Spermatogenesis 2:3, 127-128; July/August/September 2012; © 2012 Landes Bioscience

Overview
Special issue on Drosophila spermatogenesis

Julie A. Brill[1,2,†,*] and Mariana F. Wolfner[3,†,*]

[1]Cell Biology Program; The Hospital for Sick Children (SickKids); Toronto, ON Canada; [2]Department of Molecular Genetics; University of Toronto; Toronto, ON Canada; [3]Department of Molecular Biology and Genetics; Cornell University; Ithaca, NY USA

[†]These authors contributed equally to this work.

Keywords: Drosophila, spermatogenesis, review, cell morphology, cell cycle, stem cells, testes, evolution

Drosophila melanogaster sperm are nearly 50 times longer than human sperm.[1] Their nuclei are exceptionally compact and have a distinctive needle-like morphology.[2] They develop in syncytial cysts where they are interconnected via intercellular bridges along their whole length, rather than being linked at a single point near their nuclei.[3] Once transferred to the female, they are stored for ~2 weeks (i.e., for a whole generation time), rather than for days, as occurs in most mammals.[4] These superficial differences obscure the fundamental similarity of spermatogenesis across distant phyla. Indeed, cellular processes and regulatory mechanisms discovered in Drosophila have proved to be conserved in other organisms, including humans.

Studies of Drosophila spermatogenesis have revealed important concepts and genes for each aspect of sperm behavior and function, from testis development through sperm storage and competition. These studies have taken advantage of comprehensive collections of mutants[5,6] and RNAi-generating stocks;[6-8] methods to drive knockdown or ectopic expression specifically in the germline or in their supporting cells[9] or to create, within a testis, clones of cells of one genotype surrounded by cells of another (for example, see ref. 10); and markers for different cell types, stages and subcellular structures of spermatogenic cells (for example, see ref. 11). This special issue of *Spermatogenesis* reviews the latest findings from studies of Drosophila spermatogenesis, including cellular and molecular events that shape the testis and that drive male germ cells through a complex differentiation process to produce motile, fertile sperm.

Spermatogenesis proceeds in a gonad that is made of somatic cells, and to which primordial germ cells migrate. Interactions between the somatic gonad and the germ line are crucial for successful spermatogenesis. Many events in gonadogenesis, and some of the genes that underlie them, are conserved (see this issue's article by Whitworth et al.[12]). Moreover, in addition to contributing to our understanding of spermatogenesis, studies of Drosophila testis formation have illuminated aspects of sex determination, cell migration, cell determination, cell communication and cell-cell interaction.

The testis contains niches for both germline and somatic stem cells. Genetic analyses uniquely possible in Drosophila have shown that these niches function through signaling pathways that ensure maintenance of stem cells throughout adult life; the use of these pathways is conserved for stem cell niches in testes of other animals (see articles in this issue by Matunis and colleagues,[13] and by Zoller and Schulz[14]). Furthermore, cell signaling and cell-cell interactions in the niche and at later stages of gametogenesis serve as models for interactions that occur between different cell types in other tissues during development.

As with other cases of differentiation, spermatogenesis begins with a switch of gene expression program from that of a relatively undifferentiated state to one that results in formation of a specific cell type. In the case of spermatogenesis, the changes in gene expression promote the transition from a mitotic germline cell (the spermatogonium) to one that will form a functional gamete (see article in this issue by Lim et al.[15]). Some spermatogenesis genes are needed for meiosis and meiotic cytokinesis (for reviews of these processes, see this issue's articles by McKee and colleagues,[16] and by Giansanti and colleagues,[17] respectively). Others are required for formation of mature, motile sperm (described in this issue's article by Fabian and Brill[18]). Understanding this developmental program is relevant not only to spermatogenesis, but also gives insights into the process and regulation of cell cycle control and chromosome segregation (mitotic as well as meiotic), cell morphogenesis, chromatin condensation, organelle biogenesis and cell motility.

The resulting sperm contain a complex array of proteins (see article in this issue by Rettie and Dorus[19]). In addition to being of relevance to sperm form and function, identification and analysis of these proteins dissects the proteome of a single, pure cell type. Some sperm proteins are conserved across a wide range of species, indicating structures or functions integral to sperm in all organisms, whereas others are unique to Drosophila, providing a window into potential species-specific processes or functions.

After they are transferred to females, sperm are stored within the female reproductive tract (described in this issue's article by Schnakenberg et al.[20]). During this time, they must be maintained in an active form, and must be released to fertilize eggs. In addition to allowing extended fertility after even a single mating, sperm storage provides an opportunity for sperm competition[21]

*Correspondence to: Julie A. Brill and Mariana Wolfner; Email: julie.brill@sickkids.ca and mfw5@cornell.edu
Submitted: 08/08/12; Accepted: 08/09/12
DOI: http://dx.doi.org/10.4161/spmg.21797

and female sperm choice[22] in situations where females mate multiple times (as occurs in Drosophila). Sperm competition and female sperm choice, as well as cross-species isolating mechanisms, are forms of selection that may drive dynamic changes in the sequences, abundance, or presence of some reproductive proteins, including those in the sperm proteome.

Drosophila has become a preeminent model for studying all of these processes, in part because Drosophila sperm are in many ways typical and in part because of the powerful genetics, conserved genes and well-characterized stages of spermatogenesis available in the fly system (previously reviewed in refs. 1, 23–25). The reviews in this issue offer an updated snapshot of this exciting field of research. We hope they will be of value to newcomers and experts alike.

Acknowledgments

We are grateful to Yan Cheng for inviting us to compile and edit this special issue. We thank the authors of the articles for their thoughtful reviews; the reviewers for their prompt and helpful evaluations; and Laura Sirot, Lacramioara Fabian and John Ashkenas for their comments on this overview. For our support, we gratefully acknowledge funding from NIH grants R01-HD038921 (to M.F.W.) and R01-HD059060 (to M.F.W. and A.G. Clark) and CIHR grant MOP-102546 (to J.A.B).

References

1. Cooper KW. Normal spermatogenesis in Drosophila. In: Demerec M, ed. Biology of Drosophila. New York: Wiley, 1950:1-61.
2. Rathke C, Barckmann B, Burkhard S, Jayaramaiah-Raja S, Roote J, Renkawitz-Pohl R. Distinct functions of Mst77F and protamines in nuclear shaping and chromatin condensation during Drosophila spermiogenesis. Eur J Cell Biol 2010; 89:326-38; PMID:20138392; http://dx.doi.org/10.1016/j.ejcb.2009.09.001.
3. Tates AD. Cytodifferentiation during spermatogenesis in *Drosophila melanogaster*: An electron microscope study. Leiden: Rijksuniversiteit, 1971.
4. Wolfner MF. Precious essences: female secretions promote sperm storage in Drosophila. PLoS Biol 2011; 9:e1001191; PMID:22087072; http://dx.doi.org/10.1371/journal.pbio.1001191.
5. Wakimoto BT, Lindsley DL, Herrera C. Toward a comprehensive genetic analysis of male fertility in *Drosophila melanogaster*. Genetics 2004; 167:207-16; PMID:15166148; http://dx.doi.org/10.1534/genetics.167.1.207.
6. Bloomington Drosophila Stock Center. http://flystocks.bio.indiana.edu/
7. Dietzl G, Chen D, Schnorrer F, Su KC, Barinova Y, Fellner M, et al. A genome-wide transgenic RNAi library for conditional gene inactivation in Drosophila. Nature 2007; 448:151-6; PMID:17625558; http://dx.doi.org/10.1038/nature05954.
8. Ni JQ, Zhou R, Czech B, Liu LP, Holderbaum L, Yang-Zhou D, et al. A genome-scale shRNA resource for transgenic RNAi in Drosophila. Nat Methods 2011; 8:405-7; PMID:21460824; http://dx.doi.org/10.1038/nmeth.1592.
9. White-Cooper H. Tissue, cell type and stage-specific ectopic gene expression and RNAi induction in the Drosophila testis. Spermatogenesis 2012; 2:11-22; PMID:22553486; http://dx.doi.org/10.4161/spmg.19088.
10. Goldbach P, Wong R, Beise N, Sarpal R, Trimble WS, Brill JA. Stabilization of the actomyosin ring enables spermatocyte cytokinesis in Drosophila. Mol Biol Cell 2010; 21:1482-93; PMID:20237160; http://dx.doi.org/10.1091/mbc.E09-08-0714.
11. Sartain CV, Cui J, Meisel RP, Wolfner MF. The poly(A) polymerase GLD2 is required for spermatogenesis in *Drosophila melanogaster*. Development 2011; 138:1619-29; PMID:21427144; http://dx.doi.org/10.1242/dev.059618.
12. Whitworth C, Jiminez E, Van Doren M. Development of sexual dimorphism in the Drosophila testis. Spermatogenesis 2012. In Press.
13. Matunis EL, Stine RR, de Cuevas M. Recent advances in Drosophila male germline stem cell biology. Spermatogenesis 2012. In Press.
14. Zoller R, Schulz C. The Drosophila stem cell linage - partners behind the scene? Spermatogenesis 2012. In Press.
15. Lim C, Tarayrah L, Chen X. Transcriptional regulation during Drosophila spermatogenesis. Spermatogenesis 2012. In Press.
16. McKee BD, Yan R, Tsai J-H. Meiosis in male Drosophila. Spermatogenesis 2012. In Press.
17. Giansanti MG, Sechi S, Frappaolo A, Belloni G, Piergentili R. Cytokinesis in Drosophila male meiosis. Spermatogenesis 2012. In Press.
18. Fabian L, Brill JA. Drosophila spermiogenesis: Big things come from little packages. Spermatogenesis 2012. In Press.
19. Rettie EC, Dorus S. Drosophila sperm proteome evolution: Insights from comparative genomic approaches. Spermatogenesis 2012. In Press.
20. Schnakenberg SL, Siegal ML, Bloch Qazi MC. Oh the places they'll go: Female sperm storage and sperm precedence in *Drosophila melanogaster*. Spermatogenesis 2012. In Press.
21. Parker GA. Sperm competition and its evolutionary consequences in the insects. Biol Res 1970; 45:525-67; http://dx.doi.org/10.1111/j.1469-185X.1970.tb01176.x.
22. Eberhard WG. Female Control: Sexual Selection by Cryptic Female Choice. Princeton (New Jersey): Princeton University Press, 1996.
23. Lindsley D, Tokuyasu KT. Spermatogenesis. In: Ashburner M, Wright TR, eds. Genetics and Biology of Drosophila. New York: Academic Press, 1980:225-94.
24. Fuller MT. Spermatogenesis. Cold Spring Harbor, New York: Cold Spring Harbor Press, 1993.
25. Renkawitz-Pohl R, Hollmann M, Hempel L, Schafer M. Spermatogenesis. In: Gilbert LI, Iatrou K, Gill S, eds. Comprehensive Insect Physiology, Biochemistry, Pharmacology and Molecular Biology. Oxford: Elsevier Ltd., 2005:157-78.