# FRACTALS PHYSIOLOGY PARADOX

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Current proposals that fractal geometry enables us to understand and manipulate many aspects of physiology (such as circulatory, respiratory, cardiac and nervous phenomena), however attractive and innovative they may appear, may be over-simplistic and as equally limited as other theories and methods which they are intended to replace.

# Background

The concept of fractals was devised by Benoit Mandelbrot in 1975, his book 'Fractals: Form, Chance and Dimension' 1977) becoming a modern classic soon after appearing on the bookshelves. Mandelbrot coined the word 'fractal' because he assigned to each of the self-similar curves in systems like tree branches and roots a fractional dimension greater than its topological dimension. Fractals refer to any geometric pattern (other than Euclidean lines, planes and surfaces) which display the remarkable property that no matter how closely you analyse, subdivide or magnify it, any given segment of the pattern always looks the same. This property is known as 'self-similarity'.

Thus, if we look at a large branch of a tree with many smaller branches extending out from the main stem, we will notice that the selfsame pattern of branching continues right down to the tiny branching displayed by the veins in the leaves or the roots supporting the trunk. Applications in physiology draw the parallel that the dendrites of neurons, the veins and capillaries of the circulatory system and the network of airways associated with the lungs all display the same sort of branching within branching, like the old 'boxes within boxes' game known since ancient times.

Ary Goldberger of Harvard Medical School and colleagues have been especially active in modelling various physiological systems in terms of fractal geometry (Goldberger A & West B Yale J of Biology & Med 1987, 1: 421-435; West B & Goldberger A American Scientist 1987, 75 (4): 354- 365; Goldberger A et al Experientia 1988, 44: 983-987), especially insofar as fractal theory is related to so-called chaotic processes in biology, which have been shown to innovatively explain sudden heart death, cell division, sudden changes in hormonal levels, apparently erratic nervous events and other non-linear processes in many life forms. Other work and theories by scientists such as Ilya Prigogine ('Dissipative Structures'), David Bohm ('Implicate Order') and Rene Thom ('Catastrophe Theory') also relate to the same type of non-linear or indeterministic processes.

Besides stimulating the development of a new paradigm in the biological sciences, many popularisations of the applications of chaos, catastrophe, quantum, relativistic, fuzzy logic and other latter day physical theories and models have even reached the general public in the form of books such as 'The Tao of Physics', 'The Dancing Wu-Li Masters', 'Fuzzy Thinking', 'The Search for Schrödinger's Cat', 'Order out of Chaos' and 'Chaos: Making a New Science'.

Chaos and other non-linear theories explain that highly deterministic and linear processes are very fragile in maintaining stability over a wide range of conditions, whereas chaotic systems can function effectively over a wide range of different conditions, thereby offering adaptability and flexibility. This plasticity of function enables these systems to cope with the unpredictability and variability of the environment, bestowing dynamic adaptability instead of a more vulnerable precise homeostasis.

In this context, the psychiatrist, A Mandel reflected: "Is it possible that mathematical pathology, i.e. chaos, is health? And that mathematical health, which is the predictability and differentiability of this kind of a structure, is disease?". Furthermore, he added: "When you reach an equilibrium in

# **More Applications**

Dorko has suggested that fractal models of physiological systems be used to take conventional physical therapy further. In doing so, he applies the categorisation that the nervous system and the skin are fractal or non-linear in character, whereas muscles, bones, ligaments and tendons are linear or non-fractal. This classification leads him to suggest that linear tissues display a highly predictable response to irritation, stimulation or injury.

Dysfunction or pain arising from these structures, therefore, is easily interpreted. On the other hand, disorders affecting fractal systems like the nerves and skin are often idiosyncratic and difficult to analyse and control. This leads him to propose a fractal model and therapeutic approach which may overcome some of the problems not adequately explained by what might be termed the classical mechanistic model of physical therapy.

### **Further along the Branches**

If we travel further along the branches of fractalism in biology, we reach the stage that Alice reached when she tried to look beyond the Looking-Glass: what happens when we reach the level of magnification or subdivision where the apparent boundaries suddenly become living cells and components of cells?

That is precisely the question posed by the ancients when the atom was defined as that smallest indivisible particle which remains when you continue to subdivide matter indefinitely. This is the same issue which is captivating the attention of many of the world's greatest physicists who long ago progressed to a level of scrutiny and imagination that postulated the existence of quarks as even tinier constituents of matter.

At some stage of subdivision of the dendritic, alveolar or dermal branches we have to reach the point where the boundary must be seen as cell membranes, myelin sheaths, the constituents of the cells and ultimately the molecular building blocks of the cellular material, RNA, DNA and so forth. Does fractal theory then imply that all physiological fractal systems remain fractal even to this level of subdivision - or is there a breakdown of fractalism at a certain stage? Can we then deduce that the molecular structures comprising many physiological systems are really fractal? Maybe we can view them as being non-linear in structure and function, but does this entitle us to regard them as fractal? Is fractalism (fractality?) identical to non-linearity in such contexts?

Are we justified in classifying the musculotendinous and ligamentous systems as linear, when microscopy has shown very clearly that their fine structure is actually helical, similar to that of DNA? At an even more microscopic level, many proteins also exhibit helical structuring. Indeed a major question concerns the reasons why and how newly made inactive and loosely coiled proteins wind themselves into specifically shaped biologically active balls able to perform their particular tasks in a living cell (Richards F The Protein Folding Problem Scientific American Jan 1991). While we are at this level of conjecturing, we have to ask if we are justified in referring to helically twisted, dynamically strung sequences of amino acids as linear systems? Or would Mandelbrot be more satisfied to call these structures fractal?

Are we justified in focusing on the fractal nature of neurons and neglecting the interactive role of the surrounding neuroglial cells, which are far more numerous than the neurons? Traditionally the neuroglia are often thought of only as supportive tissue which play some role in neural nutrition and

stability, but for many years have been known to exhibit slowly varying electrical potentials.

What are we to make of the electrostatic, electrodynamic and electrochemical processes associated with these biologically alive chemical aggregates? Do we consider these forces and processes to be fractal or linear? What are we to make of the 'life force' associated with these biochemically wedded units? Would it be better to think of them as bits of information or packages of entropy, so that we should rather look at this microscopic melee in terms of mathematical non-linearities rather than structural fractals? After all, matter and energy have, since the days of Einstein, been regarded as two faces of the same coin.

Now this is tending to sound very abstruse and mathematical with very little attachment to the 'real' world of anatomy and therapy - but this foray into the microscopic world had to be done to examine whether or not the notion of fractality may break down somewhere en route to explaining or controlling 'reality' or the apparently macroscopic problems of medicine.

### **Fractal Structure or Fractal Function?**

Fractal theory has been used successfully to describe and analyse physical structures such as nervous, venous or river systems, as well as the outputs or functions of these and other structures. This brings us to the very fundamental issue of the differences and relationship between fractal structure and fractal function.

After all, Dorko and others imply that non-linear, non-deterministic, fractal output is of necessity produced by fractal or non-linear structures. Are we justified in making this deduction? Is it not possible for a linear structure to produce a non-linear or fractal output, or for a non-linear or fractal structure to produce a linear output? To enhance adaptability and survival, might biological systems not sequentially flip-flop between fractal and linear function or simultaneously exhibit linearity and fractal behaviour (these possibilities are allowed for in certain books on fractal mathematics).

Is Alice looking from one side of the looking glass at her reflection and her reflection is simultaneously looking at Alice from its side of the mirror, so that part of the answer lies in understanding the nature of the mirror and another part lies in understanding the nature of the viewer? How self-similar is a mathematical model to the structure or function it is attempting to describe?

### How much is the fractal map the territory?

In trying to apply theories of fractal mathematics and non-linear dynamics to physiological systems, are we not raising more questions that may be misleading us almost as much as the classical models that have served us so far? Are these borrowings from 'modern' physics not simply a matter of describing the same phenomena in a different language, rather than offering a method of real advancement of knowledge and application? Or do they really add a valuable dimension to what we have been using blindly for many decades? After all, Mandelbrot himself acknowledged that his system described better than it explained.