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- NEWS OF THE WEEK

EVOLUTIONARY GENETICS

The Why Behind the Y Chromosome

Gretchen Vogel

The human Y chromosome may be best known as a champion testosterone booster, but its functional powers are puny compared to those of its partner, the X chromosome: It is only one-third the size of the X and has only 1/100th as many genes. Despite this mismatch, scientists have long suspected that the X and Y were once equals, but they gradually diverged over time. Now, on page 964, two researchers report evidence for how this split occurred.

In a kind of molecular-scale fossil dig, geneticists David Page of the Whitehead Institute for Biomedical Research at the Massachusetts Institute of Technology and Bruce Lahn, now at the University of Chicago, analyzed genetic "fragments of history"—genes still found on both chromosomes that have remained relatively unchanged for millennia. They used these genetic relics to piece together a rough history of how the chromosomes drifted apart. The distinctions between X and Y didn't happen gradually, they concluded, but in a stepwise fashion, implying that at least four distinct events—most likely rearrangements of the Y chromosome—drove the chromosomes apart over hundreds of millions of years.

"It's fascinating work," says geneticist Huntington Willard of Case Western Reserve University School of Medicine in Cleveland. "It gives us an intriguing glimpse" into the evolution of the human sex chromosomes. The work may also shed light on the evolution of the sex chromosomes of birds and insects, which developed independently of the mammalian system.

The mismatch between the X and Y chromosomes creates some unusual biology. During the specialized cell division that creates sperm and eggs, most chromosome pairs are able to line up and swap pieces, a process called recombination. Like two friends who keep in touch despite being separated by long distances, this occasional exchange keeps the pairs up to date with each other. It also creates beneficial combinations of genes that can spread throughout the population. But recombination won't work if the pairs are a poor match, and in humans, the X and Y chromosomes recombine only at their tips.

Although X and Y look very different, in recent years geneticists have turned up at least 19 genes that are present on both—all of them leftovers from the days when the chromosomes were kept similar by recombination. Lahn and Page scored each gene pair for sequence similarity, focusing on the number of "synonymous" gene differences between them—changes in DNA that don't change the protein's amino acid sequence. These mutations presumably are subject to little selective pressure and accumulate randomly. Thus, as more time elapses, more mutations should accrue. If so, the number of actual synonymous gene changes should offer a rough estimate of the length of time that the genes have been evolving independently, Page explains.

When the researchers looked at this value for different parts of the chromosomes, they were "stunned," says Page. He wasn't expecting a clear pattern, but in fact the values for genes on the X chromosome grouped into four "strata" neatly arrayed along the chromosome's length. The genes on the chromosome's long arm were most different from their Y counterparts, and as the scientists examined the opposite end of the chromosome, the genes became more and more similar to their Y doubles.

To explain this pattern, Lahn and Page propose that the Y chromosome was reshuffled four times, perhaps through a process called inversion, in which a piece of chromosome breaks off, flips over, and reattaches so the order of the genes in that stretch is inverted. Each inversion prevented a stretch of the Y from aligning and exchanging pieces with the matching piece on the X. After all four inversions, the X and Y can now recombine only at their tips.

To get a rough estimate of when these inversions occurred, the scientists used divergence times that are known from fossils and genetic evidence. For example, two gene pairs in the fourth "stratum" of the X chromosome are still able to recombine in prosimians but have diverged in both Old and New World monkeys, so Lahn and Page estimated that the most recent reshuffling happened between 30 million and 50 million years ago, after monkeys diverged from prosimians but before New and Old World monkeys split. In a similar way, they estimate that the third inversion happened between 80 million and 130 million years ago and the second between 130 million and 170 million years ago. But because only a few genes remain similar in the oldest "layer," estimating the age of the first rearrangement was tougher. So the scientists used the ages of the three youngest strata as a rudimentary clock and concluded that the oldest section of the chromosomes diverged between 240 million and 320 million years ago—shortly after birds and mammals are thought to have split from their common, reptile-like ancestor.

Such a scenario fits with the biology of animals today: Many reptiles lack specific sex chromosomes (depending instead on temperature differences during development to modulate individual sex-determining genes), and presumably the reptilian ancestor of birds and mammals lacked sex chromosomes, too. In birds, the avian sex chromosomes, W and Z, seem to be derived from the chromosome pair that is today number nine in humans.

Indeed, "everything seems to fit together," says evolutionary biologist Brian Charlesworth of the University of Edinburgh. The result is "really pleasing," agrees evolutionary biologist James Bull of the University of Texas, Austin, and offers a surprisingly clear evolutionary record. Says Bull: "This is the study that's going to go into the textbooks."