH, and to release antibacterial agents to prevent infection.



Multifunctional coatings of Titanium implants and osseointegration/ MDPI.

The idea of using the wings of insects as inspiration for new medical technologies is not new. Insects have evolved to survive in a wide range of environments, and their wings are some of the most versatile and efficient structures found in nature. Dragonflies and cicadas, in particular, have wings that are covered in tiny nanostructures that help to repel water and prevent bacterial growth.

To create smart implant coatings inspired by these wings, researchers have been using a combination of advanced materials science, nanotechnology, and biotechnology. The coatings are made up of multiple layers of materials, each with a specific function.

The bottom layer of the coating is a flexible sensor that can detect changes in temperature, pressure, or pH. This sensor is made from a special polymer that can bend and flex without breaking, allowing it to conform to the shape of the implant and provide accurate readings.

Above the sensor layer is a nanostructured antibacterial surface that is inspired by the wings of dragonflies and cicadas. This surface is made up of tiny pillars or ridges that are arranged in a specific pattern to repel water and prevent bacterial growth. The nanostructures are so small that they are invisible to the naked eye, but they play a crucial role in preventing infection.

The top layer of the coating is a thin film that can release antibacterial agents in response to changes in temperature, pressure, or pH. These agents are carefully selected to target specific types of bacteria, minimizing the risk of antibiotic resistance and reducing the likelihood of infection.

In a new study published in the Journal of Science Advances ("A smart coating with integrated physical-antimicrobial and strain-mapping functionalities for orthopedic implants"), a multidisciplinary team of researchers found the coatings prevented infection in live mice and mapped strain in commercial implants applied to sheep spines to warn of various implant or healing failures.

This is a combination of bio-inspired nanomaterial design with flexible electronics to battle a complicated, long-term biomedical problem," said study leader Qing Cao, a U. of I. professor of materials science and engineering. Both infection and device failure are major problems with orthopedic implants, each affecting up to 10% of patients, Cao said.

Several approaches to fighting infection have been attempted, but all have severe limitations, he said: Biofilms can still form on water-repelling surfaces, and coatings laden with antibiotic chemicals or drugs run out in a span of months and have toxic effects on the surrounding tissue with little efficacy against drug-resistant strains of bacterial pathogens.

Taking inspiration from the naturally antibacterial wings of cicadas and dragonflies, the Illinois team created a thin foil patterned with nanoscale pillars like those found on the insects' wings. When a bacterial cell attempts to bind to the foil, the pillars puncture the cell wall, killing it.

"Using a mechanical approach to killing bacteria allowed us to bypass a lot of the problems with chemical approaches, while still giving us the flexibility needed to apply the coating to implant surfaces," said pathobiology professor Gee Lau, a coauthor of the study.

Scientists are using the special physics of dragonfly wings to create surfaces that shred bacteria on contact/ Nature.

On the back side of the nanostructured foil, where it contacts the implant device, the researchers integrated arrays of highly sensitive, flexible electronic sensors to monitor strain. This could help physicians watch the healing progress of individual patients, and guide their rehabilitation to shorten the recovery time.

The engineering group then teamed up with veterinary clinical medicine professor Annette McCoy to test their prototype devices. They implanted the foils in live mice and monitored them for any sign of infection, even when bacteria were introduced. They also applied the coatings to commercially available spinal implants and monitored strain to the implants in sheep spines under normal load for device failure diagnosis. The coatings performed both functions well.

The prototype electronics required wires, but the researchers' next plan to develop wireless power and data communications interfaces for their coatings, a crucial step for clinical application, Cao said. They also are working to develop large-scale production of the nanopillar-textured bacteria-killing foil.

“These types of antibacterial coatings have a lot of potential applications, and since ours uses a mechanical mechanism, it has potential for places where chemicals or heavy metal ions – as are used in commercial antimicrobial coatings now – would be detrimental,” Cao said.

One of the key advantages of these smart implant coatings is that they can provide early warning of implant failure before any symptoms appear. For example, changes in temperature or pressure may indicate that the implant is not functioning properly, allowing doctors to take action before the situation becomes critical.

Another advantage is that the coatings can prevent infection without relying on antibiotics, which can be expensive and have side effects. By using nanostructured surfaces and targeted antibacterial agents, the coatings can kill bacteria without harming healthy cells or contributing to the development of antibiotic resistance.

Of course, there are still challenges to overcome before these coatings can be used in clinical settings. For example, the coatings need to be biocompatible and durable, able to withstand the rigors of implantation and long-term use. Researchers are also working to optimize the sensing and release properties of the coatings, fine-tuning the materials and the design to improve their performance.

Despite these challenges, the potential benefits of smart implant coatings are clear. By preventing infection, these coatings could improve the safety and effectiveness of surgical implants, enhancing the quality of life for millions of people around the world.