An Evolutionary Theory of Dentistry

Why are our teeth so rotten? Biologists point to a mismatch between our diets and lifestyles and those of our ancestors

DURHAM, NORTH CAROLINA—Remember the Coca-Cola jingle that went, "I'd like to buy the world a Coke and keep it company"? Well, it worked. And here's what happens when everyone can buy a soda every day in a small town on the northern tip of Mexico's Yucatán Peninsula: Young adults in the town of Dzilam González had three times as many cavities as those who live in a poorer, more isolated village nearby where people can't afford soft drinks every day, according to a new study. In the poorer village, people eat a traditional diet of maize tortillas at every meal. The richer village has a pizzeria in its central square, shops with ads for soft drinks, dentists' offices—and significantly more tooth decay in people aged 20 to 30, according to a new study by Elma Vega Lizama and Andrea Cucina of the Autonomous University of Yucatán in Mérida, Mexico.

Cucina presented the study of these two Maya villages at a recent meeting* here. The work offers an elegant demonstration of the message that emerged at the meeting: Human teeth, jaws, and mouths are not adapted in a healthy way to the diet of modern industrial society. We evolved to thrive on coarse seeds, nuts, tubers, fruit, and meat. In our skeletons, too, our evolutionary history leaves us prone to medical problems (see sidebar, p. 974). But when it comes to our mouths, the mismatch between our adaptations and our environment causes the dental cavities, overcrowding of teeth, overbite, and gum disease that run rampant today.

Not-so-sweet tooth. This German jaw from the 16th to 18th century shows the perils of a poor diet in tooth loss, cavities, and gum disease.

CREDITS: AMARNA PROJECT; LESLIE WILLIAMS

*"Evolution of Human Teeth and Jaws: Implications for Dentistry and Orthodontics," National Evolutionary Synthesis Center, 28–30 March, Durham, North Carolina.

Healthy bite. This ancient Egyptian had healthier teeth and jaws than most living humans.

The Maya of the two villages are before-and-after images of a population undergoing the so-called nutrition transition in which people switch from a traditional subsistence diet to an Industrial Age diet of refined sugars and processed foods. At the meeting, an unusual mix of paleoanthropologists, archaeologists, dental researchers, and food scientists explored what is known about the diets and dental health of ancient humans, and how that information might be useful to dentists today. "How does our oral environment today differ from those in which our teeth evolved?" asked co-organizer Peter Ungar of the University of Arkansas (UA), Fayetteville. "Can an understanding of this discordance inform clinical research and ultimately dental and orthodontic practice?"

Online
sciencemag.org
Podcast interview with author Ann Gibbons (http://scim.ag/pod_6084).

When the ancients smiled

The meeting began with grim slides of primates with terrible teeth and swollen gums, demonstrating that humans aren't the only ones with toothache. "Trauma, dysplasia, hypoplasia, arthritis, cysts—it's all there in animals," says anatomist Christopher Dean of University College London (UCL). "These are usual in wild animals in the last decades of their life, as part of the aging process." But tooth decay and gum disease get worse with a soft, sugar-rich diet in captivity.

Cavities and periodontal disease used to be diseases of aging in humans, too. In fossils of ancient humans, "you can count the number of cases of dental caries [cavities] on one hand," says UCL bioarchaeologist Simon Hillson. Researchers, such as Ungar, who have examined thousands of fossilized human ancestors estimate that cavities appear in fewer than 2% of teeth from earlier than 20,000 years ago. Traditional foragers, such as Australian aboriginals in the 1940s, still had beautiful teeth, with cavities in only the very old. (Other foragers with diets rich in plant carbohydrates, which are sugars, are an exception.) Gum disease and malocclusion—problems in the way the upper and lower teeth fit together,

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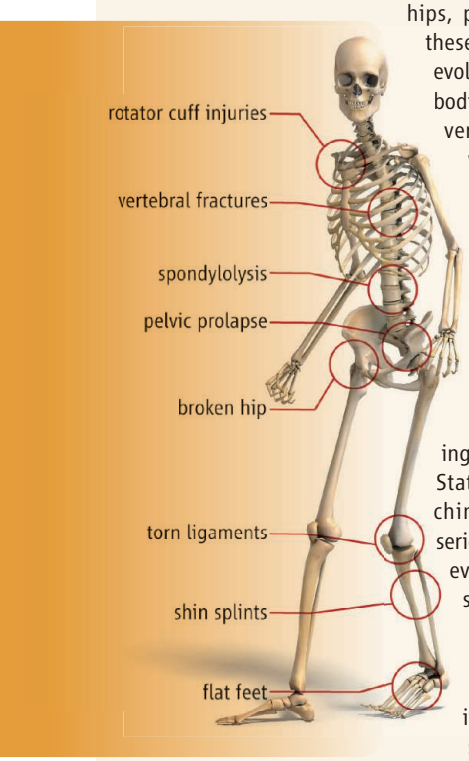
such as overbite—are also surprisingly rare in prehistoric teeth, says Robert Corruccini of Southern Illinois University in Carbondale, who reviewed 20 years of research on cross-cultural differences in occlusion.

This clean bill of dental health began to deteriorate, however, as farming started to take root as early as 13,000 years ago in the Middle East and later in other parts of the world. Roughly 9% of Neolithic people—the first farmers—had cavities, as they began to consume cereal grains rich in carbohydrates, Ungar says. Even so, many millennia elapsed before dietary changes resulted in serious oral damage. For example, the skeletons of 93 commoners excavated at Amarna, Egypt, who apparently died between about 1330 B.C.E. and 1350 B.C.E., had surprisingly good teeth, says UA anthropologist Jerome Rose. These Egyptians ate more carbohydrates than hunter-gatherers did, in the form of coarse bread, but they also ate so much grit and fiber that the surfaces of their teeth—including any cavities—wore down rapidly. "The wear was fast enough to erase decay until late in life when decay showed up between teeth," Rose says.

The Burdens of Being a Biped

Just as many dental problems are rooted in our evolutionary history (see main text, p. 973), a number of musculoskeletal issues are also traceable to our past, in particular to the switch to walking upright more than 7 million years ago. "We've taken a body that was adapted to being horizontal to the ground and made it erect," says Bruce Latimer, a comparative anatomist at Case Western Reserve University in Cleveland, Ohio. "We've had to change nearly every bone in the body, and as a consequence, there are many things that humans suffer from that no other animal does."

Shifting from a four-legged support system to a two-legged one put extra stress on the legs and vertebrae. Adaptations in the feet, knees, hips, pelvis, and spine accommodate these forces, but at a cost. Imperfect evolution and constraints on how our bodies could change have left us with vertebrae that break more easily, weaker bones, and feet prone to heel spurs and sprained ankles. Our relatively inactive lifestyles and longer life span only exacerbate our orthopedic imperfections. A brief tour of the body reveals a number of design flaws, the legacy of our past.



Walking can be a pain. Bipedalism leaves the human body vulnerable to a range of problems, just a few of which are pinpointed here.

Spine. Back pain is the leading health complaint in the United States. In dogs, horses, and even chimpanzees, the backbone is a series of vertebrae neatly stacked and evenly spaced to form a relatively stiff, gently curving beam. Not so with the human spine, which is highly flexible and can even bend backward. Yet this flexibility creates wear and tear on joint surfaces and predisposes us to osteoarthritis.

Furthermore, evolution has left our spines with an S-shaped curve, which is necessary to keep the upper body centered over the hips. Thus the lower spine curves toward the belly button, causing a hollow in the back and bringing the torso upright. To keep the head centered, the thoracic vertebrae in the chest curve in the other direction. "Spinal curvatures cause a lot of problems in humans that other animals don't have," particularly slipped disks and broken vertebrae, says Carol Ward, an anatomist at the University of Missouri, Columbia.

One type of break, called spondylolysis, affects about 6% of the U.S. population and is a leading cause of lower-back pain in teenage athletes. In this condition, the neural arch—a triangle of bone that surrounds the spinal cord—detaches from the rest of its vertebra, allowing the spine to slip forward relative to the back of the pelvis, pinching nerves and causing pain.

Ward, Latimer, and their colleagues surveyed thousands of human skeletons in the 1990s and determined that the problem lies in inadequate spacing between the joints connecting the vertebrae. If the lower vertebrae are too crowded, the bone is chronically pinched, eventually causing it to dissolve and the neural arch to separate. "When people don't have that correct spacing, they tend to get spondylolysis," Ward says. X-rays can reveal vulnerability to this condition, Latimer notes, and children with narrow vertebral spacing should avoid gymnastics, swimming butterfly stroke, and other sports that involve excessive back arching.

Feet. To cope with the added load on just two feet, the foot evolved a shock-absorbing arch by bringing what was a grasping big toe into line with the other toes. When that arch fails to form fully, as in people with flat feet, fatigue fractures can result. And when the big toe's tendon gets misaligned from improper shoes, bunions develop. Latimer blames heel spurs, plantar fasciitis, hammer toes, shin splints, chronically sprained ankles, and even varicose veins on our erect posture.

Fragile bones. The added load on two feet also caused knee and hip joints to expand, creating more surface area to absorb foot-fall forces. But the joints—and vertebrae as well—evolved to be bigger by enlarging the spongy, inner bone and thinning the hard, outer bone. As a result, human bones are less dense than those of other primates, a team led by mechanical engineer Christopher Hernandez of Cornell University, who studies osteoporosis, reported on 19 October 2011 in *PLoS ONE*.

Bone builds mass during childhood—more so if stressed with exercise—then loses mass during adulthood. With humans having ever longer life spans, bones, particularly vertebrae, may become fragile and break spontaneously. Apes lose bone mass as they age as well, but they don't suffer fractures because their bones are so much denser to begin with. Humans could have more apelike bones if they got more exercise as youths, as early humans did, Ward says. "If we treated our skeletons the way they were designed to be treated, they would serve us better later in life."

Bipedality leaves its mark in other parts of our bodies, too, for example in the difficulty of childbirth and in our vulnerability to rotator cuff injuries of the shoulder. Understanding these connections can suggest preventive measures, as in the case of spondylolysis, notes Latimer, who urges such understanding even if there's no immediate biomedical application. He helped organize a series of workshops through the National Evolutionary Synthesis Center to come up with evolutionary medicine curricula about musculoskeletal disorders. "If you don't understand the evolutionary background," he says, "you are treating the symptoms without understanding the underlying cause."

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The Egyptians' coarse diet also had a positive impact on jaw development. Chewing stresses stimulate growth of alveolar bone, the thin layer of bone surrounding the roots of teeth, which causes children's lower jaws to grow more robust and longer, with little overbite or malocclusion. As a result, when the ancient Egyptians closed their jaws, their upper and lower incisors (the four front teeth) met in an edge-to-edge bite, with good spacing between the teeth in their robust faces. People today, who eat softer foods, have a "scissors configuration" bite, in which the upper incisors protrude over the lower incisors, because the lower jaw is smaller than the upper one.

Following the old ways. Maya in the Yucatán of Mexico who still eat a traditional diet have fewer cavities.

Perils of a sweet tooth

In Europe, less than 10% of individuals had cavities until Alexander the Great brought sugar to Greece in the 4th century B.C.E., according to earlier studies, says pediatric dentist Kevin Boyd of Children's Memorial Hospital in Chicago, Illinois. Cavities increased first in Greece, then Rome; their incidence also rose throughout Europe in the Middle Ages. But the biggest spike was from 1800 to 1850, when Britain took control of the West Indies and imported far more sugar than previously. Sugar helped fuel the Industrial Revolution, which was a transition from an agriculture-based economy to a machine-based economy. In 1874, the British reduced the tax on sugar, and it became available to all social classes. "In London, mostly 1800 onwards, they have absolutely dreadful teeth," Hillson says.

The damage caused by refined sugar is well known: It alters the optimum pH of 5.4 in the mouth, making saliva more acidic. That saliva, as well as acid produced by bacteria in plaque, dissolves minerals in the enamel, causing cavities. By the middle of the 20th century, between 50% and 90% of the population in Europe and the United States had cavities. This improved in the 1970s when water was fluoridated. But for the first time in 40 years, the U.S. Centers for Disease Control and Prevention recently noted an increase in cavities in children aged 2 to 5 years. Dentists blame snacking and sugars in juice and sodas.

In the latter half of the 20th century, overcrowding of teeth and malocclusion became rampant. Today, nine in 10 adolescents in the United States have some malocclusion, and half could benefit from orthodontic treatment, Corruccini says. Impaction of the third molars, or wisdom teeth, occurs 10 times more frequently in people eating an Industrial Age diet than in hunter-gatherers. "Our jaws are underdeveloped because softened, highly processed foods do not provide the chewing stresses needed to stimulate normal growth of the jaw during childhood," Corruccini says.

As researchers at the workshop reviewed the data, it became clear that the biggest challenge for our teeth wasn't the initial transition to agriculture, as many researchers had once thought. It was the Industrial Revolution and then, in the 1980s, another marked increase in refined sugars in processed foods, such as high fructose corn syrup in sodas. "Caries and malocclusion is not a Neolithic problem, but an industrial problem," Boyd says.

After establishing the complexity of the problem, the researchers began to consider solutions. "If we remove carbohydrates from the diet, do we have less disease? Is this something I should be recommending to my patients?" asked dentist John Sorrentino of Hopewell Junction, New York.

The answer, it appears, is not simple, other than the obvious advice to cut back on refined sugars. The role of starch in causing cavities is not well known and needs study, Hillson says. Boyd suggested that consuming sugars with more fiber, such as fructose in fruit, lessens the damage because the sugars are absorbed more slowly in the gut, rather than rapidly in the mouth. But our ancestors consumed a variety of diets, so the solution may not be as simple as trying to recreate a hunter-gatherer's diet. "There was not a single oral environment to which our teeth and jaws evolved—there is no single caveman diet," Ungar says. "Still, we need to acknowledge that our ancestors did not have their teeth bathed in milkshake."

Further research is needed on how sugar affects the balance of species of bacteria in the mouth, such as *Streptococcus* strains, which are linked to cavities in humans. These complex communities of bacteria mix with minerals from saliva and immune cells to form plaque on the teeth. Our immune systems react to the bacteria, causing gum disease. "Normally, young kids are more resistant to the effects of plaque than adults," Dean says. But with more sugars in the diet, plaque-forming bacteria may flourish, which may trigger a bigger immune response and inflammatory reaction. That, in turn, can lead to a higher risk of systemic diseases such as cardiovascular disease and diabetes. But the response to plaque varies: "Everyone's mouth is its own ecological field," Dean says.

As for malocclusion and jaw disorders, Corruccini noted that a "fringe" branch of evolutionary dentistry has emerged in which children do mouth exercises and wear devices that put stronger force on their growing jaws. Ungar admitted feeding beef jerky to his own children to boost chewing stresses on their developing jaws, but he says the jury is still out on those methods to reduce overbite. "An understanding of this discordance [between traditional and modern diets and lifestyles] can inform clinical research and, ultimately, dental and orthodontic practice," Ungar says.

For now, one thing is perfectly clear: Our teeth have not evolved a defense against sodas. "People should understand that evolution is not as fast as the cultural changes we're seeing," Cucina says. **–ANN GIBBONS**

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