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Production of Eggs and Sperm

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Synonyms

Eggs; Gamete dimorphism; Gametes; Intersexual selection; Intrasexual competition; Sexual reproduction; Sperm

Definition

Males and females produce gametes that are differentially specialized to facilitate the sexes in reproduction.

Introduction

The production of gametes is a biological process occurring in organisms that sexually reproduce. Females make gametes called eggs, and males make gametes called sperm. Both egg and sperm cells begin as identical germ cells and are produced through a process of cell division called meiosis, which reduces the number of chromosomes in the germ cell from 46 (diploid) to 23 (haploid). In human males, meiosis begins after birth, and, upon reaching puberty, men produce sperm continuously for the rest of their lives. In human females, meiosis begins before birth and the raw materials for egg cell production are formed while the female fetus is still within the uterus of her mother. Every female is born into the world with a limited number of egg cells in her reproductive system. These eggs are released one by one (occasionally two at a time) into the uterus at each monthly cycle of ovulation when and after she has reached puberty, and this cycle ceases when she has reached menopause. Fertilization occurs when a sperm cell successfully combines with an egg cell inside the female reproductive system, and this restores the gametes to a diploid with 46 chromosomes in the form of a zygote. The process of gestation then begins and will likely result in pregnancy as the zygote develops into a fetus.

The Evolution of Sex-Differentiated Gametes

To understand the significance and implications of sex-differentiated gametes, it is important to consider how sexual reproduction evolved. This chapter covers the selection pressures that likely led to sperm and egg cells as highly specialized gametes each with their own reproductive interests and how these differences between gametes lead to intrasexual competition and intersexual selection on the part of males and females, respectively.

From Asexual to Sexual Reproduction

Before there was sexual reproduction or sex, organisms reproduced via asexual reproduction, where all of a parent organism's genes are passed on to its offspring through a process of mitosis, or the division of the mother cell into two genetically identical daughter cells. In contrast, in sexual reproduction, two individual parent organisms are required and only half of each parent's genes are passed on to the next generation. A

major constraint of sexual reproduction is that individual organisms must find and coordinate copulation with a conspecific mate in order to reproduce. Despite this significant cost, sexual reproduction dominates among multicellular forms of life, indicating that the gains in fitness to offspring produced sexually have, over evolutionary history, outweighed the costs of sex, especially for more complex life forms. The process of meiosis – recombination of genes from two genetically different parents from the same species – thus underlies the benefits of sex (Maynard Smith 1978).

The recombination of genes through sex provides another avenue besides random mutations for evolutionary adaptations to develop by allowing offspring of each generation to have genetic information and thus, phenotypic traits, that are different from what either parent has. A species that generates greater phenotypic variation can evolve faster in response to selection pressures because with greater variation, more advantageous phenotypes are likely to surface (Zimmer 2009). For instance, when new environmental parasites attack a population of asexually reproducing organisms, the organisms are unlikely to quickly adapt new defenses against these novel parasites as asexually reproducing organisms in the population share the same defense systems that only work against familiar (pre-existing) parasites. On the other hand, the genetic variation of sexually reproducing organisms enables offspring – from genetic recombination – to vary more greatly in their parasitic defense systems, thereby reducing the likelihood that an entire population would be rapidly wiped out from a single novel parasitic attack (Hamilton et al. 1990). Environmental factors therefore serve as useful selection pressures that eventually allow only the fittest organisms (i.e., those that have the most adaptive combination of genes) to survive and reproduce. Further, sexually reproducing organisms tend to find mates with good genes attractive, leading to different recombinations that, on average, lead to better offspring fitness (Zimmer 2009). Sex therefore creates new gene combinations that can weed out bad genes and propagate good genes.

The Origins of Gamete Dimorphism, or Males and Females

Sexual reproduction occurs in two ways: either through isogamy, which refers to the fusion of gametes of similar shape and size, or anisogamy, which refers to the fusion of gametes that differ in shape and size. Among sexually reproducing organisms, isogamy is commonplace (but not universal) in unicellular organisms. As the gametes contributed by isogamous parents are similar, they cannot be differentiated as male or female. In contrast, anisogamy prevails exclusively in multicellular animals and plants (Zimmer 2009), and the smaller gamete is considered to be male while the larger gamete is considered to be female. In humans, an egg cell is 85,000 times larger than a sperm cell, and sperm are also produced in much larger quantities than eggs.

Ghiselin (1974) argued from an economic specialization standpoint that anisogamy could have originated from a physiological division of labor, whereby some gametes began specializing in nutritional and material resource provision, thus becoming larger, while other gametes specialized in motility, therefore maintaining a small size and growing tails for propulsion. Parker et al. (1972) also proposed that anisogamy evolved via individual-level selection and competition. Males that produce more (but smaller) gametes stand to gain a larger proportion of fertilizations because they produce a larger number of mobile gametes that can “seek out” the larger gametes. However, because zygotes formed from larger gametes have better survival prospects, this process can lead to the divergence and specialization of gamete sizes into large and small (female and male) gametes. The end result is one where numerous small gametes compete for access to large but scarce gametes that are tasked with providing maximal nutritional and material resources for the offspring (Parker et al. 1972). Males therefore tend toward achieving “quantity,” while females tend toward achieving “quality” in a bid to increase reproductive success.

Intrasexual and Intersexual Selection Drives Production of Large Numbers of Tiny Sperm to Compete for Access to Valuable Female Gametes

In humans as well as many other anisogamic species, sperm are much cheaper than eggs. Men replenish their sperm at roughly 12 million per hour, while women only have a finite lifetime supply of approximately 400 eggs. This sex difference in the value of gametes is fundamental to psychological, behavioral, and physiological differences between males and females. Trivers' (1972) theory of parental investment described how the sex with more resources (usually females) evolve to be more discriminant about having sex while the other sex (usually males) evolve to compete for access to the higher-investing sex. As there is an abundance of sperm, the selection pressure shifts for an egg producer to be prudent in choice as it is unlikely that her eggs will fail to find eager sperm. Conversely, the selection pressure shifts for a sperm producer to ensure that the sperm can reach the egg before it is fertilized by numerous other rival sperm. Evolution thus favors selectivity in females to ensure that their limited eggs get fertilized by the best sperm and greater sperm quantity production in males to increase their chances of winning during sperm competition.

In humans, men evolved to be more sexually persistent and have a stronger desire for sexual variety compared to women and to favor a short-term mating strategy in order to increase their access to more sexual partners. These adaptations serve to increase the chances that their sperm can fertilize as many eggs as possible. Women, on the other hand, evolved to be more sexually restricted than men and to prefer a selective, long-term mating strategy (e.g., Li and Kenrick 2006) in order to procure the qualities of one or a very limited few desirable mates (for their good genes, resources, etc.), since being wasteful with their limited eggs would be detrimental to reproductive success (Goetz and Shackelford 2009). Females are also attracted to the victors of intrasexual contests, and thus men may have also evolved to be more aggressive and stronger than women in order to compete intrasexually with mating rivals (Buss and Duntley 2006).

Sperm competition is another form of intrasexual competition by males and intersexual selection by females for the best genes to be passed on to the offspring (Goetz and Shackelford 2009). As sperm quality and offspring quality may be correlated, a female's reproductive fitness can be increased when more sperm competition is encouraged. Sperm quality (which pertains to how healthy and mobile the sperm are) and sperm quantity (which differs among males) both serve to signal the fertility of a male and the eventual differences in probability of successful conception. Indeed, in some species, females may mate with multiple males so that the sperm of these males can compete and only the best sperm will achieve successful fertilization of their eggs (Baker and Bellis 1995). Several studies have found that large testes size, hence greater sperm production capacity, is a feature of species that exhibit multi-male mating systems (Shackelford and Goetz 2006). Male reproductive fitness increases linearly with increasing mating encounters (with different females), whereas female fitness increases less rapidly with multiple matings (Trivers 1972; Goetz and Shackelford 2009). These circumstances create evolutionary pressures for males to produce the most and best-quality sperm within their own metabolic constraints to increase the odds that their sperm can fertilize the egg over rival sperm, while scarce and valuable eggs incentivize females to entice sperm competition so that they can be selective of mates with better quality sperm.

Among humans, women sometimes engage in multiple matings to generate sperm competition at some point in their lives, and women are also most likely to multi-mate when the chances of conception are high, indicating that women may (either consciously or unconsciously) schedule their copulation activities to allow the most competitive sperm to fertilize her egg (e.g., Baker and Bellis 1995). Women in contemporary human populations may therefore mate in a polygamous manner to differing extents across cultures, potentially generating sperm competition in their reproductive tracts (Shackelford and Goetz 2006). Even in purportedly monogamous, committed, and long-term mating contexts, as the proportion of time a couple spends together since their last copulation decreases, the probability that the man's partner has been

inseminated by another man also increases. Correspondingly, the longer a couple spends time apart, the greater the volume of sperm the man ejaculates at the couple's next copulation (Baker and Bellis 1995). Therefore, the pressures of sperm competition can further drive the dimorphism of gametes that were initially differentiated through the benefits of specialization.

Conclusion

The reproductive benefits of genetic variation gave rise to the evolution of sexual reproduction, where parents each share half of their genetic material to produce genetically different offspring through meiosis and fertilization of gametes. This process tends to eliminate bad genes and propagate good genes, thereby producing fitter offspring. Further benefits of gamete specialization drive the dimorphism of gametes such that males produce tiny and mobile sperm that specialize in seeking out eggs that specialize in carrying vital nutrients and resources. As eggs are more valuable than sperm, the reproductive success of a female hinges on the quality of the sperm that fertilizes her egg, while the reproductive success of a male depends on the quantity of sperm he can produce, which increases the likelihood that his sperm wins over rival sperm in fertilizing the egg. Reproductive success for anisogamous life forms therefore benefits from sperm competition (i.e., intrasexual competition between the quantity and quality of rival males' sperm and intersexual selection by females of the best sperm among rival males). Taken together, these factors drive the evolution of gametes such that males produce larger quantities of small sperm relative to the large and scarce eggs of females.

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