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The NEW Body Politic: How Knowledge of Our Bodies Can Affect the Wisdom of Our Policies

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Abstract

The metaphor of body politic works in both directions. The corporal body is thought to mimic those interactions of the social collective; the behaviors of the social collective are seen to form an entity whose structures mirror the physical organism. As scientists gain new knowledge of the body, these metaphors change. The realization that the body was composed of living cellular units, the discovery of the nervous system, and the discovery of the immune system, for instance, reorganized thinking about the body. Recent discoveries that our bodies are multilineage organisms whose microbial components are normal and essential for body development maintenance may be causing another alteration in how we view our bodies, nature, and societies.

I. Of the body politic

Let me begin with two quotations that will frame the talk. The first is from the religious philosopher, Abraham Joshua Heschel (1965).

> "A theory about the stars never becomes a part of the being of the stars. A theory about man enters his consciousness, determines his self-understanding, and modifies his very existence. The image of man affects the nature of man."

The second quotation is from feminist sociologist Emily Martin:

> We are not seeing the end of the body, but rather the end of one kind of body and the beginning of another kind of body."

These quotations point to and bracket the idea that there is a new theory that relates to humans, and that this new theory will cause one idea of the body to decompose while providing sustenance for the growth of another conception of the body—and of body politics.

The body politic metaphor has a long history and it is often based on the current perceptions of the body given it by science. Durkheim (1893), for instance used this model in his concept of the division of labor, where each person contributed to the social body by their individual tasks. Moreover, these tasks created a consensual value of shared common goals, which helped the society function in a healthy manner. Especially during wartime, the notion that there must be internal cooperation in competition with an external enemy rallies the body politic metaphors.

But the body politic can't escape how science envisions the physical corpus. The modernist body was a "neural" body, with the brain as its the command center and the nervous system empowering the rest of the tissues to do its bidding (Gilbert 1997). The neural body was structured on the Y axis of the Great Chain of Being. At its apex resided the brain with its God-given rational soul and self-knowledge. At the base lay the genitals. The heart of man was torn between these two poles: reason and emotion, intellect and passion. Through nerves and hormones originating at the brainstem, the

head dictated the production regimen of the body. This body is the "Fordist" body whose death has been proclaimed by Jonathan Parry (1989) and Emily Martin (1992).

However, after World War II, the authority of the neural body has become shared with two other views of the body, two other claimants to "selfhood". In addition to the neural body, there now exist the immune and genetic bodies. Each of these bodies privileges a different notion of identity ("self") that corresponds to a different type of body politic (Gilbert 1995; 1997). When one makes the "body politic" or "body of knowledge" metaphor, one is extrapolating a particular type of body into the social or academic sphere. The neural body privileges a polity defined by laws, mores, and culture. The immune body privileges a polity defined by defensible borders. The genetic body privileges ethnicity and race as the bases for polities. The bodily derived metaphors are among the most central to our perceptions of reality, and each of these views of the body has important consequences when extrapolated into political and social spheres (Lakoff and Johnson 1980).

II. The New Body: The Holobiont

Recently, however, a new version of the body has appeared, and this new conception does away with the notion that the body has a single lineage, all cells being from the fertilized egg, and constructs the body as a chimeric organism, whose

components have many different genomes. This is the notion of the *holobiont*—the animal (or plant) plus its persistent colonies of symbionts. This idea actively goes against the usual characterizations of biological individuality.

For instance, when you think of a cow, you probably envision an animal grazing, eating grass, and perhaps producing methane at her other end. However, cows cannot do this. Their bovine genome does not encode proteins with the enzymatic activity needed to digest cellulose. What the cow does is chew the grass and maintain a symbiotic community of microorganisms in its gut. It is this population of gut symbionts that digests the grass and makes the cow possible.

The cow is an obvious example of what is called a holobiont, an organism plus its persistent communities of symbionts (Zilber-Rosenberg and Rosenberg, 2008). The notion of the holobiont is important both within and beyond biology because it shows a radically new way of conceptualizing "individuals." Recognizing the holobiont as a critical unit of life highlights process and reciprocal interactions, while challenging notions of genomic purity. And it appears that the holobiont is universal (Margulis and Fester 1991; Gilbert et al 2012; McFall-Ngai et al 2013). It is a signature of nature. Termites cannot eat wood without their symbionts. Corals cannot survive without their symbiotic algae. And mammals without symbionts would soon die from the lack of

normal immune systems or the malnutrition caused by a poorly formed circulation system.

Usually, when we think of animals, we think of each organism as an individual, separate from its environment. We generally postulate six types of individuality (Gilbert et al 2012)

1. *Anatomical individuality.* Anatomical boundaries are what separates us from the environment and from each other. When we look at each other, we appear to be anatomically distinct individuals.

2. *Genetic individuality.* This is the notion that each of us has a single genome. This genomic individuality has largely superseded others and is now often considered prior to other forms of individuality. It is the one highlighted by forensic scientists seeking the DNA of the perpetrator; and it is the one highlighted by anti-abortion activists, including several present Republicans hoping to become president, saying that your DNA makes you who you are.

3. *Developmental individuality.* This is the concept that each of us comes from the fertilized egg and that we are defined as individuals by the common origin of all our cells (Huxley 1852).

4. *Immune individuality.* If I were to put my skin onto you, you would reject it because is not you. In this view, our immune system exists to recognize that which is non-self

and to protect us against a hostile outside world waiting to infiltrate and destroy the individual.

5. *Physiological individuality.* This is the individuality wherein the different parts of the body come together for a common end. It is a body defined by a harmonious division of labor.

6. *Evolutionary individuality.* This form of individuality focuses on the individual that is selected within evolutionary processes, be it a genome or an organism.

The concept of the holobiont, upsets all these notions of biological individuality. First, we are certainly not anatomical individuals. If you look closely at a human body, you will find that most of our cells, some say 90 percent of the cells, in our body are prokaryotic. A minority of the cells in our body are those containing a human genome. The other cells include about 160 different bacterial species, and they form complex ecosystems. Human bodies are and contain a complex network of ecosystems. Our mouths are different ecosystems than skin, or our intestines. The volume of the microbial organisms in our bodies is about the same as the volume of our brain, and the metabolic activity of those microbes is about equivalent to that of our liver. The microbiome is another organ; so we are not anatomically individuals at all (Ley et al. 2006; Lee and Mazmanian 2010; McFall-Ngai et al 2013.)

But what about the notion of the genetic individual? We are told that each of our cells has same unique genome, the one established at fertilization. This is a concept that is used increasingly to define who we are. Life Magazine, when it describes "the first days of creation," i.e., our embryonic development, tells us that "the result of fertilization is a single nucleus that contains an entire biological blueprint for a new individual. Genetic information governing everything from the length of the nose to the diseases that will be inherited" (Life Magazine, 1990).

DNA is constantly being represented to us as the secular version of our soul. It is depicted as that which is our essence and that which determines our behaviors. Dorothy Nelkin and Susan Lindee have called this our "sacred DNA" (Nelkin and Lindee 1996). This genomic notion of individuality is the one that's being used by anti-abortion lobbyists, because if your genome is formed at fertilization, and if DNA is your essence, then, fertilization has become the equivalent of ensoulment. Several anti-abortion websites each tell us, " and even more amazingly, intelligence and personality, the way you look and feel were already in place in your genetic code. At the moment of conception you were essentially and uniquely you." It is the message of the Republican presidential primary contenders Huckabee, Rubio, and Fiorina, as well as the message of conservative philosophers (George and Lee 2015).

However, this alleged genetic basis of individuality is scientifically wrong on many levels (Gilbert 2008; Gilbert and Howes-Mischel 2004). One of these levels involves the symbionts. The symbionts are another mode of inheritance. Indeed, while the human genome contains some 22,000 different genes, the human body includes the bacteria that bring about eight million more genes to the scene. We acquire our symbionts primarily by infection from the mother as we pass through the birth canal after the amnion breaks. These bacteria are supplemented by those from the mother's skin and from the environment. (Funkhouser and Bordenstein 2013; Gilbert 2014). In many arthropods, the bacteria come packaged, like mitochondria or ribosomes, in the egg cytoplasm. In *Drosophila* (fruit flies), for instance, the *Wolbachia* bacteria that are important for their immune system are transmitted from their mothers, inside the oocytes from which the flies develop (Ferree et al 2005). Animals are not monogenomic organisms.

Moreover, these symbiont genes can play important roles, even selectable roles, in the lives of holobionts. In pea aphids, for instance, the color of the adult aphid, the thermotolerance of the aphid (whether it can reproduce at high temperatures) and the ability of the adult aphid to resist parasitoid wasp infection, are conveyed by the genetic differences in the aphids' symbiotic bacteria. (Dunbar et al 2007; Gilbert et al 2010; Moran and Yun 2015 Oliver et al 2009; Tsuchida et al 2011). Different alleles of

symbiotic bacteria exist in humans, including one species of *Bacteroides plebius*, whose Japanese population contains two genes that enable it to better metabolize the complex carbohydrates found in the algae used in sushi (Hehmann et al 2010, 2012).

Recent evidence shows that we are not individuals by developmental criteria, either. Organisms need their symbionts to construct "themselves." For mammals, bacteria are critical for body development. Without its normal gut symbionts, a mouse cannot form its gut capillary system nor the gut associated lymphoid tissue. The bacteria function in development by inducing normal gene expression in the Paneth cells of the mouse intestine. The genes of these intestinal epithelial cells are instructed to turn off or on by chemical signals coming from the bacteria! For instance, the expression of the gene encoding angiogenin-4, which is important for forming gut capillaries, is increased ten-fold when normal gut bacteria are present. In other words, a germ-free mouse is like a mutant with only ten percent of the angiogenin-4 mRNA production of normal mice (Hooper et al 2001; Stappenbeck et al 2002). Without such proteins, capillaries do not develop and the guts do not develop and function well. In zebrafish, symbiotic bacteria regulate the division of the intestinal stem cells. So zebrafish without their normal symbionts lack a complete gut tube (Rawls et al. 2004; Bates et al. 2006).

There is growing evidence that in mice, and possibly in humans, bacteria are also partly responsible for normal brain development. The brains of germ-free mice are

different from those of mice with their normal symbionts (Diaz Heijtz et al 2011; Sampson and Mazmanian 2015). When one considers that 30% of the metabolites in the mammalian blood circulation (including nearly all the serotonin) comes from bacterial metabolism, one can see that every developing organ in the body can be affected by the microbes (McFall-Ngai et al 2013). One large study (Hsaio et al 2013) used viral stress in mothers to induce an autism-like condition in their offspring. These mice spend a lot of time self-grooming, lack normal exploratory behaviors, and prefer solitary cages. This study found that the autistic-like mice act more like normal mice when you alter their bacteria. If one adds certain species of *Bacteroides*, this alters the community of the bacterial symbionts, and it increases the integrity of the gut epithelium. This simple procedure stops the leaking of bacterial products into the gut and normalizes several of the autism-like behavioral abnormalities. One of these products, 4EPS, is made by bacteria and causes anxiety-like symptoms in mice. In the "autistic" mice this product is seen in relatively high amounts in the circulation. In the mice without these symptoms—and in the "autistic" mice that were treated with the bacteria—4EPS can hardly be detected. This study opens up a new area that investigates cognitive and emotional situations as products of bacterial metabolism (Hsaio et al 2013; Desbonnet et al. 2014; McFall Ngai, et al . 2013).

What, then, of physiological individuality? As I mentioned earlier, symbionts regulate much of the metabolism that characterizes some species. The termite, *Mastotermes darwiniensis*, is a good example. The termite eats wood. It is a major agricultural pest, eating trees and wooden homes. Only it cannot digest wood. It does not have a genome producing wood-digesting enzymes. What it has inside its gut is a symbiotic protist, *Mixotricha paradoxica*, which eats the wood. Only it doesn't. *Mixotricha* is a composite organism containing a protist and at least four different types of bacteria. Bacteria and protists act together to make *Mixotricha* paradoxica, which is essential to the functioning of the gut of a termite, which itself lives in a termite community (Margulis and Sagan 2001).

In theory, the organism is an individual whose component parts cooperate for the betterment of the whole. This was the division of labor seen by biologists such as Henri Milne-Edwards and Rudolf Leukert as well as by social theorists such as Thomas Hobbes and Adam Smith. Originally, the living cells of the body cooperated in a harmonious dynamic fashion to construct the organism. But in the holobiont, these cells do not have to be from the same egg, or even from the same species. One well-studied case is the milkweed bug, *Planococcus*. This insect has a symbiont, *Tremblaya*, a bacterium residing within its cells. In turn, that bacteria has another bacterial symbiont, *Moranella*, inside of it. This set of symbionts, nested one inside the other like a set of

Russian matryoshka dolls, is necessary for the insect to synthesize several amino acids. For instance, *Planococcus*, alone, cannot make phenylalanine. Its genome does not contain the genes encoding the enzymes involved in its synthesis. The symbionts do. Phenylalanine synthesis starts in the symbiont, then it goes into the symbiont's symbiont. The product made by the symbiont's symbiont returns into the symbiont. Only the last step of phenylalanine synthesis is done by the enzyme encoded by the genome of the insect itself (McCutcheon et al 2011). The production of a single compound thus requires a three-fold symbiosis.

This co-metabolism—the physiological integration of the host and the symbiont—is seen in mammals, too. Research on mice indicates that as much as one-third of a mammal's metabolome, the diversity of molecules carried inside its blood, has a microbial origin. The circulatory system extends the chemical impact of the microbiota throughout the body. For instance, 95 percent of the serotonin in mammal blood appears to be made, not by the eukaryotic cells, but from the bacteria that dwell within us. (Bäckhed et al 2004; McFall-Ngai et al 2012, Yano et al 2015).

Human pregnancy, too, is an amazing co-metabolic situation. The bacteria that are in a woman's reproductive and digestive tracts during the last months of pregnancy are different than those that are usually present. It appears that the hormones of the mother are changing the bacteria so as to shape the bacterial population that her baby

acquires during birth. Thus, the bacteria that colonize the fetus as it is leaving the birth canal are different from those that are normally present (Koren et al 2012). The mother has selected a subset of microbes for transfer. Moreover, once the baby is born, the mother's body will further promote the health of her offspring by selectively nourishing certain bacteria. A mother has two sets of nutrients in her milk—one set for the newborn, and one set for the bacteria that will help finish the construction of its gut capillaries and lymphoid tissues (Zivkovic et al 2013; Makino et al 2013). A human mother's milk contains several complex sugars that cannot be digested by the baby. These are not sugars for the baby; these are sugars for bacteria such as *Bifidobacteria*, which has genes that encode enzymes capable of digesting those special milk sugars. Through her symbionts and through her milk, the mother is causing developmental changes in her infant even after its birth. Indeed, "birth" is not the birth of a so-called individual. Birth is the continuation of the holobiont community (Gilbert 2014; Chiu and Gilbert 2015).

One of the biggest changes in our ideas of individuality is at the level of the immune system. Throughout the 20th century, we have been taught that the immune system was the defense network of our bodies, an amazing set of weaponry to protect us against a hostile environment. This certainly was the case during the AIDS epidemic in the later years of that century. Now, it seems that such protective functions probably

constitute a relatively minor part what an immune system does. Rather than being imagined as a force of protective soldiers, the immune system can be envisioned as a set of passport control agents and bouncers. Over the millions of years of evolution, it has learned which bacteria to let in and which to keep. The immune system is not simply fighting anything that is "not-self." Rather, it keeps out potential pathogens and at the same time facilitates the entry and maintenance of those bacteria that are supposed to be welcomed into our body, because, as in the many examples so far have shown, the bacteria are needed for completing our development and for our physiological functioning (Tauber 2008; Obata et al 2010; Round et al 2011). Indeed, in a remarkable set of dialectics, the immune system is generated, in part, by the microbes it will eventually come to regulate. Without the proper microbial symbionts, important subsets of immune cells fail to form. Germ-free mice have an immunodeficiency syndrome (Olszak et al 2012; Wesemann et al 2013). When monkeys are given infant formula instead of breast milk, they develop a different set of bacteria in their guts. And these bacteria do not induce the normal sets of T-lymphocytes in the immune system of the monkeys. This make the newborn monkeys more prone to opportunistic infections (Ardeshir et al 2014). We are thus not individuals by immune criteria.

Lastly, I want to focus on holobiont evolution. Evolution may be the evolution of holobionts, not monogenomic individuals. As Lynn Margulis (1999, p.33) said, "In short,

I believe that most evolutionary novelty arose and still arises directly from symbiosis." We are seeing this being played out in many fascinating ways. First, as mentioned earlier, in our discussion of pea aphids, the symbionts can provide selectable variation to the holobiont. Second, symbionts can effect reproductive isolation (Sharon et al 2010; Brucker and Bordenstein 2013) And a third program of symbionts in evolution suggests that we were *never* individuals! Indeed, the ability to become a metazoan, a multi-cellular animal, is probably a result of bacteria-eukaryotic interaction among choanoflagellates (Alegado et al 2012; Dayel et al 2011). One has to remember that the bacteria were here first. They had a two-billion-year head-start on eukaryotes. When eukaryotes came into being, they found themselves in a rich microbial environment.

It appears that there is no individuality in the classical biological sense. We have no anatomical individuality: most of our cells are microbes. We are not physiological individuals: we are joined in extensive co-metabolism with our microbes. We are not individuals by developmental criteria: the microbes help build our gut and our immune system. We have outsourced developmental signals to our symbionts. We are not even individuals by immune criteria--the microbes actually help make our immune system, and the immune system helps make niches for the microbes in our bodies. Genetic individuality falls apart, too: since we have over 150 genomes in our body beside our eukaryotic inheritance. Moreover, there is evidence that in many animals these genomes

function to give selectable phenotypes to the holobiont. We are multi-lineage organisms. Our "phylogenetic trees" may resemble real trees—i.e., being full of symbionts of different lineages. Evolutionarily, we are not individuals: In fact, we may evolve as consortia, as teams.

III. Rebuilding the body politic

In a social sense, symbionts play havoc with the notion of a pure body politic. We are definitely not monogenomic individuals. Our cells do not share the same single lineage. So what are symbionts? If one thinks of an animal organism in the classical sense of being an individual, then the symbionts are seen as *Gastarbeiten*, guest workers who do the work that the stable members of the population won't dirty themselves with. (One can think of such places as Saudi Arabia and Yemen, where certain lineages have citizenship and most of the population in the country are not citizens, but are temporary residents.) If one thinks of an animal as having porous borders, then the symbionts can be considered as legal resident aliens, like Greencard-holders in the United States. Only if one thinks of the animal or any other organism as a holobiont, where the body is constructed by the immigrant population, are the symbionts full citizens of an evolving and heterogeneous community. The body and the body politic reflect each others' awareness and anxieties.

And there's also the notion of competition and cooperation. One of the best-selling books this year has been Daniel Brown's *The Boys in the Boat*. One of its central themes is the interplay of competition and cooperation. First, one has to "make the team." This is a fascinating metaphor. The team is constructed through competition. But the competition is based on which group cooperates best. Different people cooperate better in one group than another. Anyone who has "tried out for a team" knows the intense competition to become part of a cooperating entity. In the symbiosis of the squid and bacteria that creates the squid's light organ, the squid poisons al other species but one—*Vibrio fisheri*—with which it has evolved to cooperate (McFall-Ngai 2014).

And once it has formed, the team competes against other teams. And, it is a team that advances not the individuals. One may have the best quarterback in the league, but if he has no pass protection, his team won't advance. And even as they compete, they cooperate to form a higher entity, the league, just as the species form a stable ecosystem. From competition comes cooperation; from cooperation comes competition. Both Thomas Huxley and Petr Kroptkin saw this interplay as a major part of evolution (Huxley emphasizing the [1]external competition; Kropotkin emphasizing the internal

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An ironic footnote: We've been looking at society from the standpoint of the big guy. But most of our cells are microbes. From their point of view, we are a source of niches. Taking an "inclusive fitness" perspective from the symbionts' standpoint, they want more niches. In other words, they want us to reproduce. There are parasites that are able to change the behaviors of their hosts to make them more amorous and have more offspring. (Adamo 2014; Adamo et al 2014). So maybe symbionts can do the same. We also know that symbionts can communicate with between hosts to promote fertility, and we

cooperation; See Gilbert 1979), but neither saw how multilineage individuals would be cooperating. "Making the team" becomes another metaphor for society. Symbiosis becomes recognized as a major player in the strategies that support life on this planet. The notion of "becoming with the other" has to be taken literally and has to become part of an evolutionary biology that had been based on the "war of each against all" (Gilbert and Epel 2015). If we are to model our societies on the structure of our organisms, we have a lot of new vocabulary to invent.

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also know that symbionts can alter sexual development to promote the production of females (Pontier and Schweisguth 2012; see Gilbert and Epel 2015). So, in female mammals, symbionts would promote reproduction--make more niches for our progeny. (Maybe they would erase the memories of previous pregnancies and deliveries.) In males (where the symbionts from the males mother are not propagated), the symbionts would benefit if the males mated with relatives of their mother. Hense, the Padan-Aram strategy of the Biblical patriarchs, who returned to Sarah's hometown to find their wives.

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