PART VI
General Microbiology

Studies on bacteria

1875 • Ferdinand Cohn

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FOR A NUMBER OF YEARS I HAVE endeavored, in association with my friend Herr Oberstabsarzt Dr. Schroeter, to study bacteria with the aid of the more perfect optical systems now available to us. Since Schroeter left this plant physiological institute in the summer of 1870, I have carried on these studies alone. I have first attempted to discover the biological relationships of the bacteria as well as to arrive at a decision concerning the differentiation of species. In addition, I have considered general questions, above all the fermentative activity of bacteria. Several preliminary communications of my results have already been presented to the Verhandlungen der Schlesischen Gesellschaft. Although these studies are still uncompleted, I believe it would be useful to present here a detailed discussion of them.

1. SYSTEMATICS (CLASSIFICATION)

What organisms belong to the group known as bacteria? What genera, what species, can be distinguished in this group? My first studies have been directed to this question.

Whoever is acquainted with the literature in recent years knows that there is a great confusion in the nomenclature of bacteria. Almost every observer has given new names to the forms that he sees, without consideration for his predecessors. The rule of

priority, which is universally used as the basis of nomenclature, has been completely disregarded here.

It is true that there are tremendous difficulties in differentiating and naming these organisms. Only Ehrenberg and Dujardin have attempted to classify the whole group of bacteria and related organisms and divide them into genus and species, and their works must serve as a point of departure. But aside from the fact that the principles which these workers used for separating out the groups leave much to be desired, they were further handicapped by the magnifications with which they could study the organisms. It is not surprising, therefore, that Ehrenberg has indicated structural relationships which we can no longer observe.

Even with the strong immersion systems available on microscopes today, we must admit that most bacteria are still at the limits of resolution, so that we cannot observe clearly their forms, the organization of their interiors, and the details of their reproduction. Even the very existence of some of the smallest forms would be in doubt if it were not for the fact that they occur in very large numbers.

An important difficulty lies in the small number of characteristics which are available for the classification of bacteria. In other organisms, the separation of genera is based on differences in reproduction, while the bacteria have not revealed as yet any true reproduction (egg or spore formation). So far as we can differentiate, their bodies show no diversity in arrangement and no characteristics of membrane or interior. Only the size, and within certain limits, the form of the members, as well as their combination into groups, offer certain characteristics which might be used, although we cannot always know how much these differences are due to species differences and how much they are due to the effect of external conditions, or indeed whether they are different stages in the development of the same organism. It is the most easy to differentiate bacteria by their size. But since they are usually composed of two or more members in a chain, we have the question of whether we should measure the size of the whole chain or of the single members. The former shows very marked variations in number of members, while the latter is difficult to measure due to the small size. It is impossible to isolate single bacteria and observe them for a long time under different conditions. But in mass culture there is no certainty that the inoculum was composed of a single type, or whether several types were inoculated at the same time. Therefore we possess no methods as yet for distinguishing age and developmental states, varieties, and species.

All of these difficulties arise when we attempt to separate bacteria into natural genera. The genera of bacteria do not have the same significance as do the genera of higher plants and animals, since bacteria only reproduce by vegetative reproduction, not sexually. It is therefore necessary to use in many cases a technique which has been used for a long time in mycology when it has not been possible to arrive at culture methods which will reveal the entire life history. This technique has also found applications today in the field of paleontology. It consists of calling every form which shows wide differences a genus. Then every small deviation from this is called a different species. In this way the possibility is not eliminated that various of such species may have arisen from one and the same parent form, and even that different genera may be only stages in the life history of one and

the same individual. In this way we differentiate species of *Uredo*, *Puccinia* and *Aecidium*, without knowing whether all three genera might only be single stages in one life history.* We speak of *Oidium* and *Aspergillus*, of *Achorion* and *Microsporon*, of *Stigmaria*, *Sigillaria*, and *Sigillariostachys*, without any certainty over the separateness of these "form genera." In the bacteria as well, we cannot avoid differentiating into "form genera and form species," except for a certain number of natural types. These form species must be accepted for every form showing deviation from the type, when this deviation under certain conditions is the exclusive or predominant form. The task of further research will then be to discover which of these form genera and species are perhaps merely stages in one life history.

Although Leeuwenhoek had observed bacteria in the seventeenth century, and O. F. Müller had recognized and described the most important forms in the eighteenth century, the first separation of forms on a scientific basis began with Ehrenberg. . . . In the basic work on the animal infusoria in 1838, he separated the family Vibrionia into four genera in the following manner:

Straight, rigid filaments: *Bacterium*

Straight filaments, twisted, nonrigid: *Vibrio*

Spiral filaments, nonrigid: *Spirochaeta*

Spiral filaments, rigid: *Spirillum*

He described 3 species of *Bacterium*, 9 of *Vibrio*, 1 of *Spirochaeta*, and 3 of *Spirillum*. . . .

Dujardin accepted Ehrenberg's family Vibrionia as the lowest in the series of infusoria in his work on the natural history of the zoophytes in 1841. . . .

* [It was later shown that these three genera were merely different stages in the life history of one species.]

However clear the characteristics for the differentiation of the genera *Bacterium*, *Vibrio*, and *Spirillum* might have seemed through Ehrenberg's description, in practice their use is quite difficult. . . .

All of those who have studied bacteria in the last 30 years have either accepted the genera of Ehrenberg or Dujardin without question, or they have designated the forms they have observed with indeterminate and occasionally completely obvious names (*Microphytes*, *Microzoaires*, etc.). This has been especially true of Pasteur, who sometimes speaks of *végétaux cryptogames microscopiques*, sometimes of *animalcules*, of *Champignons* or *Infusoires*, or of "*Torulacées*, *Bacteries*, *Vibrioniens*, *Monades*" without any sharp distinctions. . . .

If we turn then from the genera to the species, we find that even O. F. Müller, in spite of the low magnifications available to him, has named and illustrated the most surprising forms. But we should mention Ehrenberg, who continued the work of Müller, and who brought light and order into this confused area with his remarkable insight, and who not only used for his species precise and reliable characteristics, but also gave us a series of illustrations that have not been surpassed, which enable us to recognize these forms when we see them again. . . .

One can therefore ask the question if, in the bacteria, species generally occur in the usual sense that we find them in higher organisms. Even those who do not agree with the doctrine of some mycologists that everything comes from everything and develops into everything will despair when they look at a mass of bacteria, to perceive a separation into natural species of these countless little bodies.

It seems, therefore, that all of these forms are only stages in the life history

of one and the same organism, and intermediate stages can be found between the different forms varying in shape and size. Actually most of the recent workers on bacteria have come to accept this opinion as more or less proven. (Perty, Hoffman, Karsten.)

However, I have become convinced that the bacteria can be separated into just as good and distinct species as other lower plants and animals, and that it is only their extraordinary smallness and the variability of the species which makes it impossible for us with our present day methods to differentiate the various species which are living together in mixed array. I base this opinion upon the fact that in the larger bacterial species, always, even under different conditions, the same forms can be found in countless numbers and without intermediate forms. This is especially true for the spirilla which remain different from true rod-shaped bacteria. Also the individual species of spirilla are constant, in the same way as a "good" species of algae or infusoria. If in the smaller bacteria we cannot always delineate natural species but must be limited to the construction of form species, I consider this to be due to the inadequacy of our experimental methods. In general it will be difficult to determine the species of individual bacteria with certainty. However, when one and the same form is present in huge numbers without other organisms being present, the constancy of this type will usually be quite easy to determine.

A special difficulty arises from the fact that there are forms which cannot be distinguished at all on morphological grounds but nevertheless differ in important ways and show constant physiological differences, whether this may be in the environments in which they live, or in the products which they produce, or in the characteristics of their motility. . . .

Pasteur, who has already remarked that one cannot with certainty distinguish the nature of the organized ferments through microscopic structure, but only through physiological function, has cited the extraordinary similarity between the lactic acid and the acetic acid fermentations, as well as between the ammonia fermentation of urine and the slimy alcoholic fermentation (vin filant). The bacteria which produce red, yellow, orange, blue and other pigments can hardly be distinguished from each other under the microscope but when inoculated each always produces the same pigment. The bacteria present in various contagions agree in their forms at times with those of the urine or butyric acid fermentation, at other times with those that produce pigments. Should one consider each form which always occurs in a special environment, or which brings about a characteristic fermentation, to be a particular species, even when it cannot be distinguished from others microscopically? If we say yes, we will be erecting purely physiological species, which are characterized on exclusively physiological grounds, and not like the "good" morphological species.

I believe that it is not yet time to attempt an absolute answer to this question. . . . It is perhaps to be expected that amongst many apparently similar organisms which differ physiologically, we will find by more precise microscopical examination that morphological differences will be evident which can be used for primary differentiation. On the other hand, I consider it possible that we will find bacteria which cannot be differentiated by morphological characteristics but show chemical physiological differences, and these will be varieties or

races which originally arose from the same germ, but through constant, natural, or artificial culture under the same conditions and on the same medium always produce the same product. Since all bacteria reproduce only by asexual methods, such as budding or fission, such a fixation of a race characteristic is easier to accept. In the various types of yeast the production of races through artificial culture has been shown by Rees. In the same way that summer rye cannot be used as winter rye, although both races are of the same origin and could be returned to the same race through continued culture over a long period of time, top yeast cannot be used for the preparation of Bavarian beer (bottom yeast), and almost every wine or beer producer has his own yeast, so that it seems probable that many alcohol-producing yeasts are only a large number of cultural races of the same species. I assume that the bacteria which cause different chemical and pathological processes consist of a small number of individual species which have developed into a large number of natural and cultural races, which, since they only reproduce by asexual means, are able to maintain their physiological characteristics with more firmness.

2. ORGANIZATION AND DEVELOPMENT OF BACTERIA

The general characteristics of all of the organisms which I have included together in the bacteria appear to me as follows:

The bacteria are cells without chlorophyll, spherical, oblong, or cylindrical, containing also twisted or curved forms, which reproduce exclusively by transverse fission, and are either single or in families of cells. . . .

I divide the bacteria into four groups (Tribes) in each of which are one or more genera. In the nomenclature of the genera, I have retained throughout the older names, so that the nomenclature will not be overburdened, but I have used more clear cut characteristics and at times used other bases.

Tribe I. Sphaerobacteria (Sphere bacteria)
  Genus 1. *Micrococcus char. emend.*
Tribe II. Microbacteria (Rod bacteria)
  Genus 2. *Bacterium char. emend.*
Tribe III. Desmobacteria (Filament bacteria)
  Genus 3. *Bacillus n. g.*
  Genus 4. *Vibrio char. emend.*
Tribe IV. Spirobacteria (Corkscrew bacteria)
  Genus 5. *Spirillum Ehrenberg*
  Genus 6. *Spirochaete Ehr.* . . .

9. RELATIONSHIPS OF THE BACTERIA

Are the bacteria animals or plants? A review of the literature shows that the bacteria were earlier considered to be animals, but now most of the researchers consider them to be plants. . . .

In relationship to this question I can indicate the conclusion which I have already published in 1853:

"The bacteria (Vibrionien) seem to belong to the plant kingdom, because they are in direct and close relationship with undisputed algae."

On the other hand, the bacteria have no relationship with clear-cut animals. . . .

Most writers who include the bacteria amongst the plants consider them to be fungi. This is correct if one includes amongst the fungi all cellular plants or thallophytes which do not have chlorophyll or an equivalent pigment and do not assimilate carbon dioxide. But bacteria have no relation-

ships with a typical fungus which develops a filamentous mycelium and reproduces either through basidiospores or ascospores.

Comment

This paper illustrates some clear thinking regarding the problem of bacterial taxonomy. Considering the limited knowledge of the times and the absence of pure culture methods, it is amazing that Cohn was able to analyze the problem as accurately as he did.

Throughout the nineteenth century a controversy raged regarding the variability of bacteria. Some workers thought bacteria were highly variable (pleomorphic) and that all of the different forms that could be seen under the microscope were different stages of one species. Using modern genetic concepts, this would mean that all bacterial cells contained exactly the same genes, and the different appearances which they sometimes revealed were due to environmental influences. Other workers felt that different forms of bacteria were actually separate species with different genetic backgrounds. Cohn belonged to this latter group and presented his case here.

The controversy could not be ended until the pure culture methods of Koch became available (see page 101). Only then could it be shown that different bacterial types bred true and could be considered separate species. Cohn's attempt here to delineate several bacterial tribes and genera was premature but set the stage for later discoveries.

The problems of bacterial taxonomy are not yet solved today. Our current bacterial classification, as presented in *Bergey's Manual of Determinative Bacteriology*, was devised on the assumption that genetic recombination between bacteria did not occur, making classification strictly artificial. We know now that genetic recombination can occur. Future taxonomic studies will have to attempt to include this concept. Thus some day Cohn's objection that: "The genera of bacteria do not have the same significance as do the genera of higher plants and animals, since bacteria only reproduce by vegetative reproduction, not sexually," will no longer be valid.