Highlight: Bacteria Shed DNA as They Adapt to Hot Temperatures

Danielle Venton*

*Corresponding author: E-mail: danielle.venton@gmail.com.

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Prokaryotic genomes are no-nonsense items: small, compact, with very little DNA between their genes compared with eukaryotes. Whether this is adaptive has, for decades, been a mystery.

Genomic researchers have proposed that natural selection may favor small genomes—weeding out superfluous material—through a process called "genomic streamlining." Streamlining makes inherent sense because a small genome should aid metabolic efficiency, because genome size is correlated with cell size. Many researchers believe cells divide and replicate faster if they remain small.

As logical as genomic streamlining might be, few examples have so far been found. Instead, a bevy of articles from the last 10 years show that three separate lines of evidence argue against widespread streamlining in prokaryotes. Genetic drift, a purely random process, has been suggested as the driving force behind small prokaryotic genomes.

"There exists a kind of cognitive dissonance between the common wisdom among many biologists—that bacterial genomes are streamlined," says Andreas Wagner, an evolutionary biologist at the University of Zurich, "and rather solid proof from molecular data that most genomes are not."

That may be set to change, at least for one bacterial group. In a recent article by Sabath et al. (2013) in *Genome Biology Evolution* article, the authors report that the heat-loving bacteria have extremely trim genomes and that the same three lines of evidence (mentioned earlier) argue in favor of streamlining among thermophiles.

Finding such evidence came as a great surprise. "Given that some of the best researchers out there had looked into this problem," says Wagner, "I was surprised that the same kinds of evidence that argues against streamlining in general argues for it for thermophiles."

The finding was actually a secondary question—a piece of scientific serendipity. The team began the research as a look at the association between bacterial genome size and growth temperature (previously unreported). Only later on, says Sabath, did the team decide to test the streamlining hypothesis.

To start, they found that all species living at temperatures above 60 °C have genomes smaller than 4 million base pairs (4 Mb), and species living at temperatures below 45 °C have genomes larger than 6 Mb. The hotter the habitat, the smaller the genome.

To find out whether this reduction is caused by genetic drift or streamlining, they asked three questions. First, evolution should weed out noncoding regions of DNA faster than coding regions. Second, generation time (or cell division rate) should correlate with genome size. Last, the smaller genomes should have a slower protein evolution rate (evidence of stronger selective pressure).

Comparing the percentage of a genome's intergenic DNA with genome size revealed that, across bacteria, genomes of smaller thermophiles also contain a smaller percentage of their DNA in noncoding regions. No such correlation was seen in nonthermophiles. Similarly, thermophiles living at higher temperatures divide significantly faster. Past work looking at general bacteria, however, has found no correlation between genome size and reproduction time.

For the last line of evidence, the team compared 40 gene pairs evolved from a common ancestor gene in independent, but closely related, taxa. The more quickly the genes evolve, according to current biological thinking, the weaker the selective constraints on those proteins. They found no significant correlation between evolution rate and temperature, in either bacterial group. (Interestingly, proteins in thermophilic bacteria were generally shorter than their orthologs in nonthermophilic bacteria, probably because loops which can destabilize structure get lost in the proteins of thermophiles.) Neither did they find a correlation comparing rate and genome size. With a larger sample size, the authors suspect a negative association might be detected with thermophiles.

"Although our analysis did not show an equivalent significant decrease in dN/dS ratios [a measure of evolution rate] . . . it shows that selective constraints are not weaker in thermophiles (as they are in obligate parasites and endosymbionts)," write the authors. "Thus, genome size reduction is unlikely to be the result of drift."

The team wanted to test whether heat was the actual cause of the detected streamlining, not the habitat of thermophiles. It is conceivable that the environment might be driving genome shrinking. That's because bacteria living in more variable environments are capable of more enzymatic reactions to metabolize a variety of nutrients. "Such organisms would need to have larger genomes," the authors write, "to accommodate all the genes that encode these enzymes." If organisms in high temperature habitats live with less environmental variability, that might explain the pattern observed. To determine whether this might be an influencing factor, they examined about 500 microbes' species for which information on both growth temperature and habitat was available. They saw no relationship between habitat variability and genome size (with the exception of host-associated organisms), but the link between temperature and genome size remained clear.

So what is going on? Sabath et al. say it is unlikely that fast replication is slimming down genomes. The cost of DNA replication is relatively low. It's more likely, they think, selection is acting upon cell size itself (small cells have small genomes, for reasons that are foggy at the moment). A small cell might be an advantage for absorbing scare nutrients or to escape predation by other organisms or viruses. At high temperatures, small size might be a special advantage—to save nutrients. "[Temperature] requires cells to increase the lipid content and change the lipid composition of cell membranes . . . [And] high temperature increases the amount cells need to expend on non-growth associated maintenance," write the authors.

However, nailing down the exact mechanistic cause of the streamlining, Wagner says, is work for the future.

Literature Cited

Sabath N, Ferrada E, Barve A, Wagner A. 2013. Growth temperature and genome size in bacteria are negatively correlated, suggesting genomic streamlining during thermal adaptation. Genome Biol Evol., Advance Access published April 5, 2013, doi: 10.1093/gbe/evt050.

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