Evolutionary genetics

Duplication resolves conflict

A duplicated gene in *Drosophila melanogaster* showcases an example of how sexual antagonism can be resolved

Jennifer Perry

Sexual species face a two-body problem. Males and females usually achieve fitness in distinct ways, so there is selection for distinct phenotypes in each sex. Yet, apart from the sex chromosomes, the sexes share a genome, and so divergent phenotypes must be built using the same raw material. We can therefore expect powerful selection pulling genes in opposite directions, depending on the sex that they are expressed in. This evolutionary tension, known as intralocus conflict², is pervasive and might act as a widespread barrier to adaptation³. Yet sexually dimorphic traits represent some of the most spectacular phenotypes nature has to offer, suggesting that the tension has often been resolved. On page XX of this issue, VanKuren and Long⁴ reveal the molecular underpinnings of one such resolution. They demonstrate that a gene duplication in the fruit fly *Drosophila melanogaster* allows both sexes to move closer to their sex-specific optimum, thereby resolving part of the genetic battle of the sexes.

There are several ways through which males and females achieve different phenotypes despite a shared genome. Sex differences in transcription levels can resolve conflict over gene-expression level, or different exon splicing can resolve conflict over protein structure². Gene duplication is another potential solution. When a gene duplicates, the initial functional redundancy provided by two nearly identical paralogs can allow one or both to diverge in expression levels and protein structure. This specialization might allow each sex to move closer to its optimum phenotype^{5,6} (Fig. 1).

There is a wealth of evidence consistent with this duplication process. For example, genes with male-biased expression (especially those involved in male gametogenesis) are more likely to be duplicates than non-duplicates⁵; duplicated genes often acquire male-biased expression after duplication⁷; and male-specific duplicates evolve rapidly⁵. But most of these results come from genome-wide surveys, and it has been difficult to rule out other explanations. Duplicated paralogs might acquire male-biased expression more rapidly because rates of new mutations are higher in males⁸ or because male-biased expression is less likely to disrupt essential function⁹.

VanKuren and Long now complement these broad-scale patterns with an in-depth study of the tandem gene duplication *Apollo* and *Artemis*. They show that this duplication arose in *D. melanogaster* approximately 200,000 years ago and underwent a selective sweep around 50,000 years ago, suggesting adaptive divergence of the two paralogs.

Using genetic knockout studies, the authors show that *Apollo* and *Artemis* have mirrored effects on male and female fertility. *Apollo*-null males cannot sire offspring, and *Artemis*-null females cannot produce viable eggs. Microscopy experiments revealed why: *Apollo*-null males never make mature sperm because actin structure is disrupted during spermatid maturation, preventing sperm individualization, whereas *Artemis*-null females make mis-shapen eggs that can't be fertilized because actin networks that restrict oocyte girth are disrupted. The evolutionary scenario supported by these results is that the ancestral, pre-duplication gene affected cellular actin structure, that one type of actin structure works best for male gametes and another one works best for female gametes, and that duplication allowed sex-specific actin specialization.

Remarkably, VanKuren and Long found that expressing a copy of the mis-matched paralog is actually costly: *Apollo*-null females and *Artemis*-null males produce more offspring than wild-type controls that express both paralogs (each by over 15%). This suggests that divergence in each paralog has indeed moved each sex closer to its optimum, rather than a general refinement that benefits both sexes. Moreover, it supports the prediction that the resolution of one conflict through gene duplication can generate new conflict in each paralog⁵. If this pattern is general, then it might help explain why intralocus conflict persists over extended evolutionary time¹⁰.

A 15% reduction in offspring production seems extreme in terms of Darwinian fitness. So why do males and females express the costly, mis-matched paralog at all? One hypothesis is that fully optimized sex-specific expression is difficult to engineer, and so it might not have happened yet in this recent duplication. An alternative is that the reproductive costs are balanced by other benefits. For example, larvae that express *Apollo* have higher survival to adulthood in both sexes, which could more than make up for costs to fecundity. Or, as VanKuren and Long suggest, reproductive costs measured in the lab might not reflect realized fitness costs in a natural setting.

By quantifying the expression of this putative conflict-resolving locus across related drosophilids, VanKuren and Long uncover a fascinating pattern: *D. melanogaster* and three other *Drosophila* species with independent duplications at the same locus have evolved broadly convergent patterns of gene expression, with one paralog highly expressed in testis and the other in ovary. In contrast, three *Drosophila* species without a duplication at this locus express the single gene in both testis and ovary. This extraordinary finding suggests the convergent resolution of intralocus conflict at the same locus.

VanKuren and Long's clear links between sexually antagonism, sex-specific function and across-species patterns make a compelling case study, and lay the groundwork for future research. Does the developmental function of *Apollo* – influencing larval survival – constrain the full resolution of intralocus sexual conflict? How frequently do gene duplications resolve conflict as opposed to other mechanisms? How often does gene duplication and sex-specific specialization result in new conflict? Addressing these and other fascinating questions will continue to uncover how gene duplication can resolve the two-body problem.

Jennifer Perry
Department of Zoology
University of Oxford
jennifer.perry@zoo.ox.ac.uk

References

1. Chau, L.M. & Goodisman, M. A. D. *Evolution* (2017).
2. Bonduriansky, R. & Chenoweth, S.F. *Trends Ecol. Evol.* (2009).
3. Gardner, A. & Úbeda, F. *Nat. Ecol. Evol.* (2017).
4. VanKuren, N. W. & Long, M. *Nat. Ecol. Evol.* (2017).
5. Gallach M. & Betrán, E. *Trends Ecol. Evol.* (2011).
6. Connallon, T. & Clark, A. G. *Genetics* (2011).
7. Wyman, M. J., Cutter, A. D., & Rowe, L. *Evolution* (2012).
8. Wright, A.E. & Mank, J.E. *J. Evol. Biol.* (2013).
9. Mank, J. E. & Ellegren, H. *Biol. Lett.* (2009).
10. Griffin, R. M., Dean, R., Grace, J. L., Rydén, P. & Friberg, U. *Mol. Biol. Evol.* (2013).