

DNA-grabbing bacteria hint at early phase of evolution

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PARTS of us may never die – not quite, anyway. Lab tests involving microbes and a mammoth bone have shown that bacteria can passively soak up the genetic remains of long-dead organisms from the environment and add them to their own genomes.

This ability is a previously ignored mechanism of evolution, says [Søren Overballe-Petersen](#) of the Natural History Museum of Denmark in Copenhagen. It joins sex, where two organisms combine their genes by mating; random DNA mutation; and the active transfer of genes between live microbes.

By absorbing snippets of DNA that float in the environment, bacteria can access a junk shop of genetic material – some of which may no longer be in circulation in living things. What's more, the mechanism requires hardly any cellular machinery, suggesting it may be left over from the earliest forms of life. Long before the advent of sex, the first cells may have randomly scavenged stray bits of DNA to survive and evolve.

When organisms die, their DNA breaks into pieces. But these tiny, damaged fragments aren't lost, says Overballe-Petersen. He fed short pieces of degraded synthetic DNA to *Acinetobacter baylyi* and found that the bacteria added them to their genomes. Then he smashed up a 43,000-year-old mammoth bone, extracted DNA from the shattered bits, and fed it to his cultures. The dead mammal's DNA ended up in the live bacterium's.

Overballe-Petersen presented his [results](#) at the conference of the [Network of Researchers on Horizontal Gene Transfer](#) in Milton Keynes, UK, this month.

Many bacteria take DNA from other live microbes using a complex system of around 40 genes. But when Overballe-Petersen knocked out part of this machinery in his bacteria, they carried on taking in short snippets of DNA, unfazed. They were automatically added to the genome during normal DNA copying. Overballe-Petersen thinks the bacteria absorb DNA passively, creating the tantalising possibility that the mechanism is simple enough to have existed in the earliest forms of cellular life.

It's not clear what the bacteria do with their new DNA. The fragments are too small to hold a full gene, but could carry a promoter to switch others on, says [Laura Weyrich](#) of the Australian Centre for Ancient DNA in Adelaide. Or bacteria could grab bits of viral DNA, which would prime their [immune systems to fight off the virus](#), like a vaccine.

Regardless of what it is used for today, the ability to incorporate DNA from other organisms may have been key when life was just getting started. Early microbes [are thought](#) to have [regularly swapped genes](#), says [Nigel Goldenfeld](#) of the University of Illinois at Urbana-Champaign. Pre-sex, this would have helped life to evolve rapidly.

"Taking DNA from the medium [they live in] looks pretty accessible to early cells," says [Jonathan Lombard](#) of the National Evolutionary Synthesis Center in Durham, North Carolina. His research suggests they were encapsulated by leaky membranes, and probably didn't have much control over what moved in and out. They most likely got food from their surroundings, he says, so it's not much of a stretch to suggest they scooped up DNA at the same time.



Broken, but not dead (Image: [Pasieka/SPL/Getty](#))

PHENOMENA: NOT EXACTLY ROCKET SCIENCE



Columbian mammoth skeleton. Credit: WolfmanSF

NOT EXACTLY ROCKET SCIENCE: November 18, 2013

The Bacteria That Absorbed Mammoth DNA

by Ed Yong

An average gram of soil is full of DNA. Some of it is enclosed inside bacteria, worms or insects, but a lot of it is just lying around. It came from living things that died and decomposed, releasing their genetic payload into their surroundings. Exposed to the elements, this environmental DNA breaks, degrades and distorts.

But, sometimes, it finds its way back into a living thing.

Bacteria can feed on bits of DNA from their surroundings. They can also incorporate these fragments into their own genome, as easily as you might put a new book onto your shelf. These horizontal gene transfers give bacteria an edge in the evolutionary race. Rather than just inheriting genes from their ancestors, they can pick up fresh DNA from all around them.

Now, [Soren Overballe-Petersen](#) from the University of Copenhagen has shown that they can even do this with extremely short and damaged pieces of DNA. As dramatic proof, he showed that soil microbes can incorporate 43,000-year-old mammoth DNA from a fossilised bone.

Let's be clear: it's irrelevant that the DNA came from a mammoth. Mammoth DNA is like human DNA is like cabbage DNA. It's the same molecule. There's no special mammothity imbued within strands that small. The microbes aren't suddenly going to sprout tusks and a shaggy coat.

The point is that the DNA is *old*. Really damn old. If an Ice Age microbe (or, indeed, a mammoth) could donate DNA to a living bacterium, then “generations long past can influence the evolution of future generations,” says Overballe-Petersen. He calls it anachronistic evolution. “It's something we've not considered before and it's not in our models of microbe evolution.”

“The idea is something very similar to [a concept called] [genome recycling](#),” says [Hendrik Poinar](#) from McMaster University, who studies microbes and ancient DNA. “This idea that DNA of very different ages could make its way back into the evolutionary light of day is certainly a fascinating possibility.”

It's also possible that the more bacterial there are in the environment, the faster they evolve. If you have a lot of microbes around, you have more DNA in the environment for the survivors to pick up and use. “There's the possibility of a positive evolutionary feedback loop,” says Overballe-Petersen.

Scientists have long known that bacteria can efficiently suck up DNA from their surroundings, but these fragments have typically been thousands of 'letters' long. “When the fragments become shorter, the efficiency drops very fast,” says Overballe-Petersen. However, his team, led by ancient DNA specialist [Eske Willerslev](#), showed that the soil microbe *Acinetobacter baylyi* can take up fragments just 20 to 120 letters long.

The bacteria presumably digest much of this DNA, but they can also integrate it into their

genomes. This doesn't require any fancy tricks. Bacteria need to make copies of their DNA whenever they divide, and if the environmental strands are around at the time, they can get slotted in.

“It's not something that the bacterium *tries* to do, or necessarily gives it an advantage,” says Overballe-Petersen. “It's a consequence of feeding on what it finds around itself. I liken it to rummaging through garbage. Most of the time it'll go nowhere, but you could find all sorts of wonderful things that people have thrown out.”

The team found that this process works even if the environmental DNA is severely damaged, and they wondered if bacteria could take up extremely old and tattered DNA too. The problem is that it's hard to find DNA that definitely came from ancient microbes—too often, modern bugs contaminate the samples. So, the team turned to a source of DNA that they knew was definitively ancient—a 43,000 year old mammoth bone. “We already had one available,” says Overballe-Petersen. “And we're pretty confident that a mammoth didn't run around the lab last week and dropped hair into our samples.

It worked. The soil microbes made the mammoth DNA part of them. This genetic material, broken and shattered by many millennia of decay, is now back in living cells again.

The concept is tantalising but “there is no evidence that this has occurred in nature,” says [Howard Ochman](#) from Yale University. “Just from scanning genomes, horizontal gene transfer from [living] sources seems to have had a much, much larger impact on bacterial evolution.”

And it's still the case that bacteria are much less efficient at transforming their genomes with small pieces of DNA than with larger fragments. On the other hand, Overballe-Petersen argues, there's a *lot* of free DNA in the environment. Even if bacteria aren't great at picking it up, they have many chances to do so.

Poinar says that there are two big questions: how often does this happens in the wild, and how often does the extra DNA changes something meaningful in the bacteria rather than doing nothing? After all, these fragments are far too small to include entire genes. Adding them to a bacterium's genome is like adding a few letters or words to a book, rather than an entire page.

But the team notes that it doesn't take many such changes to, say, turn a vulnerable bacterium into a drug-resistant one. That has important implications for hospitals, which

are often teeming with drug-resistant bacteria. Medical equipment, toilets and water supplies could all be sources of DNA carrying resistance genes. “In hospital rooms, you’re focused on killing the living bacteria. But that’s not enough to destroy the DNA, which could fragment and potentially be picked up again,” says Overballe-Petersen. “You’d have a vicious cycle of recurring resistance.”

If this is a genuine problem (and that’s not clear yet) it would also be a difficult one to fix. Destroying environmental DNA is very hard. In Willerslev’s lab, they wipe their work surfaces with strong chlorine solutions, and irradiate them at night with ultraviolet lights. “You can’t treat patients in this way, but maybe you could use UV lights in operating theatres, when they’re not in use in the night.”

Reference: Overballe-Petersen, Harms, Orlando, Moreno Mayar, Rasmussen, Dahl, Rosing, Poole, Sicheritz-Ponten, Brunak, Inselmann, de Vries, Wackernagel, Pybus, Nielsen, Johnsen, Nielsen & Willerslev. 2013. Bacterial natural transformation by highly fragmented and damaged DNA. PNAS <http://dx.doi.org/10.1073/pnas.1315278110>

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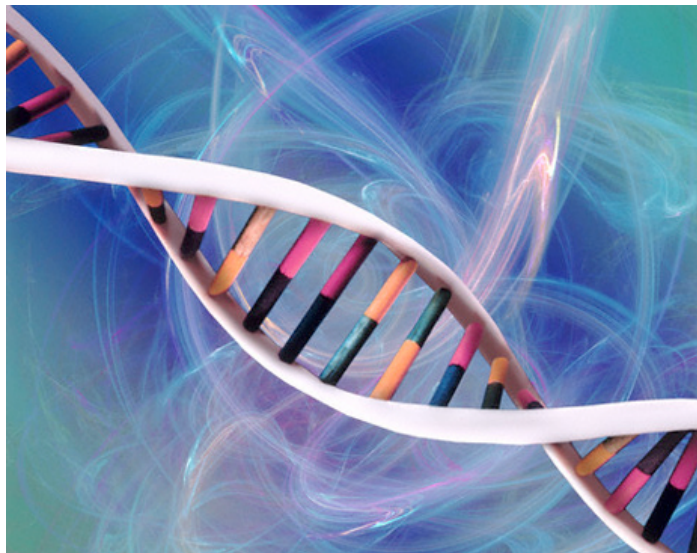
Il batterio che inventò l'evoluzione "anacronistica"

Il batterio *Acinetobacter baylyi* è in grado di inglobare nel proprio genoma frammenti di DNA degradati dispersi nell'ambiente, anche appartenuti ad organismi vissuti decine di migliaia di anni fa, come il mammut. La scoperta svela un nuovo meccanismo di evoluzione dei batteri, dimostrando inoltre la possibilità di un incredibile salto temporale nel trasferimento dell'informazione genetica da un organismo a un altro, secondo un processo battezzato "evoluzione anacronistica". (red)

Che fine fa il DNA degli organismi dopo la loro morte? Viene degradato e disperso nell'ambiente, ma i suoi frammenti possono resistere fino a un milione di anni ed essere addirittura inglobati nel genoma di alcune specie di batteri, come hanno scoperto Søren Overballe-Petersen dell'Università di Copenhagen e colleghi di un'ampia collaborazione internazionale, che ne riferiscono sui "Proceedings of the National Academy of Sciences".

La materia organica, decomponendosi, disperde continuamente materiale genetico nell'ambiente. La degradazione del DNA nucleare inizia con la morte cellulare e si deve all'azione congiunta di enzimi noti come nucleasi e successivamente dei microbi che si nutrono di materia organica. Allo stesso modo, il DNA extracellulare viene degradato da processi fisici, chimici e biochimici, i più importanti dei quali sono l'idrolisi e l'ossidazione.

La degradazione della catena molecola di DNA procede assai rapidamente, ed è per questo che non ci si aspetterebbe che i frammenti, che raramente superano la lunghezza di 100 coppie di basi, possano resistere una volta dispersi. Invece, possono sopravvivere per migliaia di anni, e addirittura fino a un milione di anni in condizioni di conservazione ottimali.



Rappresentazione artistica della doppia elica del DNA: anche corti frammenti della molecola, di lunghezza inferiore alle 20 coppie di basi, possono essere inglobati nel genoma dei batteri (© Denis Scott/CORBIS)

infatti un incredibile salto temporale nel trasferimento dell'informazione genetica da un organismo a un altro: Overballe-Petersen e colleghi hanno battezzato questo nuovo fenomeno "evoluzione anacronistica".

La limitata lunghezza dei frammenti genetici integrabili dai batteri ha notevoli conseguenze, studiate dagli autori con simulazioni al computer. La prima conseguenza è che i geni batterici che ospitano i frammenti acquisiti possono perdere la loro funzionalità, cosa che invece non succede se vengono acquisiti interi geni, che anzi ampliano il *pool* di proteine che il batterio è in grado di sintetizzare. Con nuovi frammenti, il genoma batterico nel suo complesso tenderebbe quindi a diminuire la sua funzionalità invece che ad aumentarla. Una seconda conseguenza è che quando il processo riguarda batteri patogeni per l'uomo, l'acquisizione di frammenti di DNA potrebbe far emergere ceppi resistenti agli antibiotici, un problema di enorme rilevanza in tutto il mondo.

Il DNA frammentato o chimicamente danneggiato è un'importante fonte di nutrimento per i microbi, ma finora non erano emerse indicazioni che contribuisse all'evoluzione del genoma batterico. In questo studio, Overballe-Petersen e colleghi hanno testato l'ipotesi che i batteri possano acquisire questo DNA degradato, anche di antica origine, mediante trasferimento genico orizzontale, un processo grazie al quale le cellule batteriche integrano nel proprio genoma DNA che si trova libero nell'ambiente. Questo processo finora è stato documentato sperimentalmente solo per sequenze nucleotidiche molto lunghe o per interi geni.

La sperimentazione in laboratorio ha dimostrato che ciò può effettivamente avvenire: il batterio della specie *Acinetobacter baylyi*, un organismo modello molto utilizzato nelle ricerche di microbiologia, è in grado di acquisire corti frammenti di DNA – anche di meno di 20 coppie di basi - e persino derivati da ossa di mammut di 43.000 anni fa.

Queste evidenze sperimentali hanno portato i ricercatori a enunciare due nuovi principi biologici generali: il primo è che la degradazione chimica del DNA non basta a renderlo biologicamente inattivo, e il secondo è che sequenze di DNA disperse nell'ambiente, anche quando sono molto frammentate, possono contribuire all'evoluzione del genoma dei batteri secondo meccanismi finora sconosciuti. La capacità dei batteri di integrare frammenti di DNA anche molto antico introduce