Policy Forum

Evolutionary biology in the medical curriculum—what every physician should know

by Randolph M. Nesse and George C. Williams

The study of evolution, traditionally of purely intellectual interest, has recently found practical applications in a diversity of fields, including conservation, agricultural pest management, cognitive psychology, and medicine. We have argued (Nesse and Williams 1995, Williams and Nesse 1991) that there is no branch of medicine that cannot benefit substantially from an evolutionary approach in its research and, sometimes, its current clinical practice. Infection is increasingly recognized as an all-out arms race between hosts and fast-evolving pathogens whose virulence is adjusted up or down by natural selection (Ewald 1993b, Frank 1996). Defenses, such as fever, cough, pain, fatigue, and anxiety, are readily recognizable as sophisticated, carefully regulated adaptations that are expressed when needed but, unfortunately, are also subject to manipulation by pathogen adaptations (Ewald 1993a, Goodenough 1991).

Many serious modern diseases, such as breast cancer and atherosclerosis, result from a mismatch between evolved adaptation and current lifestyles or environmental factors (Eaton et al. 1988). Others arise from normally adaptive tradeoffs or from maladaptive phylogenetic constraints.

An evolutionary view thus reveals the body to be nothing like a Platonic ideal; the body is, instead, a bundle of historical constraints and of compromises between benefits and costs. The genes that cause senescence are prime examples: Some genes may persist because they offer benefits early in life, when selection is stronger, despite their later costs (Rose 1991, Williams 1957). Even the genes that cause hereditary diseases are viewed differently in the light of Darwinism. It is unlikely that the more common disease-causing genes represent mutations that have not yet been weeded out; rather, many are probably alleles that are advantageous in other contexts (e.g., in other genetic combinations, at other life history stages, in the other sex, or in different environments). Other "disease genes" may be genetic quirks with deleterious effects only in a modern environment (e.g., myopia, breast cancer). The enterprise of Darwinian medicine is revealing a human body that is both more superbly designed than it first appears and, yet, intrinsically compromised, flawed, and vulnerable to myriad diseases (Nesse and Williams 1995).

On the Origin of Species was published almost 140 years ago, and evolutionary biology has been synthesized with population genetics for nearly half of that time. Why should a Darwinian approach now have something new to offer medicine? There are several reasons. First, some of the most important evolutionary ideas, notably the weakness of group selection and the power of kin selection, were formulated rather recently (Cronin 1993). Second, some well-established distinctions, especially that between proximate (physiological and developmental) and evolutionary causation, are only now becoming widely appreciated. Third, the reflex rejection of functional questions as teleological or speculative is fading as the medical profession incorporates more young doctors whose undergraduate education showed them how evolutionary hypotheses can be formulated and tested (Mayr 1974). Finally, previous attempts to explain the evolution of disease have failed for the good reason that disease is not a direct product of selection. A more fruitful approach is to try to explain the human bodily vulnerabilities that result in disease and to consider why the body is designed as it is instead of in ways that might appear more robust.

Despite the general neglect of evolutionary insights by the medical profession, most biological educators acknowledge that a complete understanding of any biological phenomenon, including those of medical importance, must make use of evolutionary ideas. One might imagine that these principles are covered routinely in undergraduate courses, but they are not. In a recent lecture to 200 medical students, one of us asked how many understood the distinction between proximate and evolutionary explanations. Only a dozen hands went up. A few more students had heard about kin selection, but hardly any grasped the problems with group selection. Far from being arcane, these concepts are essential foundations for understanding how organisms are shaped by natural selection. Biologists and medical doctors should know these principles, but most do not.

Indeed, a bachelor's degree in biology may require only a superficial understanding of evolution. At many universities, a student can earn a degree in biology by taking courses that deal only in proximate causation—that is, in the anatomic and physiological mechanisms of organisms (from genes to brains) and ontogeny (from the DNA code to a mature organism). A student can even take courses in paleontology and molecular genetics and still not learn about natural selection in any depth. The superficial treatment of evolution in modern biological education was recently documented in detail by Linhart (1997). In our experience, a deep understanding of how natural selection shapes adaptations

comes most often from courses in animal behavior, comparative biology, or population genetics, or explicitly in evolutionary biology.

Because most students lack this background, many enter medical school with simplistic notions about the human body. Instead of appreciating the compromises between investments in self and in reproduction or investments in kin and in mating effort, students imagine that family life should normally be free of conflict. And instead of recognizing the forces that constantly influence gene frequencies, and thus the body's design, students often have the notion that the body is riddled with deficiencies that natural selection is not powerful enough to influence. In short, students do not understand where the human organism came from, and they do not understand the forces and compromises that make the body vulnerable to disease.

Do medical schools fill in these gaps for their trainees? No. In fact, the vast majority of medical curricula never even address the topic of natural selection directly, much less how it accounts for vulnerability to disease. Although the average medical curriculum allocates 20–30 hours of classroom time to embryology, thus giving students some sense of how bodies develop from DNA to maturity, few schools devote even one hour to the study of how the body evolved from its ancestors in human phylogenetic history. Thus, a major basic science—arguably the most fundamental of all the basic sciences for medicine—has been omitted from the medical curriculum.

How is such an oversight possible? The answer, we believe, is analogous to the explanation for the design of mammalian eyes, which have an inside-out structure in which the vessels and nerves rise into the eyeball and spread out between the retina and the lens, instead of the more sensible plan that is found in mollusc eyes, in which the nerves and blood vessels are behind the retina. This difference in design is the result of nothing more than chance, initial happenstance followed by millions of years of path dependence. The body cannot, after all, start afresh. Every intervening model had to work. After all, none of our ancestors went extinct.

Medical education has been subject to similar constraints. It chanced that the standardization of medical curricula early in this century coincided with a low point in evolutionary understanding. Evolution as such was accepted, but the scientists were confused about what the mechanisms might be, its medical relevance was not apparent, and it was not established as part of medical education. Once the curriculum is established, those who teach the courses naturally tend to maintain the status quo; new courses may be welcome in principle but not if they require money, curriculum time, or additional faculty. So, like phylogeny, the medical curriculum is path dependent and resistant to change. Fortunately, there are some differences between the human body and human institutions. Although human organizations may be conservative, there is always the possibility of major change, even of starting from scratch in a way that is impossible for the design characteristics of a biological organism.

Despite the difficulties of implementing change in medical curricula, educators can justifiably ask how evolutionary biology should be taught to

Learning objectives: what every physician should know about evolutionary biology

- Tinbergen's four questions about an adaptive feature
  - By what proximate mechanisms (anatomic and physiological) are the adaptive effects produced?
  - What is the ontogeny of these mechanisms?
  - What fitness advantages shaped and preserved the characteristics of this feature?
  - What phylogenetic history led to the feature's present configuration?
- Population genetics formulations of how natural selection works
- Sexual selection and mate competition
- Levels of selection: genes, genomes, individuals, groups
- Kin selection
- Segregation distortion
- Adaptations and their analysis
- The role of chance in evolution
- Optimization and its limits
- Rates of evolutionary change
- Formulation and testing of evolutionary hypotheses
- The comparative method
- Evolutionary explanations for the vulnerabilities that lead to disease
  - Infection: levels of virulence and host–pathogen arms races
  - Novel factors in the environment: physical, social, etc.
  - Cost–benefit tradeoffs at the level of traits: life history traits, including senesecence
  - Cost–benefit tradeoffs at the level of the gene: heterozygote advantage and others
  - Historical constraints: path dependence, the role of chance factors
  - Defenses that are often mistaken for diseases: fever, cough, anxiety, etc.
- Hominid phylogeny
- Sources of genetic variation within a species
- Natural selection on mechanisms that regulate behavior
- Reciprocity, social and familial relationships, and the problem of altruism
- Implications for molecular biology
- Current controversies, such as the adaptive significance of menstrual bleeding and morning sickness, the origin of HIV and its variation in virulence, and the out-of-Africa versus multiple regional origins of modern *Homo sapiens*.

medical students and how such education would influence their ability to understand and to treat disease. The fundamentals of evolution that are necessary for the practice of medicine could probably be taught in 15–20 classroom hours. We do not propose a detailed syllabus here, but certain topics are crucial (see box page 665). For example, a deep understanding of Tinbergen's four questions (Tinbergen 1963) is the foundation to instill a full appreciation for the need to seek both proximate and evolutionary explanations for each trait. The details of how natural selection works is another topic, with an emphasis on how genes act, inevitably, to shape phenotypes that increase the representation of those genes in future generations, even if this compromises the perceived well-being of their bearers. Students should also understand sexual selection, how kin selection works, why group selection is usually weak, and how and why genomes protect themselves against genes that distort segregation.

In addition to population genetics, the medical curriculum should emphasize the evolution of adaptive traits: how and why every organ of the body is functionally exquisite, yet still full of compromises. Extensive discussion of hypothesis testing will be necessary to show the power of the comparative method in elucidating past evolutionary changes, to show how design features of traits can be predicted from functional expectations, and to show how experiments can be conducted on evolutionary questions, thus eliminating the mischievous notion that evolutionary hypotheses cannot be tested.

At its core, the course would address evolutionary explanations for the vulnerabilities that lead to disease: infection, novelty, tradeoffs at the level of genes and traits, compromises, historical constraints, and useful defenses that are often mistaken for diseases. If enough faculty were available to teach the students in small seminars, one good approach would be for each student to present a short analysis of the evolutionary factors that give rise to a single disease, with descriptions of the kinds of studies that could differentiate among alternative hypotheses.

Physicians who have completed such a course would have a solid framework on which to build their understanding of every disease that they encounter, and they would probably practice medicine differently. Physicians who understand the evolutionary origins of the human vulnerabilities would be more respectful of our evolved defenses, more attuned to novel environmental factors that cause disease, more respectful of the power of pathogens to evolve to evade or to disable defenses, more thoughtful about what it does and does not mean when genetic variation is found to influence disease vulnerability, and more understanding of senescence. In the early phase of medical education, students tend to stand in awe of the body's "perfections"; later, in the clinic, they often disparage the body as a haphazard, fragile mechanism. An evolutionary perspective helps to unify these contradictory perspectives into a deeper appreciation for the body, in all its adaptive subtlety and with all its compromises that lead to diseases that doctors can treat or, better yet, prevent.

Is such an addition to the medical curriculum realistic? By all means. Making evolutionary biology a part of the medical curriculum is not only realistic, but essential. The eye may be unable to turn itself inside-in, but deans, if willing to invest the effort and the resources, can make major curriculum innovations. Evolutionary biology is an essential science for medicine. It is time to include it in the curriculum.

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