HUMANS UNCOVERED

+ Get beneath the skin of our species

INSIDE THIS SECTION

By definition, nanoparticles measure less than 100nm

In contrast, a human hair is 80,000nm wide

IMAGE © GETTY

The nano elixir of life

Nanotechnology – the manipulation of matter at the scale of atoms and molecules – promises to vastly extend our lifespans

WORDS BY **Katharine Sanderson**

Humanity has made mind-boggling technological advances, from the Industrial Revolution and the Steam Age, to walking on the Moon and the internet. Yet the one thing that mankind hasn't been able to do is drastically improve on the fleshy shell in which our clever brains are located. We are still destined to grow old and frail, and meet our demise typically before we've hit 100 years old.

But if we think small enough, there's a chance that our bodies could be kept going for much longer from the inside. 'Small' in this instance means 'nano' It's difficult to visualise a nanometre-sized object, but if you were to shrink an average grain of salt half a million times you'd be getting close.

Nature is the original nanotechnician, having created life out of building blocks cells, viruses, DNA that range from tens to hundreds of nanometres in size. We've also learned how to use nanotechnology to make smarter electronics, sensors and catalysts. Now it's getting medical promising to help us live longer by killing diseased cells, delivering drugs and repairing faulty genes.

Little robots that march along our arteries, fighting off disease so that we can live to be centuries old sounds futuristic, and it is. But there are simpler ways to use nanotechnology to keep us going for longer, such as hiding a drug inside a nanoparticle, which releases it when it reaches an infected cell, or creating

Nano fact

#01 In 1959, physicist Richard Feynman made a famous speech saying, "There's plenty of room at the bottom. He was talking about building tiny machines atom by atom from the bottom up. Feynman's speech heralded the birth of nanotechnology as a concept.

Earthworms can make nanotech devices

Researchers fed them cadmium-laced soil and found quantum dots in gut cells

THE NANOTECHNOLOGY ALREADY IN YOUR HOME

Molecule-scale tools are being used right now inside everyday products

TV SCREENS

+ The latest televisions to hit the market use nanotechnology to make them brighter, smarter and thinner The technology includes organic light-emitting diodes (OLEDS), which don't need a backlight, as well as quantum dots tiny particles of semiconductors that glow in many different colours.

SUNSCREEN

+ As you were slapping on the sunscreen in your back garden this summer, you were probably benefitting from nanoparticles of zinc oxide or titanium dioxide. These minerals block out the sun's harmful rays, and making them just nanometres wide means they can't be seen by the naked eye.

SMELL-FREE SOCKS

+ If you've ever been bought antimicrobial socks, your sweeter-smelling feet are being cared for by silver nanoparticles. Silver is known for its antibacterial effects, and as nanoparticles the silver's surface area is huge, so it can work more effectively.

a nanoparticle that can sneak into a cancer cell and kill it.

Iron nanoparticles are candidate cancer killers although not yet in humans. Research published in 2012 exploited the fact that cancer cells have lots of certain receptor molecules on their surfaces, called death-cell receptors. When nanoparticles are tagged with a protein that sticks to these receptors, a magnet can be used to make the nanoparticles clump together. This triggers the death-cell receptors to spring into action and the cancerous cells self-destruct.

CUTTING WASTE

This approach is a good starting point, but not yet ideal, says Professor Kostas Kostarelos, a nanotech expert at the University of Manchester. There's a problem in making sure the nanoparticles go directly to the cancer cells and nowhere else. A single droplet of the therapy will contain millions of nanoparticles, says Kostarelos, but it's still a matter of a chance whether cancer and nanoparticle come into contact at all, or whether the particles simply get flushed out in urine.

"We're trying to improve on this," says Kostarelos, who is part of a team developing magnetic nanoparticles that swim only to where they're needed, guided by a changing external magnetic field. Another way to help nanoparticles navigate might be to make them heat-seeking. Warm up the tissue you're trying to attack, sit back and let the targeted nanomissiles go to work. Alternatively, light could one day guide cell-killing or drug-containing nanoparticles to parts of the eye. What Kostarelos wants to do is develop a range of nanotools that physicians can dip into depending on the problem they are treating.

Killing bad cells or delivering drugs might help cure us of disease, but nanotech has much more potential to ease us into old age. Imagine being able to delete a gene that made you more likely to develop

> "IF WE KNOW A SPECIFIC GENE RESPONSIBLE FOR AGEING, WE COULD MODIFY THIS TO SLOW DOWN THE PROCESS"
>
> **Prof Gang Bao** GEORGIA INSTITUTE OF TECHNOLOGY

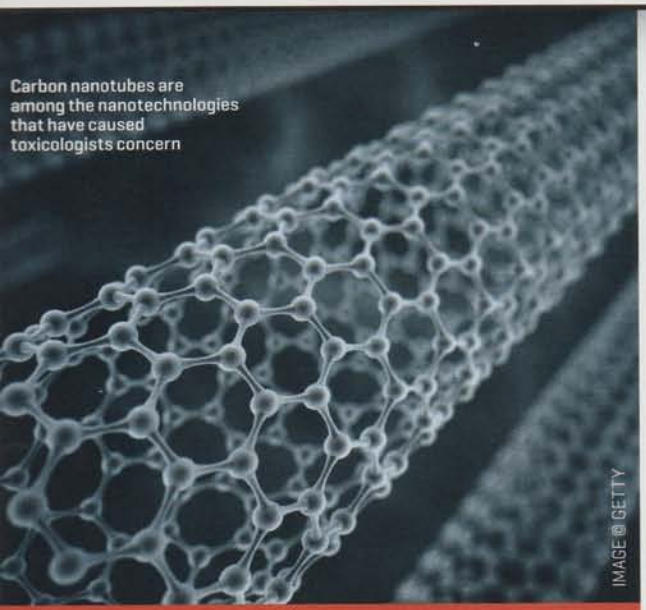
Nanoparticles could attach on to 'death-cell receptors' on cancer cells

Nano fact

#02 The computer industry led the nanotechnology charge, with its push to cram more and more components on to a chip. It developed the microscopes that have enabled scientists to manipulate matter into position on an almost atomic scale.

DNA is made up of just four building blocks

These nucleotides are called adenine, thymine, cytosine and guanine



Carbon nanotubes are among the nanotechnologies that have caused toxicologists concern

IMAGE © GETTY

ARE WE PLAYING WITH FIRE?

While its benefits could prove huge, nanotechnology does ring a few alarm bells

+ Any new technology needs to be approached with caution. Nanotechnology is no exception and is under close scrutiny by regulators and toxicologists.

The large surface area of nanoparticles makes them behave differently to bulk versions of the same materials. There is some concern that, in the body, the extra reactivity of these tiny particles could be harmful. Toxicologists' tests on them have given mixed results. Carbon nanotubes (CNTs) – tiny tubes of atom-thick sheets of carbon – can pass through the lung lining in mice, sparking fears of an asbestos-like crisis. But the conditions were contrived so the nanotubes were injected straight into the lungs – not a situation likely to face humans using the material. Risks have to be calculated based on the context in which the materials will be used. That said, toxicologists still have some concerns about CNTs and continue to test them.

Silver nanoparticles in sportswear have been shown to leach out into the body through sweat. Nanosilver could be a concern because of its heightened reactivity and tendency to make free radicals. But it isn't clear whether sportswear has enough silver in it to actually do any harm.

Nanotechnology in medical applications is under incredibly close scrutiny – just like any medicine or medical technology. There is little worry that those applications are risky.

There is also call for tighter regulation in the food industry. Details on the current use of nanotechnologies are guarded closely by manufacturers. That's not to say anybody is endangering you with toxic nanorobots in your yoghurt, but until specific nanofood regulation is in place, it's hard to know who is using what.

a certain disease. Step forward Professor Gang Bao, an expert in nanotechnology at Georgia Institute of Technology in Atlanta, and director of the Nanomedicine Center for Nucleoprotein Machines. His team are developing a technology to make repairs to damaged genes. They're starting simply, with diseases caused by a single genetic mutation. Sickle-cell anaemia – a blood disease that causes premature death – is the first target. But potentially the technique could be used to repair any specific disease-causing gene mutation, even in a healthy individual, before it does any harm.

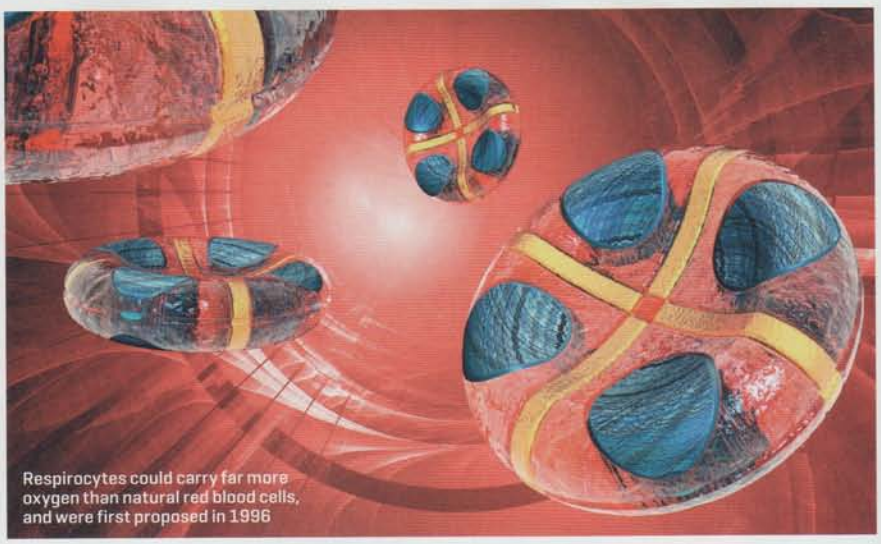
The body constantly repairs its DNA if both strands of that famous double helix break. Bao's team are hijacking one of nature's two repair methods, called homologous recombination, which uses a template from a healthy DNA strand to help rebuild the DNA with the correct genetic sequence. To treat sickle-cell diseases, Bao's team take a sample of stem cells from the patient's bone marrow and inject them with engineered proteins that can find the damaged segment of DNA and snip it out. Then a template of the correct gene sequence carried by these engineered proteins helps the DNA make itself a new non-mutated section. The corrected stem cells can then be added back into the bone marrow, and the disease is cured although this hasn't been tested in humans yet.

Bao has not only made the proteins, he's also used nanotech to build an array of nanosized silicon needles that can each inject a single stem cell. He builds the needles using the same techniques that are used to make intricate semiconducting computer devices. Being able to inject thousands of cells at once speeds up the process dramatically.

Bao hopes that in three or four years, the technique will be ripe to start clinical trials. The potential is huge for life expectancy. "We have

"WE CAN USE TECHNOLOGY DESTRUCTIVELY OR POSITIVELY IT IS A SOCIOLOGICAL AND POLITICAL PROBLEM, RATHER THAN THE TECHNOLOGY"

Prof Kostas Kostarelos UNIVERSITY OF MANCHESTER

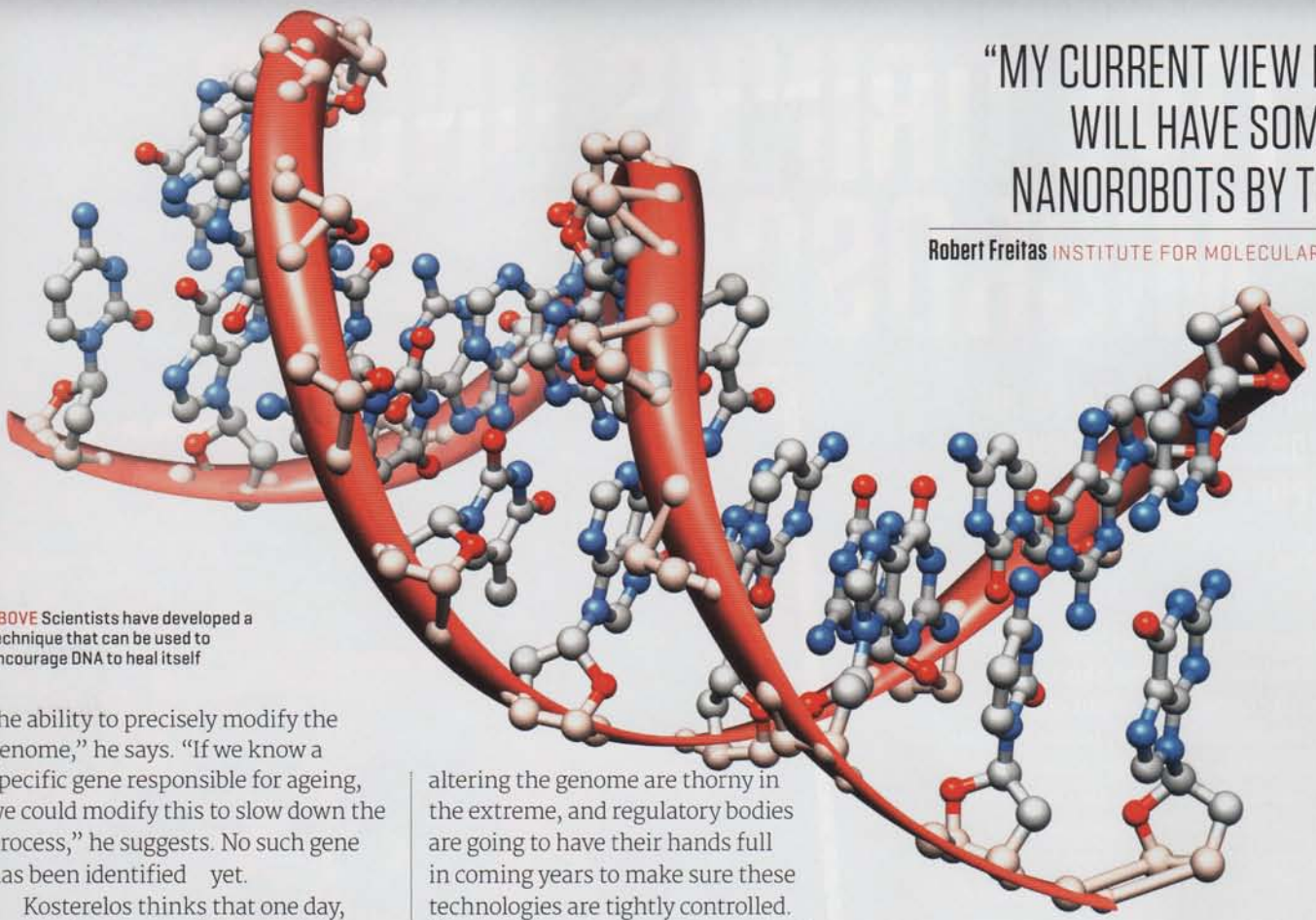


Respirocytes could carry far more oxygen than natural red blood cells, and were first proposed in 1996

IMAGE © LAGUNA DESIGN/SCIENCE PHOTO LIBRARY

Nano fact

#04 Nanotechnology takes cues from nature, such as the tiny machinery used by plants to photosynthesise, or the gravity-defying skin patterns on gecko's feet. Trying to recreate these elegant, sophisticated systems is part of the appeal for scientists.



ABOVE Scientists have developed a technique that can be used to encourage DNA to heal itself

the ability to precisely modify the genome," he says. "If we know a specific gene responsible for ageing, we could modify this to slow down the process," he suggests. No such gene has been identified yet.

Kosterelos thinks that one day, nanotechnology could be used to turn smartphones into sensors that could screen a breath or saliva sample for those diseases that Bao's technology might then be able to go in and cure.

POSITIVE APPLICAT ONS

Bao is pondering the ethics of the situation carefully. "I'm not sure we want to have a world full of old people," he says. But if the technology could also cut out cancer-causing genes or those related to dementia, being old might not equate to being frail. Bao wonders, if his work comes to fruition, whether we could one day all live to be well over 100, leading healthy lives for the duration.

He is also concerned about unleashing his work on would-be Dr Frankensteins. "We have to be careful," he says. "What if someone took this technology to do evil?" The ethics of life extension and altering the genome are thorny in the extreme, and regulatory bodies are going to have their hands full in coming years to make sure these technologies are tightly controlled. "We can use technology destructively or positively," says Kostarelos. "It is a sociological and political problem, rather than the technology."

Robert Freitas, from the Institute for Molecular Manufacturing in Pilot Hill, California, is known for thinking big when it comes to small stuff. He published the first peer-reviewed paper describing a conceptual medical nanorobot in 1996. He called these robots respirocytes: artificial red blood cells that could carry hundreds of times more oxygen than our standard-issue ones. An onboard computer would control oxygen release and could help manage blood-related disease or even resuscitate someone who was drowning.

Other nanorobots Freitas has proposed include the vasculocyte, which he says would be use to mend damaged arteries as it marched along them on telescopic legs. On top of the vasculocyte would be thousands of rotors, spinning and swapping damaged molecules for healthy ones.

In 2010 Freitas thought the first medical nanorobots would be with us by 2020. He's revised his prediction, but stands by the concept. "My current view is that we'll have some medical nanorobots by the 2030s," he says.

As for our lifespan in a nano-enhanced world, Freitas has developed models with extraordinary predictions that far outplay Bao's 100 years or so. His calculations, which assume that nanorobots can eliminate all frailty, disease and age-related deaths, suggest that as long as we avoid accidents, we could live for not hundreds but thousands of years, perhaps as long as 39,000 years. Would you want that?

"MY CURRENT VIEW IS THAT WE WILL HAVE SOME MEDICAL NANOROBOTS BY THE 2030s"

Robert Freitas INSTITUTE FOR MOLECULAR MANUFACTURING

Katharine Sanderson
Science writer
+ Katharine Sanderson has a PhD in chemistry from the University of Cambridge, and is a former reporter on the international science journal Nature.

Nano fact

#05 Hopes for nanotechnology are vast, but include: better, faster, smaller computers; smart materials that can repel dirt and bacteria; metamaterials that manipulate light, making things invisible; clever fabrics that detect vital signs of life or incorporate communications devices for use in the military.