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Author(s)	TANAKA, Yuriko
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Koch's Technologies and Postulates: How They Work Together in Connecting the Material and the Human in the Foundation of Bacteriology

Yuriko TANAKA

I. Introduction

In the last three decades of the nineteenth century, Robert Koch founded the science of bacteriology. This well-accepted statement may be confirmed by two distinct approaches, one historical and the other epistemological.

First, through the historical approach, we can examine some significant events and facts that should testify to the establishment of a science seriously pursued by a group of specialists. Koch's epoch-making paper on the etiology of anthrax in 1876, Louis Pasteur's memoir on the germ theory and its application to medicine and surgery in 1878, or the famous Seventh International Medical Congress in London in 1881 where those two leading microbiologists-"founding fathers" met in the flesh and were applauded by respected scientists, or the rather unusual success of Koch's pupil from a Far East island, Shibasaburo Kitasato, may certify that by the end of the century, a firm and universal science had certainly emerged that was in effect authorized and getting adopted globally.

On the other hand, the second approach, the epistemological one, may turn to the methodological analysis of Koch's significant inventions, i.e., his new experimental techniques and famous "Koch's postulates." These technologies and postulates were attained and refined by Koch over a period of years in his endeavor to establish causal relations between certain diseases and microorganisms. Together they paved the way for other researchers. It could be emphasized that the latter approach particularly concerns "internal" aspects of the formation of a group of specialists in bacteriology. And in this "internal" approach, we may again draw a distinction between two different possible directions: the analysis that questions the technical conditions of bacteriologists' perception and behavior, on the one hand, and the analysis of the logic that made possible the science of bacteriology on the other.

Michel Foucault in *The Archaeology of Knowledge* designated as guides in the subtle course of discursive formation four different types of "thresholds": "positivity," "epistemologization," "scientificity," and "formalization."[1] The historical approach may depict these facts as relating when and how "germs" or "contagious pathogenic microorganisms" passed the "threshold of positivity" and became an approved object of scientific activities. Here we may use the word "reality" to mean the "positivity" of objects, which would work upon and mobilize a group of researchers to become specialists in bacteriological science. On the other hand, the epistemological study concerning the logical structure of the bacteriological science too explores the questions of "reality," but from different angles. The epistemological analysis should investigate the conditions of human understanding and perception of "reality," or of substantiality, of what they were calling "pathogenic microbes."

This study takes the epistemological approach and examines how Koch contributed to the foundation of bacteriology, especially in relationship to the science's "passing of the threshold of posivity." Quite simply, this study explores the conditions, on which a particular entity finally reached to the level of "reality." With this sort of saying, some might judge that the paper should be in league with social constructivists in trying to insist that there had been a simple, or even false, fabrication at the origin of bacteriology. I should like to deny this hurried prejudgment by quoting Ian Hacking.

> Elaborating on this difference between people and thing: what camels, mountains, and microbes are doing does not depend on our words. What happens to tuberculosis bacilli depends on whether or not we poison them with BCG vaccine, but it does not depends on how we describe them. Of course we poison them with a certain vaccine in part because we describe them in certain ways, but it is vaccine that kills, not our words. Human action is more closely linked to human description than bacterial action is.[2]

Hacking continues, "The microbes' possibilities are delimited by nature, not by words."[3] It is true that at least in the life sciences one can never simply call their objects "fabrication" without first questioning his/her own authority to speak of "reality" vis-à-vis "nature." I should like to stress that it is only on the "human" side—what Hacking calls "human action" and "description"—that this paper intends to argue about the problem of "reality".

In the following sections, I will first discuss some decisive technical inventions Koch made. In this part, I will try to determine the characteristics of Koch's methodology and what

[1] Foucault, M., *L'archéologie du savoir*, Paris, Gallimard, 1969, pp. 243–244.
[2] Hacking, I., *Historical Ontology*, Cambridge, Massachusetts, Harvard University Press, 2002, p. 108.
[3] *Ibid.*

it aimed to achieve. Second, I will examine how this methodology worked together with some "postulates"—Koch's logical and linguistic innovations. In this part, I will argue that Koch's innovations affected what bacteriologists started seeing and thinking of thus providing them with a new entity and new logic that empowered them to pursue their science.

In addition, all through this paper, comparisons will be made between those two "founding-fathers," Koch and Pasteur, to explore how Koch's methodology and implied ideas were outstandingly effective in the establishment of bacteriology. Those two eminent scientists respectively founded their own sciences. A brief comparison of their concepts, methods, and logics will help us determine what was unique to Koch's science, and what was essential to the development of bacteriology.

II. Koch's Technologies

In the field of bacteriology, Koch left as his most valuable legacy three technical inventions: dyeing technique, microphotography, and pure culture technique using semi-solid media.

As has been often discussed, there had already existed a long history of arguments about the pathogenicity of microorganisms concerning infectious diseases in occidental sciences. Particularly, in the first half of the nineteenth century, there certainly existed emerging groups of researchers in medicine, botany, and biology who in different ways tried to establish causal links between certain diseases and microbes. However it is also well accepted that it was only when Koch and Pasteur emerged that the long murmured idea of "living contagious pathogenic micro-beings" somehow reached to an official level of acceptance in the scientific world.

In the history of endeavors to prove causal links between diseases and microbes, Koch's novelty rests on his insistence on the strict "specificity" assigned to distinct kinds of microbes and each one's pathogenic effect.[4] Certainly all of Koch's new techniques persistently aimed at, and progressed toward, the observation of this specific state of being of diseases and bacteria.

a. Techniques to See and Show: Dyed preparation, Microscope, and Photography

Starting with Koch's first bacteriological etiological paper on anthrax in 1876, we can trace through his successive papers the path of his technological inventions and elaboration. Having made a sensational debut into the German scientific world with the 1876 paper, he

[4] Mazumdar, P. M. H., *Species and Specificity: An Interpretation of the History of Immunology*, Cambridge, Cambridge University Press, 2002 [1995], pp. 46–103.

went on to work on the problem of wound infections (1878) and tuberculosis (1882), both of which evoked large responses from the then-emerging international scientific society. In between these was the paper presented in 1881 that he titled "On the investigation of pathogenic organisms," which should serve as a summary of the path and fruits of his endeavor during this period and explain the foundations of his methodology.[5]

In this 1881 paper, in a section titled "Enuciation of the problems to be discussed" Koch wrote, "In the first place, it must be definitely determined whether the organisms in question are pathogenic at all, that is to say, whether they can cause disease."[6] The "determination of pathogenic properties and infective virulence of micro-organisms"[7] was, for so-called "germ theory," the critical first threshold to cross, and it was by the "demonstration of the pathogenic organisms"[8] that Koch realized this monumental step.

Thomas Schlich, in his insightful study of Koch's methods as special techniques of "representing bacteria," regards this as a monumental step by Koch to open "a process of *extraction,*" in the sense Bruno Latour employed the term.[9] "Demonstration" was, needless to say, what Koch did in 1876 in front of Ferdinand Cohn, the eminent botanist whom Koch esteemed as "the best expert on bacteria"[10] of the day, in Breslau with his mice, rabbits, frogs, experimental tools and his "special details of preparation and examination."[11] Koch so excellently impressed Cohn that the latter immediately called his colleagues to see this young obscure doctor's performance. As T. D. Brock, P. M. H. Mazumdar, and Schlich respectively make clear,[12] Cohn was the one who had shared before they met Koch's passion for making

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[5] The papers referred here can be found in Gaffky, G. et. al. (ed.), *Gesammelte Werke von Robert Koch*, vol. 1, Leipzig, Geroge Thieme, 1912.: "Die Äetiologie der Milzbrand-Krankheit, begründet auf die Entwicklungsgeschichte des Bachillus Anthracis" (1876), pp. 5–26.; "Untersuchungen über die Äetiologie der Wundinfektionskrankheiten" (1878), pp. 61–108.; "Zur Untersuchung von pathogenen Organismen" (1881), pp. 112–163.; "Die Äetiologie der Tuberkulose" (1882), pp. 428–445. In this article quotations will be all from following English translations: 1876, 1878, 1882 papers are in Carter, C. K. (ed.), *Essays of Robert Koch*, Westport, Conneticut, Greenwood Press, 1987, pp. 1–19, pp. 19–56, pp. 83–96; 1881 paper is in Cheyne, W. W. (ed.), *Recent Essays By Various Authors on Bacteria in Relation to Disease*, London, New Sydenham Society, 1886, pp. 1–65.

[6] Koch (1881), *Recent Essays*, p. 4.

[7] *Ibid.*, p. 5.

[8] *Ibid.*, p. 6.

[9] Schlich, T., "Linking cause and disease in the laboratory: Robert Koch's method of superimposing visual and 'functional' representations of bacteria," *History and Philosophy of Life Sciences*, 22 (2000): 43–58, p. 44.

[10] Brock, T. D., *Robert Koch: A Life in Medicine and Bacteriology*, Washington, D.C., American Society for Bacteriology, 1999, p. 44.

[11] Koch (1881), *op.cit.*, p. 6.

[12] Brock, *op.cit.*, pp. 38–53; Mazumdar, *op.cit.*, pp. 58–61; Schlich, *op.cit.*, p. 46.

classification and representational specimens of bacteria, and he was ready to see and understand what each stage of Koch's procedure tells. Having fully understood and accepted the story Koch's demonstration related, Cohn provided Koch with the opportunity to publish his findings as well as the motive to doing so, to further brush up the technologies for "showing"[13] their observations to others.

It should be no wonder those "founding fathers" of microbiology—Koch, Pasteur, and Anthoni van Leeuwenhoek—all benefitted from the special gift of microscopy. While Leeuwenhoek, the amateur microscopist of the seventeenth century, never seriously wanted to share his extraordinary eyesight with the others,[14] Koch devoted much of his energies to the invention of devices and procedures to "enable others to take part in his observations."[15] Herein should be noticed a difference between the "scientificity" of the seventeenth and nineteenth centuries, the era of *virtuosos* and that of *scientists*.

Koch described his "special details of preparation and examination", which he performed in front of the Breslau influentials, in his 1876 paper.[16] He used slides and an incubator capable of careful humidity and temperature control, with which he cultured anthrax bacteria that had been taken before spectators from the spleen of a mouse that had died of anthrax in the culture medium he made of a cow's aqueous humor. He put the specimen on a slide, put a cover slip on it, and with the aid of microscope, one could observe the "developmental stage"[17] of anthrax bacteria. This developmental stage of bacteria, i.e., the spores with the potency "to grow into new bacteria,"[18] was what exactly Cohn, too, had sighted before, and could explain brilliantly the etiology of anthrax. Koch combined this instrumental representation of the "life history"[19] of bacteria with an experiment using the body of a frog, under the skin of which he implanted "some of the diseased spleen...to demonstrate how bacilli could develop and penetrate epithelial cells."[20]

In these observations, the bacteria on the slide and from under the frog's skin were shown to be one and the same, by displaying their morphological linkage. It means the sight seen through the microscope was above all crucial. It is well known that in 1878, Koch visited Ernst Abbe in Jena and procured the newly invented oil-immersion lenses directly from the Carl Zeiss Company, and that thereafter the researcher and the manufacturer maintained

13 Schlich, *loc. cit.*
14 Tanaka, Y., "Me to Kotoba", *Jinbun Gakuhou*（拙稿「目と言葉」『人文学報』），93 (2006): 85–105.
15 Schlich, *loc. cit.*
16 Koch (1876), *Essays of Robert Koch*, pp. 2–13.
17 Koch (1876), *Ibid.*, p. 2.
18 *Ibid.*
19 Koch (1881), *op.cit.*, p. 4.
20 Brock, *op.cit.*, p. 45.

reciprocal relationship all through their further mutual development.[21] This is the case with both the researcher and the apparatus itself. Firstly, the microscope gave Koch extraordinary sight, which led to the discovery of those novel "facts," and then in turn, Koch contributed considerably to the technological improvement of the apparatus as well as to refining techniques for utilizing it.

After the success of his anthrax study, Koch strengthened his insistence on the specific classification of bacteria and its primary link to diseases. Here is a typical assertion in the 1878 paper on wound infections: "I regard this fact as the most important result of my work. This is that there are differences among pathogenic bacteria and that each has a constant nature. As we have seen, each distinct bacteria form corresponds to a specific disease. This form always remains the same, however often the disease is transferred from one animal to another."[22] Consequently, Koch would claim, in investigations on infectious disease deemed to be caused by bacteria, that one must first of all exactly determine which kind of characteristic forms are to be seen and pursued. From that comes the necessity, which Koch mentioned in the beginning of the same paper, of "the most faithful representations of pathogenic bacteria."[23] Koch also declared it should be possible only with "dyes and photography"[24] although at that moment there still remained obstacles to overcome.

It meant, as Schlich has called the "extraction," that each "species" of bacteria related to certain diseases were to be "cut out" of all of the "background," not only by morphological observation but also with the aid of color contrast. Among microscopic images of bacteria, Koch made distinctions between the "structural" and the "colored."[25] In the 1881 paper, he meticulously prescribed the solutions for coping with the difficulties in staining specimens using the aniline dyes then available. Together with describing the utility of staining preparations in yellow or brown using "a new aniline color, methylene blue"[26] (newly introduced by Paul Ehrlich), Koch stressed that the preparations stained red or blue "catches the eye far more readily."[27] This was the case when he showed to the public "beautiful blue" tuberculosis bacilli in contrast with "all the constituents of animal tissue ... appear brown" in 1882.[28]

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21 *Ibid.*, p. 69.

22 Koch (1878), *Essays of Robert Koch*, p. 49.

23 *Ibid.*, p. 19.

24 *Ibid.*

25 Koch (1878), *op.cit.*, p. 32.; Brock, *op.cit.*, p. 68.; Turner, G. L' E., *Essays on the History of the Microscope*, Oxford, Senecio Publishing Co. Ltd., 1980, p. 175.

26 Koch (1881), *op.cit.*, p. 11.

27 *Ibid.* To this remark Koch added that "no one has succeeded hitherto in obtaining take good photographs" of the preparation stained red or blue, however, while in this regard yellow and brown had advantages.

28 Koch (1882), *Essays of Robert Koch*, p. 84.

One of Koch's notable characteristics is that he pursued all those dyeing techniques not just for the purpose of making the bacilli easier to see, but also to exhibit them, or, in other words, for propagating or persuading, getting their "good photographs"[29] out as evidence. Using oil-immersion lenses and the Abbe Condenser,[30] Koch persistently elaborated the techniques for taking these "good" and clear photographs of bacteria. In the 1881 paper he firmly asserted, "It should not be forgotten, in the treatment of the negative and development of the prints, that the photographic picture should not be mere illustration, but it should occupy the first lank as a proof ...," and consequently he added proudly that for the pictures "to show ... what can be accomplished by following the foregoing instructions I publish at the end of this paper ... must be admitted to possess an interest attaching to the object they illustrate, as well as to the fact that they are photographs."[31]

With technologies and thorough techniques, Koch told others what to do and what to see. Thus by facilitating bacteriological observation, he effectively rendered the sight of bacteriology uniform.

b. Handling: Solid or Semi-solid media and Pure Culture

Of course, it should be also stressed that in the first place there was a *thing* that Koch wanted to show—the bacteria with specific differences. On this point, Koch and Cohn were strongly allied, as "the Linneans" against their "adversaries."[32]

With the conviction of the specific differences of bacteria and their connection with pathology, Koch invented his new techniques for pure cultivations, which he detailed in the 1881 paper. Brock states that Koch's "introduction of a pure culture technique using solid or semi-solid media—soon known throughout the world as 'Koch's plate technique'" was "his greatest contribution to the development of bacteriology."[33] Simultaneously Brock underlines that it was not Pasteur who invented this new technique. Certainly, it was "the transparent liquid media"[34]—with "as the seed a drop of the preceding culture"[35]—that Pasteur used in an experiment on anthrax bacilli he boasted of in his 1878 memoir, which Brock judges to be "what today would be called as 'enrichment cultures'."[36]

Koch himself explicitly criticized "Pasteur's laboratory" that was then issuing "the

29 Koch (1881), *loc. cit.*

30 Brock, *loc. cit.*

31 Koch (1881), *op.cit.*, p. 25.

32 Mazumdar, *op.cit.*, pp. 46–97.

33 Brock, *op.cit.*, p. 94.

34 *Ibid.*

35 Pasteur, L., «La théorie des germes et ses applications à la medecine et à la chirurgie», *Œuvres de Pasteur*, tome 6-I, 1933, p. 113.

36 Brock, *op.cit.*, p. 95.

researches (carried on with really remarkable, if blind, zeal) ... which describe incredible facts with regard to pure cultivations of the organisms of hydrophobia, sheep-pox, pleuro-pneumonia, &c.," to which his harsh remark "one ... has only himself to blame if the results of his investigations are not held by scientific men to have been obtained by sufficiently exact methods, and are not therefore accepted as convincing," was "especially applicable."[37] It was simply that Koch and Pasteur did not share the idea of where the boundary of "purity" of their object of investigation should lie. The difference in the methods of Koch and Pasteur in this regard, or rather symbolically, the words "a drop" and "the transparent liquid," should tell how vague the outline of the entity called "bacteria" or "microbes" or "germs" remained in those days when they were still struggling to establish bacteriology as a science. A kind of microscopic "germ" in certain sorts of liquid should remain always in danger of being confused with its container itself, let alone with other kinds of "germs" swimming about together in the same liquid: after all, whether those "kinds" should be understood as the "species" or the phases of "morphological or physiological metamorphosis"[38] was still in dispute. And in this vagueness should also lie the biggest obstacle that has long prevented the emancipation of microbes and their pathogenic power from those miasmic figures—such as river water and gases over wetlands—in human understanding that should call for another "extraction from the background."

Solid or semi-solid medium provided solutions mainly in two ways: pinning and picking. After underlining the difficulties inherent in the pure culture using liquid medium, which included the careful sterilization of vessels and medium and the continuous microscopic control and exclusion of microorganisms other than the pursued bacteria from successive cultures, Koch declared, "I have abandoned the principles on which pure cultures have hitherto been conducted, and have struck out a new path, to which I was led by a simple observation, which any one can repeat"[39] and went on to describe the advantages he had found of "a boiled potato."[40] Koch found the potato as eminent nutrient as well as an excellent nest for bacteria, on which various microorganisms in the air dropped and settled, and then developed colonies around themselves, distinctively and separately, bearing different colors, and always on the surface. "We learn this most striking fact, that with a few exceptions every droplet or colony is a pure culture, and remains so until by growth it pushes into the territory on a neighbor ... ."[41] With those droplets which would grow but never swim nor dive, handling of a specific "family" of bacteria should become far more manageable. The smallest quantity

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[37] Koch (1881), *op.cit.*, pp. 35–36.
[38] *Ibid.*, p. 51.
[39] *Ibid.*, p. 37.
[40] *Ibid.*
[41] *Ibid.*, p. 38.

of the chosen—through microscopic examinations—droplet should be picked out of the surface, with a disinfected needle or platinum wire, and then inoculated to another surface, as "the sowing"[42] for further pure cultivations.

The capacities that a slice of boiled potato symbolized, i.e., nutritiousness, solidity or stickiness, or flatness, were respectively taken over by instrumental inventions such as variously compounded nutrient solutions solidified first with gelatin and later with agar, and flat glass plates, which evolved into the Petri plate. The ensemble of those instruments and their uses is what is called "Koch's plate technique." Brock deems the technique a "miracle" and questions why it "had not been thought of earlier."[43] Brock's own answer is that "earlier workers lacked the will to develop new techniques" while "... Koch was strongly committed [to the germ theory], and he realized the importance of the pure culture."[44] Maybe here it should be emphasized again that the "germ" in the theory of which Koch exceptionally devoted himself to was, in the first place, the bacteria "*which retain their characteristics, by which they differ from another, unaltered on the same soil and after several transplantations (so-called generations), should be regarded as different one from another, whether or not they be spoken of as species, varieties, &c.*"[45]

III. Koch's Postulates

Koch's techniques divide and isolate the presence of bacteria by their exclusiveness: they accentuate each bacterium's distinctiveness, morphologically as well as chemically (in relationship to nutrition or dying substances), as clearly and objectively as possible. Next, bacteriology should chase down the whole life course of one of these specific beings, of which each phase should be observed, and captured in pictures, as the evidence to everyone's eyes. Telling this life course is to show another aspect: a disease. Schlich calls such status of diseases in bacteriological researches "the functional representation" of microorganisms, which "can be regarded as another manifestation of the bacteria's existence"[46] and states "Koch's procedure was based on combining functional with visual representations, which together, in overlapping one another, made the causal agent appear as such."[47]

A reverse should become possible once the role of bacteria as the primal cause of infectious diseases was established. The following remark made in 1944 by Yoshio Kawakita, a

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[42] *Ibid.*, p. 44.
[43] Brock, *op.cit.*, p. 104.
[44] *Ibid.*
[45] Koch (1881), *op.cit.*, p. 52. The italics are in the original.
[46] Schlich, *op.cit.*, p. 43.
[47] *Ibid.*, p. 55.

Japanese bacteriologist, testified to the occurrence of this reverse and declared it was the very sign of the development of their science.

> Although as I have stated above the study of pathogenic microorganisms should begin with studying diseases as the initial clues for it, once ... the germ theory was established, we should know there has emerged a new standpoint from which one should observe now reversely from the side of pathogenic organisms. That was the attitude that we should no longer look at infectious phenomena in their *protean* final appearances but to the contrary examine them from where they originate.[48]

In this perspective, a phenomenon long called disease became the representation of another process. The human experience of disease, or rather sickness, as the content of the phenomenon turned out to be an effect, or a "protean" aspect, of another being's biology, appearing on the body of patients. Koch himself stated in the 1878 paper: "Thus, the animal body is an excellent apparatus for pure cultivation."[49] "The animal body" was therefore truly a sort of medium, a container, a culturing environment ("nutrition"[50]), as well as a stage or a screen on which the representation of pathological processes could be reproduced and watched.

Besides, Koch's experimental demonstrations were, as a whole, the representations of the bacteriological theory itself. As is well known, Koch himself never clearly fixed certain "postulates" as any kind of "dogma" for bacteriology, but through his early works, he gradually and persistently tried to put his experimental demonstrations in a logical order that would in the end most effectively convince observers of the "germ theory."[51] Thus, Koch elaborated a set of conditions, the fulfillment of which would result in the theory being visually reproduced or physically experienced. It is those conditions that the successors accepted as the dogmatic "Koch's postulates,"[52] and later partly altered according to their new findings. So "Koch's postulates" were not simply proclaimed all at once by Koch, nor by Jacob Henle as his predecessor, but should be understood as an accumulation of the subtle work pursued over years regarding the theoretical prop of bacteriology.

What are called Koch's postulates until today, basically with either three or four crite-

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48 Kawakita, Yoshio, "'Koch no jyouken' ni tsuite: byougentai-ron jyosetsu," *Nisshin Igaku*（川喜田愛郎「『Kochの條件』について：病原體論序説」,『日新医学』）, 33-1 (1944): 34–50, p. 45.

49 Koch (1878), *op.cit.*, p. 51.

50 Schlich, *op.cit.*, p. 55.

51 Carter, K. C., *The Rise of Causal Concepts of Disease*, Hants, Ashgate, 2003, pp. 129–145 (cf. Carter, "Koch's postulates in relation to the work of Jacob Henle and Edwin Klebs," *Medical History*, 29 (1985): 353–374); Kawakita, *op.cit.*; Brock, *op.cit.*, pp. 179–182.

52 Kawakita, *op.cit.*, p. 35.; Brock, *op.cit.*, p. 238.

ria,[53] reflect various historical consequences that resulted from a threshold, which Koch as a founder gave to the history, or the development, of bacteriology. Instead of examining closely the changes in those postulates in and after Koch's lifetime, however, here I will limit myself to examining a version of the postulates stated in his paper "On bacteriological research" in 1890,[54] which is, as K. Codell Carter states in his detailed study of the logical evolution of the postulates,[55] the last of those different versions that Koch himself proposed and revised. There Koch wrote:

> But the microorganism could not be regarded as an accidental concomitant of the disease once it was proved, first, that the parasite was present in every single case of the disease and, indeed, under conditions that corresponded to the pathological changes and to the clinical course of the disease, second, that it never occurred in other diseases as an accidental or non-pathological parasite, and third, that it could be isolated from the body and capable, in pure culture and often without other nourishment, of generating fresh cases of the disease. Given these facts the only possible relation between the parasite and the disease is that the parasite is the causal agent.[56]

Note that this statement, in which we can read three criteria, was made in 1890, when the struggle to establish the causal, and specific, relationships between bacteria and infectious diseases and the conflict with the adversaries of the germ theory were both reaching their ultimate resolution. The opponents that Koch's experimental demonstrations were to fight down, and the assertions to make prevail, were all present in those sentences. The first and the second criteria together told that a kind of parasite should "in every single case" of a kind of disease be "present", and at the same time "never" be "accidental." The presence of the parasite should no way be a "concomitant," as the most frequent objection that the germ

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53 The posulates' "final 'textbook' form" writen in 1883 by F. A. J. Löeffler, one of Koch's eminent pupils, introduced by Brock is "1) The organism must be shown to be constantly present in characteristic form and arrangement in the diseased tissue. / 2) The organism which, from its behavior appears to be responsible for the disease, must be isolated and again grown in pure culture. / 3) The pure culture must be shown to induce the disease experimentally.", while a version found in a 1884 issue of the British Medical Journal is "(1)that a special bacterium with definite characteristics marking it out form other forms of bacteria, is constantly present in the parts affected; (2) that this bacterium is present in sufficient numbers to account for the disease; (3) that it is not similarly associated with other diseases; (4) that this bacterium can be cultivated apart form the body, and that its introduction into lower animals is followed by the same effects as the introduction of the infective material itself" (Brock, *Ibid.*, pp. 180–181). See also Carter (1985), p. 353 (note 2).

54 Koch, "Über bacteriologische Forschung," *Gesammelte Werke*, vol. 1, pp. 650–660. English translation by Carter is in *Essays of Robert Koch*, pp. 179–186.

55 Carter, *op.cit.*, note 49 above.

56 Koch (1890), *Essays of Robert Koch*, p. 182.

theory faced insisted. To the contrary, it should be always "pathological," something that would entail a sequence. As we have seen, Koch offered those techniques of pointing out "the parasite" and reproducing manifestly a disease as the consequence of its—basically only its—growth in an animal body, which he regarded as virtually the final form of its pure cultivation. All of them aimed at fulfilling the third criterion: to reproduce a disease phenomenon by bacteria extracted from their background.

While the technologies Koch invented rendered the practices of bacteriology uniform, the "postulates" homogenized the perception, understanding, or interpretation of what they were seeing. An order is related by the postulates, which should connect different scenes in a sequence. Once this sequence was arranged, one can experience it in the flesh, as Cohn did through (though still unrefined version of) Koch's demonstration, which continued over a period of two days.[57] In the demonstration, the accentuated first and final stages of the procedure tell firmly what should be the origin and the result of the sequence: the bacteria as the former, and the disease as the latter. Thus, observers were bodily persuaded to accept the "germ theory" *in* the demonstration.[58]

Schlich states that Koch "combined" or "superimposed" those "visual and functional representations" of bacteria and thus realized "linking cause and disease in the laboratory." To this insightful remark I would like to add two further closely intertwined dimensions of Koch's procedure. First, it is the *time*, or the "superimposing" of the "beginning" and the "end" apparently as well as logically, that, together with his technologies and postulates, Koch made use of as a bonding agent to connect two things which are otherwise ontologically difficult to meet. And second, it is the human experience of disease or sickness, which was the ancient phenomenon as well as the collective memory and meanings lived and perceived by human beings, and the material presence and biology of microbes, the perception of which was newly made possible by technology, that the bonding agent acrobatically linked in the frame of a theory, and there opened a new plain on which bacteriology could develop.

The nature of Koch's contribution to the establishment of bacteriology by his technological inventions and "postulates" can be accentuated by comparing it with Pasteur's bacteriological demonstrations, such as the experiment against spontaneous generation with his famous swan-necked flasks or the anthrax vaccination trial in Pouilly-le-Fort. Both Pasteur's and Koch's demonstrations proved decisive "facts" empirically and persuaded observers of the reliability of the bacteriological science, but not in the same sense. Pasteur convinced his spectators of certain facts, while Koch showed the distinctive agents to watch in those facts and told a theoretical context to situate them in. Pasteur showed significant results while

57 Brock, *op.cit.*, p. 45.

58 Carter writes: "To achieve conversion, bacteriologists required, not mere evidence, but something akin to *miracles*" (Carter (2003), p. 126).

Koch pointed out the origin and the end.

Koch divided *and* connected the elements. Critics have often said that since the end of the nineteenth century, largely because of the success of bacteriology, biomedicine has fractionated the disease as pathological processes and its scientific reductionism has thus repressed the aspects of the human experience of suffering. However it should also be noted that making disease the representation of bacteriological processes never means the total erasure of the vision of disease as a human experience, for if bacteriology loses this human value of the phenomenon, then the biology of microbes should lose its essential significance too; thereby, the very word and concept of "pathogen" would vanish. Koch's postulates and technological inventions delicately connected the most human element and the material minute factors, and through that they designated the latter as nothing but the "germs" or the "pathogenic microorganisms." Thus, Koch as a founder of bacteriology secured the sphere of the latter, since then privileged for researchers to explore uninhibitedly.

And this should be stressed again: with all those minute materials and the sequence in which they should be observed their presence to its end, Koch proved them by his unique, synthetic methods of reproduction. This methodological facilitation, especially the stable repeatability of it, was Koch's outstanding and decisive contribution to the foundation of bacteriology. This methodological repeatability endowed bacteriology and its theory with unprecedented *portability*, which is what enabled the bacteriological science prevail so rapidly after Koch, almost literally all over the world.