Insects that produce males from unfertilized eggs reveal a surprising cellular feat

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Scientists have long known that the social insects in the order Hymenoptera--which includes ants, bees, and wasps--have an unusual mechanism for sex determination: Unfertilized eggs develop into males, while fertilized eggs become females. But the development of an unfertilized egg into an adult (called parthenogenesis) remains a mysterious process.

One mystery has been the origin of the centrosome, an essential cellular component that is ordinarily derived from the sperm after fertilization. A new study led by researchers at the University of California, Santa Cruz, describes a remarkable process by which the egg cells of Hymenopteran insects make new centrosomes from scratch. The process involves enigmatic cellular structures called accessory nuclei, the function of which has not been explained since they were first discovered in the 1960s.

"Centrosomes arise from other centrosomes through duplication, but there is no centrosome in the egg that could give rise to new ones. We found that the accessory nuclei seed the formation of new centrosomes in unfertilized eggs," said Patrick Ferree, a graduate student in molecular, cell, and developmental biology at UCSC.

Ferree is first author of a paper describing the new findings in the April 18 issue of the journal Current Biology. Coauthor William Sullivan, professor of molecular, cell, and developmental biology at UCSC, said the findings have implications for understanding basic cell biology, the evolution of Hymenopteran insects, and centrosomal anomalies in cancer cells. The study also shows just how much remains to be discovered about the diversity of life at the cellular level, he said.

"You would think we'd have identified all the structures in the cell by now, but 90 percent of the material in cell biology textbooks comes from research on nine or ten organisms," Sullivan said. "Every time I look at a honeybee now, I think about these amazing structures they have, and it implies that among the millions of other species there must be cellular mechanisms we haven't even imagined."

Centrosomes help orchestrate cell division, building an apparatus of microtubules called the mitotic spindle, which pulls apart the duplicated chromosomes so that each of the two daughter cells gets a complete set of chromosomes. The centrosome contains about a hundred different proteins, including the main protein for making microtubules, called gamma tubulin.

The UCSC researchers studied the development of centrosomes in the eggs of two parasitic wasps (Nasonia vitripennis and Muscidifurax uniraptor). Using fluorescently labeled antibodies that recognize and bind to gamma tubulin and other centrosomal proteins, they demonstrated the presence of these proteins in accessory nuclei and showed that the accessory nuclei appear to give rise to centrosomes.

Accessory nuclei bud off from the membrane of the nucleus, the cellular structure that contains the chromosomes. By the time the egg is fully developed, it contains several hundred accessory nuclei that look much like the nucleus except that they don't contain chromosomes. Late in the development of the egg cell, the accessory nuclei disintegrate and centrosomes appear in the same locations in the cell.

"Right before the egg is laid, the membranes of the accessory nuclei break down, and at the same time the centrosomes begin to form," Ferree said.

One of the most striking aspects of this mechanism is the large number of accessory nuclei and centrosomes that form in the developing eggs of these Hymenopteran insects.

"You only need two centrosomes, and they make hundreds of them. So they go through a lot of work to make a male," Sullivan said. "A lot of energy goes into making these centrosomes, and if the egg gets fertilized they don't use them--the centrosome from the sperm is used preferentially."

Centrosomes remain somewhat mysterious structures, Ferree said, but researchers may be able to learn more about them by purifying accessory vesicles and studying their protein components.

Accessory nuclei have been observed in other species besides Hymenopteran insects, and they may have other functions in addition to making centrosomes, he said. They may also hold clues to the evolutionary origin of the Hymenoptera. Because the males of these insects develop from unfertilized eggs, they have half the number of chromosomes that females have--in technical terms, the males are haploid and the females are diploid.

This situation, known as haplodiploidy, results in interesting genetic relationships that are thought to underlie the complex social behavior of Hymenopteran insects. One of the key steps in the evolution of social insects, therefore, may have been the development of a mechanism for making centrosomes from scratch.

"The Hymenoptera were probably derived from a species that had accessory nuclei, and in the evolution of haplodiploidy the accessory nuclei were co-opted as a way of building centrosomes," Sullivan said.

In addition to Ferree and Sullivan, the other coauthors of the paper are Kent McDonald, a researcher in the Electron Microscope Laboratory at UC Berkeley, and Barbara Fasulo, a postdoctoral fellow in Sullivan's lab at UCSC. This research was supported by a grant from the National Science Foundation.

Source: UCSC

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