Part I - Parasites, Human Hosts, and the Environment

6. Parasitism

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Parasitism

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Parasitism is a natural phenomenon, inherent to life (Ferreira, 1973). No living species exists without parasites. According to Cockburn (1963), the complex system formed by the three elements parasite, host, and environment is in a constant evolutionary process and can either remain unaltered, change over time, or die out completely. Parasitology is a branch of ecology and follows its general principles (Ferreira, 1973). Parasitism is an interaction between organisms and the product of natural selection, and should thus be understood as selective responses to pressures from the environment (Poulin, 2007).

Hutchinson (1980) describes an ecological niche as a hyper-volume in multidimensional space determined by a number of environmental variables in which a species is capable of existing. A parasite thus finds its ecological niche in another organism (Araújo et al., 2003). This establishes an interaction which can be more or less close, dependent, temporary, or permanent, according to the species involved.

This definition of parasitism includes all varieties of interspecies associations, with different degrees of interdependence. Using this broad concept to define parasitism means that associations traditionally defined as commensalism, mutualism, and symbiosis, among others, represent variations of the same phenomenon: parasitism (Araújo et al., 2003; Roberts & Janovy Jr., 2009).

Samuel Pessoa, in the first edition of *Parasitologia Médica*, in 1945, already reminded parasitologists that “parasitism, commensalism, and symbiosis are categories created by our spirit, emphasizing different aspects of the same general laws” (Pessoa, 1951: 5).

When German scientists Karl Georg Friedrich Rudolf Leuckart, and Heinrich Anton de Bary respectively and independently created the concepts of parasitism and symbiosis (both in 1879), they made no mention of diseases or harm that could come from the relationship between species. Various authors focused again on the same issue, including French parasitologist Émile Brumpt (Brumpt, 1913). Since the first editions of his books, Brumpt emphasized that parasitism and symbiosis merged into a single concept, that is, both parasites and symbionts or commensals could cause either harm or benefit to their hosts.

A hundred years after the definitions by Leuckart and Bary, Whitfield (1979) criticized the various terms used for relations between beings, calling them “semantic anarchy”. He proposed a return to the “classical” concept of parasitism and symbiosis as synonyms.

The definition of parasitism as the parasite’s finding of its ecological niche in the host has consequences of a logical order. What we define as parasites now ranges from genetic sequences capable of reproducing in a relationship characterized by dependence on other sequences of genetic material all the way to higher vertebrates and plants, including (along the way) viruses, bacteria, protozoa, worms, arthropods, and any other life form that finds its ecological niche in another living being.

Several important authors discuss this interesting issue, including Anderson & May (1978), who classify microparasites and macroparasites according to their capacity to multiply in the host.

It is still common (due mainly to tradition) to separate the study of fungi, bacteria, and viruses into their respective sciences, and to refer to the study of protozoa, helminths and arthropods as parasitology, without great systematic criteria, as highlighted by the editor of the journal *Parasitology* in its special centennial edition (Cox, 2009).

However, parasitism is a branch of ecology, and it is thus much more interesting to study the phenomenon in all its complexity, i.e., as the study of parasite-host-environment relations when one, the parasite, finds its ecological niche in the other, its host. There are numerous examples. Many parasites are influential in maintaining or modifying communities of hosts, studied in the line of research called the ecology and evolution of parasitism (Lebarbenchon, Poulin & Thomas, 2009).

MOLECULAR PARASITES

Many authors contend that the definition of parasites includes fragments of genome identified as external to the cell in which they are found (Walisko & Ivics, 2006).

Mobile gene sequences called transposable elements or transposons are fragments of deoxyribonucleic acid (DNA) that move and replicate in a host cell’s genome. When they insert themselves into genes, they can induce unstable mutations, but the latter are generally reversible (Van Sluys, Scotercci & Costa, 2001). Like viruses, they use the cell’s resources to multiply. According to Walisko & Ivics (2006), just as viruses developed strategies to interact and survive in the host cell, transposons produced mechanisms capable of modulating the cell cycle to their advantage.

Another example of parasites are small molecules of ribonucleic acid (RNA) called satellite RNAs (satRNAs), which act as molecular parasites in certain plant RNA viruses (Maramorosch, 1991). These satellite RNAs need helper viruses to replicate in host cells.

SatRNAs are encapsulated by the coat protein of the helper viruses. The presence of a satRNA can alter the symptoms caused by the helper viruses, usually attenuating them but in some cases intensifying them (Osman & Buck, 1991). Examples of this case of parasitism are the satellite viruses of tobacco mosaic and tobacco necrosis (Tobavirus and Necrovirus), used in agriculture (Romano & Monte-Neshich, 1996).

Another aspect of parasitism that has still received little research attention is the infection of organisms by prions. A prion is defined as a “proteinaceous infectious particle” (= *prion*) that lacks genetic material (DNA or RNA); prions multiply rapidly and can convert protein molecules into substances with the potential to cause harm to the host, simply by altering its spatial structure (Cantarino Costa & Borges, 2001).

Prions may have given rise to the first viral particles by incorporating themselves into cells' nucleic acid, causing protein adherence and their encapsulation. According to this theory, the capsids formed by the prion's proteins surrounding the RNA formed the first RNA viruses (Lupi, Dadalti & Goodheart, 2007).

Other molecular parasites consist of genetic material external to the cell. Viruses, plasmids, and bacteriophages are extrachromosomal transmissible genetic elements, or genomic fragments that depend on a host cell to multiply (Romano et al., 2001).

These elements played an important role in the origin and evolution of life on Earth, which only became possible as a consequence of parasitism in what was still a molecular world, some 4.4 to 3.8 billion years ago (Chang, 1999; Nisbet & Sleep, 2001). In this molecular world, proto-organisms associated with and related to each other in such a way that they were able to multiply by reproducing their molecular composition, using parts of another proto-organism's composition.

Since extra or intrachromosomal transmissible genetic elements depend on a host cell to multiply, they cannot have preceded it (Lederberg, 1997). These elements may have given rise to nuclear DNA and other cell organelles (Lederberg, 1998). Thus, extrachromosomal genetic elements and transposons represent relics of primitive molecular parasites. They played (and still play) an important evolutionary role, since their inclusion in the genome of host cells promotes genetic diversity. Many of the alterations resulting from this interaction were certainly deleterious, but various others proved advantageous to their hosts (Sverdlov, 1998).

As an important factor in biodiversity, beginning at the molecular level and subsequently in the intracellular milieu, parasitism fostered the diversification of life forms and species radiation, resulting from multiple associations.

Organelles originating from these associations allowed the origin and evolution of cells. (Corsaro et al., 1999) suggest that the eukaryotic cell may have emerged as the consequence of a frustrated episode of predation or parasitism. Due to the associations established during the evolution of life, not only the nucleus but the entire cell is a chimera, a poly-heterogenomic state derived from a long history of parasitic associations. The associations between microorganisms that resulted in the mitochondria, hydrogenosomes, chloroplasts, and other intracellular bodies guaranteed a significant increase in the complexity between organisms that resulted in growing capacity to occupy new ecological niches (Andersson et al., 1998; Roger et al., 1998). These important events provided cells with sources of bioenergy and biosynthesis (Dyall, Brown & Johnson, 2004). However, and above all, the advent of the cell offered possibilities for new parasite niches (Thompson, 1999).

One of the most interesting aspects in the study of these associations is the contribution by the host cell itself to the constitution of the genome in these organelles, through horizontal gene transfer (Dyall, Brown & Johnson, 2004). Ancient invasions of other cells by bacteria provided the emergence of mitochondria, chloroplasts, and other organelles. Parasite interaction was so great that it is impossible to survive separately.

AT THE OTHER EXTREME: VERTEBRATE PARASITES AND HIGHER PLANTS

Life on Earth thus results from the phenomenon of parasitism. All life forms are parasitized, and that is why they exist (Araújo et al., 2003). One of the most interesting aspects of this phenomenon is the evolution of life. For example, the evolution of mammals: assuming the broad definition of parasitism, the fetus can be considered a parasite (at least a temporary parasite) of the mother that maintains it during gestation.

Some species of birds that do not build nests are considered parasites because they use other species' nests to lay their eggs. The foster parents (i.e., hosts) incubate the eggs and care for the nestlings, sometimes to the detriment of their own brood (Smith, 1979). Parasitism between bird species occurs all over the planet.

In Central America, Smith (1979) conducted elucidating experiments on the relations between parasitic bird species, host birds, and flies. These organisms established interesting and complex interrelations.

In some species, when the female lays her egg in the host nest and the foster parents are away, she throws out the host mother's eggs. In others, the parasite nestling itself hatches first and takes charge of dumping out the host species' eggs.

Other species eliminate their foster siblings after they hatch. Still, in some species the parasite and host nestlings live together in the same nest. Since the latter are usually smaller, the parasitic nestling develops better and faster, well fed by the host parents, opening its beak wider and attracting their attention.

Zahavi et al (1999) discuss the evolution of such relations between such bird species and report that host couples previously experienced with parasitic birds are able to recognize the odd eggs and throw them out of the nest.

These examples illustrate deleterious effects in the host population, but this is not the rule. Smith (1968) demonstrated that the offspring of host birds are attacked by flies whose larvae, when numerous, lead to their death. However, the offspring of parasitic birds feed on fly larvae and are able to control infection in their foster siblings. The survival of the latter in the presence of parasitic birds becomes successful when compared to nestlings without foster siblings. This shows how parasite-host-environment relations establish mutual nuances which make it difficult to set limits between harm and benefit.

The higher plants also include examples of parasitism. Some relations are highly complex, for example between the parasite *Cuscuta pentagona* and its host. *C. pentagona*, a small vine, is capable of using volatile "cues" to locate the host plant, the tomato (Runyon, Mescher & Moraes, 2006).

Carrenho, Trufem & Bononi (2001) explore the relations between mycorrhizal fungi and various plants. Purin & Rilling (2008) discuss parasite-host relations, reviewing the concept of parasitism. According to some authors (Corsaro et al., 1999), the orchid parasitizes the mycorrhizal fungus and not vice versa, since the plant uses the fungus to germinate its seed and develop the seedling (Pereira et al., 2005).

Other examples of parasitism in higher plants include the so-called tree-strangler trees. The seeds of these species germinate on other trees, using their trunk or branches as substrate. The roots seek the ground, while the branches reach the upper tiers of the forest canopy more quickly. Little by little they envelope the host tree, which finally succumbs to the parasite's "embrace" (we recommend reading the short story "O mata-pau", or "The Tree Strangler", in the book *Urupês*, by Brazilian author Monteiro Lobato).

BETWEEN THE EXTREMES: BACTERIA, FUNGI, PROTOZOA, WORMS, AND MUCH MORE...

The parasite does not have the exclusive capacity to cause harm or benefit to the host. The manifestations that can occur in the parasite-host-environment interaction result from specificities in each of the system's components. Parasites can in fact benefit individuals of a given host species, while others are harmed by (or indifferent to) the parasitic infection. This complexity varies according to the parasite and host species and the environment in which they live.

In the case of host species living in societies, other factors are involved. Especially in the human species, these factors are inherent to social, political, and even economic moments, besides relevant cultural aspects in each ethnic group and human community and emotions and ways of reacting to stimuli, both individually and collectively. The determinants of health and disease thus depend not only on the parasite's presence in the host, but also on a series of events resulting from complex interaction in the parasite-host-environment system. In the human species, a series of factors can lead to changes in equilibrium. The parasite is thus a necessary (but not sufficient) condition for triggering a parasitic disease (Ferreira, 1973).

Individual or regional differences commonly occur in the behavior of parasitic diseases. For example, toxoplasmosis can display absolutely benign and asymptomatic forms, but also more severe clinical forms (Machado, Silva & Pinto, 1968). Other examples include regional variations in Chagas disease, schistosomiasis, and amoebiasis, among others, in which the infection is present, but not the disease. Among a large number of individuals infected with the tuberculosis bacillus, only a few actually become ill (Ferreira, 1973).

Parasitic infection and parasitic disease are distinct phenomena. Infection is defined as the parasite's presence in the host, in which it spends part or all of its life cycle. Parasitic disease involves the appearance of signs and symptoms resulting from parasite-host-environment interaction in a given individual (Araújo et. al., 2003).

Parasites can be more or less virulent and more or less pathogenic. As categories, virulence and pathogenicity can be separated or combined in relation to the parasite-host-environment system. Some authors use the two terms as synonyms, while others make a distinction between them (Poulin & Combes, 1999, 2000). The ecological focus of parasitism emphasizes the difference: while virulence prioritizes the parasite's capacity to multiply and transmit to other hosts, pathogenicity refers to the capacity to cause characteristic signs and symptoms of clinical states in parasitic diseases.

A typical example is *Entamoeba invadens*, which parasitizes snakes. This protozoan species lives in the gut of snakes without causing any harm, feeding on the intestinal content and multiplying. However, if the temperature increases, it can cause an increase in the intestinal transit by injuring the mucosa, or become invasive, leading to the host's death. Barrow & Stockton (1960) observed eight species of snakes infected with this parasite at different temperatures, from 13°C to 25°C. At lower temperatures the researchers did not observe lesions, although they continued to isolate *Entamoeba invadens* in culture. Snakes kept at higher temperatures presented lesions, and even those that had not manifested symptoms at low temperatures became sick when placed at 25°C.

Classic articles by Noble (1962, 1966) also showed the different influences the environment can have on each parasitized individual. Squirrels infected with protozoa (*Trichomonas*) and helminths (*Syphacia*) were exposed to different stimuli such as heat, light, noise, confinement, hunger, and others, and later compared to animals that were also infected, but not exposed to these stressors. In the stressed animals, the number of parasites retrieved was significantly higher than in those kept under normal conditions of captivity.

There are numerous examples between such parasites and the human species. Petrin et al. (1998) show the relationship between emotional status and the clinical manifestations of trichomoniasis. The appearance and intensification of symptoms from *Trichomonas vaginalis* infection depend on factors involving the parasite, the human host, and the environment. Infection with *Trichomonas vaginalis* is classified as a sexually transmissible infection (or disease) (STI-STD). Some women infected with the parasite can transmit the infection without manifesting symptoms, while others become ill, with clinical states ranging from a mild or intermittent vaginal discharge or intensified by the menstrual cycle, to dyspareunia and more serious symptoms, generally associated with emotional disorders and lifestyle changes (Sobel, 1992).

Dogs infected with *Diocotophyma renale* can survive to a late age, without more serious symptoms from the renal degeneration caused by the giant roundworm lodged in one of the kidneys (Nakagawa et al., 2007).

The same happens with the giant roundworm of humans, which reaches approximately 40 cm in the host's gut. Parasitism with *Ascaris lumbricoides* can go entirely unnoticed. Individuals sometimes realize they are infected when they pass live, moving worms, both in the stool and by the mouth, nose, or even ears, in the latter with perforation of the eardrum (Rey, 2001).

Such varied situations with parasites that infect humans and other host species increasingly explain the use of the expanded concept of parasitism. How does one explain the limits imposed by definitions of “commensals” and “parasites” in the case of protozoa and helminths found in the human gut?

Aucott & Ravdin (1993) described clinical manifestations resulting from pathogenic processes caused by *Entamoeba coli*, a protozoan classified as an intestinal “commensal”. Meanwhile, Dixon (2007) described other protozoa viewed as harmless commensals, such as *Cryptosporidium parvum*, which cause serious clinical states in their hosts under specific circumstances. Other authors (Dworkin et al., 2007; Visvesvara, Moura & Schuester, 2007) have described serious clinical states caused by protozoa previously considered free-living or harmless in the human host.

Some bacteria such as *Helicobacter pylori* illustrate how the majority of the human population is infected, but asymptomatic. However, some individuals can develop clinical states in which the bacteria's presence is associated with chronic gastritis, ulcers, and gastric carcinoma (Figueiredo & Silva, 2005).

As for parasitism with intestinal helminths, a curious phenomenon occurred with infection by *Trichuris trichiura*. This helminth was associated with a clinical condition, common in colonial America, called *maculo* or *mal del culo*, in Spanish: rectal prolapse with abundant “worms”. Although we cannot be certain whether “worm” referred to helminths, since at the time of such descriptions the term could have meant either helminths or insect larvae, the fact is that this disease disappeared or became rare after the colonial period.

Rectal prolapse associated with *Trichuris trichiura* infection is part of modern clinical manifestations, although very rare and limited to individual host situations, more common in undernourished children and the elderly.

In conclusion, parasitism is a branch of ecology and should be studied as such. Infection, or the presence of a given parasite in a given host, does not necessarily mean parasitic disease. The appearance of signs and symptoms associated with a given parasite results from a set of factors that are inherent to the parasite and host and to the environment in which they are found. Aidan Cockburn described this very well when he gave examples of the different relations between the parasite, host, and environment in a dynamic and evolutionary process (Cockburn, 1963). Anderson & May (2004) considered Aidan Cockburn one of the first to discuss the impact of parasitic infections on prehistoric hunter-gatherer peoples whose bands varied from twenty to a hundred individuals (Hassan, 1981). According to Cockburn (1971), some parasite species would have been able to survive in such a number of individuals, even if some died or became immune. Meanwhile, others could only emerge as parasites in humans after a series of events, such as the emergence of villages and the first cities, agriculture, domestication of animals, and population growth, which increased the number of susceptible hosts and contact between persons, thereby facilitating the transmission of parasites.

The ecological focus of parasitism facilitates understanding the events involved in the origin and evolution of parasitic diseases. And to recover precious data from the past, nothing is more appropriate than studies in paleoparasitology.

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