Sperm Production - **Meredith Small**

Peek into Mother Nature's backyard during mating season and you're likely to see combat. The crack of antlers rings through the forest as two male deer lock heads in battle; the beach shakes from the slam-dance of male elephant seals; male monkeys face off and flash their huge canines. Long before Darwin, naturalists knew-that males compete to gain mates. But only recently have researchers leaned that these confrontations are just the most visible part of the story. After a victorious male has claimed the female in question, he still hasn't won. Apparently the more crucial battles occur offstage, inside philandering female partners, where hordes of sperm from different males must compete for the same prize all over again.

Conception, once thought a dance of simple beauty between one female's fertile egg and a solo male's hopeful sperm, is now seen as a do-or-die cellular brawl that determines which males will pass on their genes to the next generation. All other forms of male rivalry-from the youngsters' first bickering over scraps of food to the adults' fierce struggles for dominance —lead up to these sperm-size moments of truth. As evolutionary biologist Robert Trivers says, "In one sense all male-male competition is just so much sperm competition." Biologists find the new "sperm wars" view exciting because a lot of odd facts are falling into place. It means that many characteristics that we think of as "male" across a wide range of species—the distinctive body with a projecting penis; the willingness to spend staggering amounts of energy on a thousand-and one courting, mating, and cuckolding strategies; perhaps even a tendency to struggle aggressively for territory and status—may have evolved as so many weapons to aid a male's tiny sperm. The concept of competitive sperm may thus explain the basic source of maleness itself and serve as a unifying theme for male evolution. Much of that story is still unknown, but now the outlines, at least, can be drawn.

At first glance any male's sperm seems as good as another's. Yet a growing body of research points instead to a wider range of fitness than was once believed. From studies in human infertility, for example, we know that some men's sperm are notably better swimmers and can fertilize eggs far more easily than others. Breeding experiments with domestic animals and field studies on wild animals confirm this striking inequality among males. Certain males consistently father more offspring than others, and these males are not necessarily the biggest, strongest, or highest-ranking. They just have super sperm. Even among sperm, though, brute strength may not be all that matters. British biologists Robin Baker and Mark Bellis of the University of Manchester believe they've found evidence that some sperm sacrifice themselves on a kamikaze mission to further the success of their brothers. That proposal is intriguing because it suggests sperm don't always behave like an unruly mob of me-firsters rushing headlong to fertilize the egg. Just as ants and bees have highly evolved societies in which specialists perform different duties, the sperm of some species may have highly evolved strategies to beat the competition through teamwork.

The kamikaze theory began to gel in 1988, when Baker and Bellis noticed an odd feature of the vaginal plugs left behind by male rats after copulation. These plugs, made from male seminal secretions, are found in species as far ranging as fruit flies, snakes, mice, bats, marsupials, and monkeys. Researchers believed these temporary corks prevented leakage, and presumably they gave the male who mated first an advantage, because the next male would find it more difficult to make his deposit. What made the rat plugs more interesting than a simple blockage, however, was that they were full of hundreds of dead sperm—misshapen and meshed together like a spider web.

Males of all animal species have a high percentage of "abnormal" sperm, inadequate for conception. Some have two heads, others two tails, and a certain group swim in dizzy circles and never head in the right direction. In fact, "egg-getters," Baker and Bellis's term for the so-called normal sperm, may be the least common type, and useless sperm the most numerous. Could the defective sperm actually be serving some purpose? Could they be the real workhorses, and egg-getters the exceptional ones designed for the cushiest part of the job? ***Casualties in the sperm wars are staggering. In humans as many as 300 Million sperm begin a journey toward the egg; only about 200 reach its surface.***

Until Baker and Bellis proposed their idea, most biologists believed that bad sperm were just one of nature's little mistakes: rejects should be expected, the argument went, given the body's assembly-line production methods. The human male's body, for example, tosses off 300 million sperm a day, using remarkably little energy to do so. The production of these tiny germ cells, or gametes, is child's play compared with, say, the 200 billion red blood cells produced every day in the bone marrow. And clearly, no matter how sloppy the workmanship, there are more than enough fertile gametes to do the job. The average human male produces 8 trillion sperm over his lifetime, yet fathers just a few children. In contrast to this theory of lax quality control, Baker and Bellis suggest that the abnormal cells are important. They contribute to conception in two ways. First, says Baker, "like wire in rein-forced concrete, abnormal sperm put their misshapen heads together and entwine their deformed tails to form a barrier that keeps out sperm from other males." These kamikaze sperm presumably form *plugs both at the outside entrance of the female reproductive tract and on the inside, at important junctions such as the openings of the fallopian tubes. Although Baker and & Bellis haven't verified internal sperm blocks, such roadblocks might prove the most formidable. Any male might remove the vaginal plug of another male through penetration, but breaking through interior blocks would be a challenge to sperm alone-possibly a job for other specialist brigades. "The other way bad sperm can help is through search-and-destroy," Baker speculates. "Sperm not capable of fertilization might be able to kill foreign sperm with enzymes." Each sperm head carries a packet of enzymes used for penetrating the egg. These same enzymes could be directed at foreign gametes to deactivate them. Baker and Bellis have yet to show direct proof of one-on-one chemical warfare (they are currently watching rat sperm from different males in test tubes), but the thrust of their argument is clear and provocative. They, and many other animal biologists, now believe that sperm are more than simple cells designed for conception; sperm are tactically smart. Others remain doubtful of the kamikaze theory, and a convincing confirmation may be years away. Research is hampered by an age-old problem in reproductive physiology: we do not always know what makes sperm "good." Beyond obvious differences in count, appearance, and movement, researchers are not sure why the sperm from one male succeeds, while the sperm from another fails.*

The problem has been studied most intensely, of course, among humans. A typical workup for a couple who cannot conceive always includes semen evaluations. Doctors look for a sperm count of at least 20 million per milliliter of semen, but they are more interested in sperm motility—the speed and swimming direction of individual sperm—because a few fast swimmers are more likely to succeed than millions of sluggards. Reproductive physiologists believe that at least 40 percent of the sperm viewed under the microscope must be vigorous, well-aimed swimmers for a couple to have a good chance at conception.

But infertility specialists are still baffled by many things that happen once sperm reach the egg. What determines the penetrating ability of any particular sperm? Are the sperm of some men just naturally better at fertilization than the sperm of others? The first attempt to explain how sperm do their work came from the great Dutch microscopist Antonie van Leeuwenhoek. ***During the final moment of ejaculation, when catapulted forward at speeds up to 200 inches per second, sperm undergo intense shearing forces that could rip them apart****. In 1677 he observed sperm cells swimming about in semen. He assumed that each of these cells was an animalcule, or in the case of humans, a homunculus—that is, a miniaturized, self-contained version of the male himself. His discovery of the male germ cell caused a sensation, and the homunculus theory held sway well into the next century. Today we know that sperm carry single versions of the male's chromosome pairs, a set of DNA to mix and match with the female's contribution. The sperm head, full of genes, is supported by a midsection with an energy-producing engine and propelled by a whip-snapping tail.*

All day long, sperm-producing cells in the testes undergo cell division. The testes are in constant production, regardless of the intensity of a male's sex life; in humans it takes 74 days for newly created sperm to wind their way through tubes in the testes and scrotum and reach a waiting area around the prostate gland. Depending on the species of animal, each ejaculation releases millions or sometimes billions of sperm, buffeted by secretions from several glands; these fluids protect and nourish the sperm and provide a liquid medium for their long journey. In humans, for example, as many as 300 million sperm roller-coaster some 20 inches through the vas deferens and urethra before landing at the female cervix. To survive this ride, sperm have to be tough. During the fina1 moment of ejaculation, when catapulted forward at speeds up to 200 inches per second, sperm undergo intense shearing forces that could rip them apart. Biophysicist Richard Cone and colleagues at Johns Hopkins recently explored how the seemingly fragile sperm can be fired intact through a tiny tube. The sperm's toughness, they found, comes from nine dense fibers at the base of the tail. These fibers vary greatly from one species to another, and their purpose had long puzzled physiologists. Cone and colleagues, examining the sperm of sea urchins and seven mammal species, found the unifying thread: in all the species, the fibers come together to form a tough outer jacket around the tail; the longer and more vulnerable the tail, the thicker these protective fibers.

In humans and other primates, at least, the sperm's troubles are far from over after ejaculation. Once sperm land at the cervix, they face the challenge of female cervical mucus. Most of the time the mucus is a dense curtain that keeps sperm from moving any farther. Under the influence of estrogen during ovulation, however, the mucus changes. It thins out and breaks up; the strands form a pattern like the fronds of a Boston fern. Sperm are then able to navigate through the open sections, and within ten minutes of landing at the cervix many thousands speed toward the fallopian tubes at the far end of the uterus, where the egg lies in wait after drifting down from the ovaries.

When sperm get inside the uterus, the female body takes an active role in helping them. A bath of glucose gives the sperm a new burst of energy. Other substances in the uterus wipe a layer of proteins off sperm heads. This process, called capacitation, prepares them to fire their penetrating enzymes.

Why do males need to produce millions of sperm and release them with such intensity? The problems of sperm—and thus of males—are, of course, the fault of females. *The race comes to an end when the sperm find an egg at the base of the fallopian tubes. Once so wary of attaching to tissue walls, the sperm must now shed their nonstick strategy. The female does all she can to encourage them; the egg sends alluring chemical cues. In humans 200 sperm typically make it to the egg; when they arrive they spit out enzymes designed to break down the egg's outer layer. Eventually one sperm bores in, is encompassed by the egg, and achieves conception. The shell of the egg then releases its own enzymes that detach the other sperm, and the egg slams shut to all further intruders.*

The tense maneuvers between well-armed sperm and fortified egg echo back to the first moments when sexual reproduction evolved. It began, biologists speculate, when only single-celled organisms existed. At first they reproduced by cloning; they simply doubled their genes and split into daughter cells. Then exploitation reared its ugly head in the primordial soup. Some small, highly mobile cells broke into larger, more passive cells and captured their nucleus. The small cells used the larger cells for nourishment, but they paid for the service by locking their DNA with the DNA of the victim. The newly formed organism was the product of two parents rather than one, and it contained a variable combination of genes. Through millions of years, smaller, faster gametes, ones we typically associate with maleness, have continued to join larger, more stable gametes, which we consider female. But if reproduction is a cooperative venture for eggs and sperm, why do males need to produce millions of gametes and release them with such intensity? The problems of sperm—and thus of males—are, of course, the fault of females.

Although the sperm are active pursuers and the egg is a relatively passive spectator, the owner of the egg is anything but passive when it comes to mating. In spite of notions of female fidelity and coyness, new research in animal behavior describes females of all species, from insects to mammals, actively pursuing multiple mates. Even females that pair off with males in species once thought monogamous are not particularly faithful. Females that don't pair off but live in large social groups, as some monkeys do, typically sneak off and mate with males outside their own troop.

The advantages to a female are many. She might include the best potential father in her bevy of partners, and her multiple mates could provide extra food and protection. But female fickleness sets up a quandary for males. They might triumph in external battles only to deposit their sperm right alongside the deposits of rivals left hours or days before. Competition then continues inside the female, and the race goes to the best timed, best aimed, liveliest, and most numerous gametes.

Thus more is better for sperm. In fact, the higher the rate of female philandering, the higher the incentive should be for males to produce more sperm. This is starkly illustrated by recent studies of sperm counts among primates.

There are about 200 species of primates, from the tiny Malagasy lemurs to the big African gorillas. They live in various types of mating systems from the relatively monogamous gibbons to the highly promiscuous baboons. If males compete at the level of sperm, one should find the highest sperm counts in species where many males have simultaneous access to females, and this is true. The size of a primate's testicles—a measure of the number of sperm a male can produce—correlates with how many males copulate with each female. Gorillas, who live in small harems with one adult male as the ruler, have embarrassingly small testes and p___ sperm numbers of about 65 million per ejaculate, while male macaques, who live in large groups with intense breeding competition, have relatively large testicles and ejaculate sperm by the billions. Humans also fit into this scheme. Compared with other primates, human males have some of the lowest-quality semen. Counts are down, averaging just 200 million per ejaculate, and motility is slow. Some anthropologists argue that the "bad" sperm of human males might be an evolutionary bequest from proto-humans who were largely monogamous. It's not surprising that sperm counts can vary as species evolve, but this past year Baker and Bellis demonstrated for the first time that individual males can also vary their sperm counts—and quickly. It happens when a male's mating situation changes. In their experiment the two researchers housed some female rats near the one and only male they mated with; other females were housed near one male but mated with another. It turned out that male rats that had no familiarity with their new mate ejaculated an average of 51.6 million sperm, as opposed to only 29.7 million for males who knew that their partners were not mating with any other rat.

More startling are Baker and Bellis's data on humans. Here too there seems to be a relationship between presumed female fidelity and male ejaculates. They recruited ten couples with an average sex life and asked the men to use condoms during intercourse or masturbation. The couples also kept track of their time together—how much of the day they spent in each other's company. Baker and Bellis discovered that sperm counts for ejaculations during intercourse decreased the more time couples spent together, by percentages comparable to those for rats. For ejaculates during masturbation, however, the only thing that mattered was the amount of time since the last ejaculation—the longer the time interval, the more sperm.

In other words, faced with females who are out of sight and possibly mating with unknown *partners, males perceive sperm competition and release more gametes. But when a female partner is consistently close at hand, males reserve their sperm supplies. No one has suggested a physiological mechanism, conscious or unconscious, to account for this ability. But the surprising message in both the human and rat studies is that males can actually alter their sperm counts in response to the immediate social situation.*

Sperm competition explains why males produce so many gametes, but its powers reach even further—it is a fundamental explanation for maleness itself. We tend to think of males as individuals who produce sperm and are equipped with a penis, but not all males have a penis. Most birds, for example, accomplish insemination without the aid of a projecting appendage. Biologists believe that the penis evolved because some species were under intense sperm competition. Natural selection favored males able to deliver sperm high in the female reproductive anatomy. This method of direct deposit helped the males fertilize more eggs more efficiently than less-endowed males. Several insect species have pushed the penile strategy to extremes, inventing strange variants that act as special weapons in the sperm wars. The males had to go to extremes because some female insects store sperm for several months. One male after another deposits sperm sacs deep into the female storage area, the spermatheca. Over the ensuing months, before the female eggs are ready to be fertilized, the male who can wipe out all traces of his rivals' sperm wins the competition. The result is a startling array of believe-it-or-not accessories. The damselfly penis, for example, ends on two hornlike appendages with spoon-shaped flaps on each section. These scoops act as a snowplow to shove aside sperm from a previous mating. One species of dragonfly uses the sponge like end of its penis to soak up and remove others' sperm, literally wiping out the competition. The penis was not the last word in sperm war escalations. If appendages could be grown to push rival sperm around, why not grow them to push around the rivals themselves? And why not enlist glands and hormones to help whip up the impulse to fight? Large antlers, big canines, and ferocious behavior are all useful adjuncts to the sperm wars, but only during the preliminary skirmishes. Once copulation occurs, males must still entrust their heritage to their hardy, foot soldiers, and the sperm. Since we humans are a product of this same evolution, the new studies have relevance to our own reproductive urges. In fact, we know enough already to suspect there's a deeper biological truth in the maxim that absence makes the heart grow fonder. It also makes the sperm count go higher.