When sex makes you sick

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Sex and parasites are two of the most important forces in evolution, shaping everything from the appearance of organisms (sex, by favoring the evolution of ornaments and weapons) to their physiological functioning (parasites, via selection for host defenses). They have been studied both separately and together, with parasite–sex interactions similarly featuring in a wide range of areas in biology. Sexually transmitted infections (STIs) are, of course, an obvious link between the two, but until now, little attention has been paid to the ways that both host and parasite can coevolve under this circumstance, and thus influence both parasite virulence and host mating strategies. In a set of models that incorporate the degree of mate choosiness as well as virulence under different host life history states, Ashby and Boots (1) demonstrate how feedback between host and parasite can result in a variety of outcomes for each party, from stable levels of virulence and choice, to cycling between high and low levels of each, to increasing virulence, or to extinction. Their model also reveals the circumstances under which transmission avoidance behavior, in the form of choosiness for uninfected mates, is favored, and shows that such behavior is not universally favored by selection.

The relationship between sex and parasites can take numerous forms, and it is useful to distinguish among them. First, parasites have been implicated as a source of selection for genetic diversity in models of the evolution of sexual reproduction, with the advantage of generating new combinations of alleles offsetting the cost of producing males (2, 3). Under these scenarios, parasites with short life spans relative to the life spans of their hosts will be more likely to favor rapid cycling of host and pathogen genotypes. Several studies have found support for the predictions arising from this idea, with sexually reproducing populations persisting longer than asexual ones under pressure from parasites (4). Second, because finding a mate with genes resistant to prevalent infections is always favored, regardless of the specific nature of the genes conferring such resistance, females have been suggested to favor indicators of disease resistance when choosing a mate, resulting in the evolution of elaborate ornaments that can only be produced by these resistant males (5, 6). This kind of mate choice can solve the "lek paradox" of loss of heritable genetic variation in fitness over continued selection because the genes in both host and parasite can cycle despite female preference for the same exaggerated trait. Chronic parasites, such as helminths, rather than "kill-or-recover" infections, work best to favor such interactions. Note that such mate preferences for resistant mates are distinct from those mate preferences in Ashby and Boots' model (1), in which individuals use mate choice to avoid becoming infected themselves. Third, selection for appropriate host defenses in the context of life history evolution can lead to sex differences in disease susceptibility and longevity (7, 8). Among vertebrates, including humans, females are often more resistant to infections and also live longer, traits that may be the result of differential selection on the sexes (7, 8). Last, some infections are primarily transmitted during sexual activity, the topic of Ashby and Boots' paper (1).

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What Makes Sexually-Transmitted Diseases Special?

STIs are noteworthy, and distinct from what are sometimes called "ordinary infectious diseases" (OIDs), for several reasons (9). Although OIDs can be transmitted during sexual contact, STIs require it, which means that STIs are more likely to be highly host-specific, setting the stage for the kind of tight coevolution in Ashby and Boots' model (1). In addition, STIs, by definition, are mainly transmitted between adults, influencing the rate of transmission and the life history stage when defense against infection is most important. A disease that spreads to both young and old can fluctuate wildly in the numbers of infected individuals in the population at any one time, with resulting epidemics that sweep through an entire population, leaving only resistant individuals behind. The disease may then disappear, only to recur if infected visitors enter the population. In contrast, STIs can maintain more stable reservoirs with fewer large oscillations. This adult-to-adult transmission also means that STIs, unlike OIDs, give no opportunity for younger individuals, with their more malleable immune systems, to contract the disease and develop immunity after experiencing relatively milder symptoms, as is the case for most so-called "childhood diseases"; instead, STIs encounter adult bodies with full-blown virulence. They are rarely immediately lethal, because they require their host to be sexually active, which also means that a range of virulences can be effective at maintaining the pathogen. At the same time, however, STIs in nonhumans are little studied, with most information available for domesticated animals.

Much work has been devoted to the ways that virulence of STIs can evolve to facilitate transmission; for example, syphilis may have become more benign, with fewer obvious symptoms, just a few centuries after its introduction to Europe. Knell (10) suggests that selection favored syphilis-infected hosts who were able to continue having sex, and transmitting the disease, something made easier if they were not covered in "Boils that stood out like Acorns, from whence issued… filthy stinking Matter," as was reportedly the case in the 16th century. The syphilis bacterium may therefore have decreased in virulence as a response to selection for less apparent carriers. Numerous studies have also explored whether secondary sexual characters are honest indicators of resistance, with mixed results (6). The first type of effort focuses on the parasite, and the second focuses on the host. Ashby and Boots (1) examine both simultaneously, by tracing the effects of transmission avoidance in mate choice on both the host's choosiness and the virulence

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of the pathogen. Their model untangles a web of connections between choosiness, virulence, transmission rates, and disease prevalence.

Longevity and the Price of Unsafe Sex

It is obvious that avoiding becoming infected during sex is beneficial, but at what cost? Mate choice can be costly in terms of time spent searching, the cognitive or other nervous system ability to discriminate among potential partners, or the risk of predation while traveling between mates (11). Previously, the costs of mate choice have been invoked in so-called "good genes" sexual selection, in which females prefer mates that bear genes conferring higher viability to their offspring, in contrast to a more arbitrary process in which male ornaments can become exaggerated simply through their correlation with the preference for them (11, 12). Arbitrary preferences can be maintained so long as the costs of choice are minimal, but when being choosy carries a price, indirect genetic benefits become more important. Ashby and Boots (1) take this notion a step farther, showing that when being choosy is costly, avoiding infected mates becomes prohibitively difficult, thus allowing the parasite to increase its virulence.

The connection between host life span and the outcome of host–parasite interactions noted by Ashby and Boots (1) is particularly interesting. Cycling of host choosiness with parasite virulence is unlikely for short-lived hosts, and those hosts with "intermediate" life spans are most likely to be choosy, with benign parasites. Obviously, the model specifies the parameters for long vs. short life; however, in reality, organisms, whether host or pathogen, cannot assess their own life span in either an absolute or relative sense. Compared with a mayfly, a bumblebee is extraordinarily long-lived, but both have a far shorter life span than a sturgeon. Disease may be relatively rarer for the mayfly than the other two species, as Ashby and Boots suggest (1), but from the mayfly's perspective, the distinction is undetectable. How do the relationships uncovered in Ashby and Boots' models (1) resolve themselves in nature? Related to this issue is the question of the evolution of the immune system itself; some authors have suggested that insects and other invertebrates lack an adaptive immune system because their shorter life spans have meant that elaborate defenses against disease are not necessary (13). Again, however, longevity is in the eye of the beholder, and the notion that insects are less likely to become infected is questionable, given the panoply of diseases that specialize on invertebrates. The take-home message is that the role of demographic variables, including longevity, in the relationship between parasites and host mate choice remains open to exploration.

Indeed, more research on STIs in a variety of organisms, including plants, is sorely needed. Such research could be used to test some of Ashby and Boots' predictions (1), including the relationship between transmission avoidance and virulence, but, more broadly, it could lead to seeing how STIs and their influence on mate choice could, in turn, affect other biological systems. For example, Ashby and Boots (1) assume serial monogamy for simplicity's sake, but how might avoiding infected partners lead to alterations in the mating system itself? When would selection for choosiness lead to the evolution of effective indicators of fitness, and when would it favor cheating? What about the operational sex ratio; does a decreased availability of one sex favor changes in virulence? Also, from the perspective of the hapless individual that ends up mating with an infected partner, can any measures counteract or ameliorate the risk of infection? Self-medication has now been described in a wide range of species, as have postcopulatory behaviors that may serve to rid a recently mated individual of parasites (14, 15). Perhaps some of these characteristics can help make sex less of a risky business.

1 Ashby B, Boots M (2015) Coevolution of parasite virulence and host mating strategies. *Proc Natl Acad Sci USA*, 10.1073/pnas.1508397112.

2 Howard RS, Lively CM (2003) Opposites attract? Mate choice for parasite evasion and the evolutionary stability of sex. *J Evol Biol* 16(4):681–689.

3 Ashby B, King KC (2015) Diversity and the maintenance of sex by parasites. *J Evol Biol* 28(3):511–520.

4 Lively CM (2010) A review of Red Queen models for the persistence of obligate sexual reproduction. *J Hered* 101(Suppl 1):S13–S20.

5 Hamilton WD, Zuk M (1982) Heritable true fitness and bright birds: A role for parasites? *Science* 218(4570):384–387.

6 Balenger SL, Zuk M (2014) Testing the Hamilton-Zuk hypothesis: Past, present, and future. *Integr Comp Biol* 54(4):601–613.

7 Zuk M, McKean KA (1996) Sex differences in parasite infections: Patterns and processes. *Int J Parasitol* 26(10):1009–1023.

8 Restif O, Amos W (2010) The evolution of sex-specific immune defences. *Proc Biol Sci* 277(1691):2247–2255.

9 Lockhart AB, Thrall PH, Antonovics J (1996) Sexually transmitted diseases in animals: Ecological and evolutionary implications. *Biol Rev Camb Philos Soc* 71(3):415–471.

10 Knell RJ (2004) Syphilis in renaissance Europe: Rapid evolution of an introduced sexually transmitted disease? *Proc Biol Sci* 271(Suppl 4):S174–S176.

11 Pomiankowski A (1987) The costs of choice in sexual selection. *J Theor Biol* 128(2):195–218.

12 Andersson M (1984) *Sexual Selection* (Princeton Univ Press, Princeton).

13 Vinkler M, Albrecht T (2011) Phylogeny, longevity and evolution of adaptive immunity. *Folia Zool Brno* 60(3):277–282.

14 Shurkin J (2014) News feature: Animals that self-medicate. *Proc Natl Acad Sci USA* 111(49):17339–17341.

15 Zuk M (2007) *Riddled with Life: Friendly Worms, Ladybug Sex and the Parasites That Make Us Who We Are* (Harcourt, New York).