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Physics of Virus: The Special Case of Novel Coronavirus

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Abstract

In this short note we consider a possible application of fractal theory and fractional dynamics in the physics of virus. In particular, we investigate the special case of novel Coronavirus. We discuss about some physical characteristics of this virus, we emphasize on the decreasing fractal dimension of virus as a powerful strategy for a possible nanodrug design and finally we present a fractional modified model to the dynamical model of transmission of this virus.

Keywords: Fractal Theory; Fractional Dynamics; Physics of Virus

1. Introduction

A fractal is an object that has a non-integer dimension and with self-similar structures and in general they are defined by an iterative process instead of an explicit mathematical formula [1, 2]. The fractal dimension of the fractal object is defined by $D = \log(N)/\log(M)$, where N is the number of self-similar pieces (subsets) and M is the magnification factor [3,4]. Fractal nature of proteins and their surfaces has been investigated extensively in recent decades [5-8]. Nowadays it is well known that novel Coronavirus' surface is covered by the different kinds of proteins (Fig. 1).

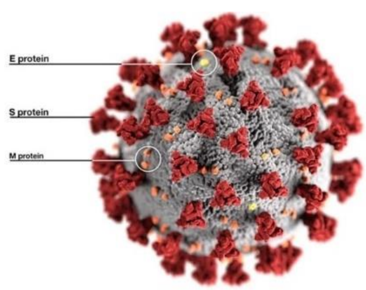

Fig. 1. Protein structure of novel Coronavirus' surface [from CDC.gov]: Spike (S), Membrane (M), Envelope (E) proteins which are embedded in the viral envelope.

Unfortunately, fractality of viruses and their surfaces has not been extensively considered by scientists yet. However recently in [9] the author proposed the idea that more complex viruses tend to be more fatal and fractality of the viruses' surfaces characterizes this complexity. Viruses with higher fractal dimension because of their unsmooth surfaces will alter the metabolic rate of host cells and in fact will result in higher metabolic rate for the host infected cells. For a single cell, its metabolic rate, Y scales as follows:

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$$Y \propto r^2 \quad (1)$$

where r is the radius of the cell. Here we consider this idea that metabolic rate change of host cell, ΔY_{hc} is related to the radius of entered viruses as:

$$\Delta Y_{hc} \propto r_{virus}^{D} \quad (2)$$

where r_{virus} is character radius of the virus, D is the fractal dimension of its surface, and it follows $2 < D < 3$. The below figure shows various viruses' surfaces [9].

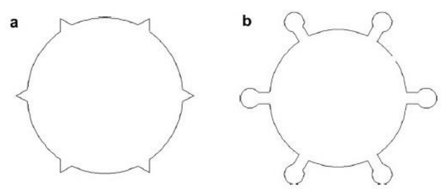

Fig. 2. Various viruses' surfaces' topology: (a) influenza virus; (b) SARS coronavirus (from Ref. [9]) with average particle size 100 nm and 90 nm respectively.

It is worth mentioning here that by fractality about viruses we just mean the low level fractal structures whose fractal dimension D is equal to $n-\varepsilon$ where $\varepsilon \ll 1$ and n is the integer number, so we do not expect having completely similar repeated structures at different scales. As we see and based on the world health organization (WHO)'s data about the above viruses it is reasonable to suggest this idea that higher fractal dimension of the viruses can results in more fatality. So based on the WHO's data about death and infected rates of people because of novel Coronavirus we expect to have more complex surface structure for this kind of virus. Following figure show this fact clearly.

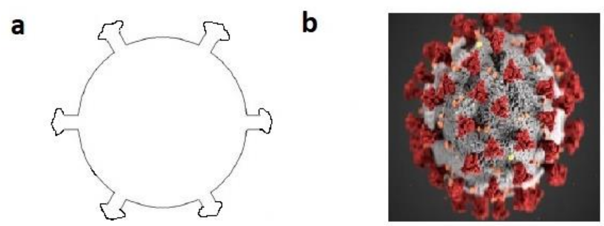

Fig. 3. Low level fractal structure of Novel Coronavirus' surface: a) schematic b) 3D view [from CDC.gov]. Topologically it seems that the novel Coronavirus is a combination of viruses in Fig. 2, i.e. influenza virus and SARS coronavirus and of course with almost identical sizes (about 120 nm) but very different molecular mass values and higher fractal dimension.

As we see in the above figure, surface structure of the novel Coronavirus is more complex (with higher fractal dimension) than those are illustrated in Fig.1. Based on this idea the author in [9] suggested a possible approach to cure or prevent fatal viruses' infections. The approach is to prevent virus infection by controlling the fractal dimension of virus' surface using nanotechnology that is by nanoparticles drug which occupy the middle spaces between proteins in the viral envelope provided that the nanoscale drugs don't be absorbed by human cells, but can be absorbed by the unsmooth surface of viruses, making the virus surface smooth, as a result, the fractional dimension of the virus becomes smaller and at the same time can prevent the virus from obtaining enough energy, leading to its final death [9]. So, when the metabolic rate of infected cells is not larger than the average metabolic rate of its host body, the viruses become harmless.

Therefore, in this approach we use the decreasing fractal dimensions as a strategy for prevention from virus infection. Finally for future variants of Coronavirus such as Omicron we predict more complex structures and also a higher transmission rate and hope the above-mentioned strategy work for it.

2. Fractional dynamic of the transmission of novel Coronavirus

As it is presented in previous section fractal theory can be used successfully for the physics of viruses and in particular the case of novel Coronavirus. Also, recently fractal theory has been successfully applied for the modeling of the growth of COVID-19 pandemic [10]. In this work they showed that the time series of infected population and deaths of the most impacted and unprepared countries exhibits an asymptotic power law behavior, compatible with the propagation of a signal in a fractal network.

However, it is noteworthy here that there is a close relation between the fractality and fractional calculus. Fractional calculus is a generalization of ordinary calculus that uses arbitrary order operators which are used to describe objects that can be characterized by a power-law non-locality, a power-law long-term memory and a possible fractal-type property [11]. The framework which describes dynamics of complex phenomena using the fractional calculus approach is called fractional dynamics and is well established as a powerful framework to study complex systems in different branch of science [12-18]. Based on the above-mentioned idea we can say that every successful dynamical studies on the physics of viruses should be conducted in the framework of fractional dynamics. Recently a mathematical model for the dynamics of transmissibility of novel coronavirus has been presented in [19]. Their model is presented using the traditional calculus. So, we can propose their model in the framework of fractional dynamics as follows:

$$\left\{\begin{array}{c} {}_0^cD_t^{\alpha}s_P = n_P - m_P s_P - b_P s_P(i_P + k a_P) - b_W s_P w \\ {}_0^cD_t^{\alpha}e_P = b_P s_P(i_P + k a_P) + b_W s_P w - (1-\delta_P)\omega_P e_P - \delta_P \omega'_P e - m_P s_P \\ {}_0^cD_t^{\alpha}i_P = (1-\delta_P)\omega_P e_P - (\gamma'_P + m_P) i_P \\ {}_0^cD_t^{\alpha}a_P = \delta_P \omega'_P e - (\gamma'_P + m_P) a_P \\ {}_0^cD_t^{\alpha}r_P = \gamma_P i_P + \gamma'_P a_P - m_P r_P \\ {}_0^cD_t^{\alpha}w = \varepsilon(i_P + c a_P - w) \end{array}\right\} \quad (3)$$

where s_P is the normalized susceptible people, n_P is the birth rate parameter of people, m_P is the death rate of people, i_P is the normalized symptomatic infected people, a_P is the normalized asymptomatic infected people, δ_P is the proportion of asymptomatic infection rate of people , e_P is the normalized exposed people, r_P is the normalized removed people including recovered and death people, ${\gamma_P}^{-1}$ is the infectious period of symptomatic infection of people, ${\gamma'_P}^{-1}$ is the infectious period of asymptomatic infection of people, ${\omega_P}^{-1}$ is the incubation period of people, ω'^{-1} is the latent period of people, k is the multiple of the transmissibility of a_P to that of i_P, ε^{-1} is the lifetime of the virus in w and ${}_0^cD_t^{\alpha}$ is fractional derivative of $0<\alpha<1$ order in the Caputo sense. fractional derivative of arbitrary order α which is defined in the Caputo sense is defined as follows:

$$ {}_{0}^{c}D_{t}^{\alpha} f(t) = \frac{1}{\Gamma(n-\alpha)} \int_{0}^{t} (t-\tau)^{n-\alpha-1} \frac{\partial^{n} f(\tau)}{\partial \tau^{n}} d\tau \tag{4} $$

where Γ denotes the Gamma function and $n-1<\alpha<n$, $n \in N$. For the solution of the dynamical models, we can use the numerical method suggested in [20]. The suggested method is as follows: consider biological models in the form of a system of fractional order differential equations of the form:

$$ \begin{cases} {}_{0}^{c}D_{t}^{\alpha} X(t) = F(t, X(t)) \\ X(0) = X_{0} \ , \ 0<\alpha<1 \end{cases} \tag{5} $$

where $X(t) = [x_1(t), x_2(t), ..., x_n(t)]^T$ and F is a continuous real-valued vector function represented by:

$$ F = \begin{bmatrix} n_P - m_P s_P - b_P s_P (i_P + k a_P) - b_W s_P w \\ b_P s_P (i_P + k a_P) + b_W s_P w - (1-\delta_P)\omega_P e_P - \delta_P \omega'_P e - m_P s_P \\ (1-\delta_P)\omega_P e_P - (\gamma'_P + m_P) i_P \\ \delta_P \omega'_P e - (\gamma'_P + m_P) a_P \\ \gamma_P i_P + \gamma'_P a_P - m_P r_P \\ \varepsilon (i_P + c a_P - w) \end{bmatrix} \tag{6} $$

and satisfies the Lipschitz condition that is:

$$ \| F(t, X(t) - F(t, Y(t)) \| \le L_F \, \| X(t) - Y(t) \| \tag{7} $$

where $L_F > 0$ and $Y(t)$ is the solution of the perturbed system. Now considering a $N-$point uniform mesh as $\mathrm{T} = \{t_0, t_1, ..., t_N\}$ we will have a discrete approximation to the fractional derivative as:

$$ {}_{0}^{c}D_{t}^{\alpha} x_i(t_n) \approx G(\alpha, h) \sum_{j=1}^{n} \omega_j^{\alpha} (x_i^{n-j+1} - x_i^{n-j}) + O(h) \tag{8} $$

where $G(\alpha, h) = \dfrac{1}{(1-\alpha)\Gamma(1-\alpha)} \dfrac{1}{h^{\alpha}}$ and $\omega_j^{\alpha} = j^{1-\alpha} - (j-1)^{1-\alpha}$.

3. Conclusion

In this work we investigated possible applications of fractal theory and fractional calculus to a possible method of infected people's treatment and also prediction of transmission due to the novel Coronavirus. For the first one we emphasized on the decreasing fractal dimension of virus as a powerful strategy for prevention from virus infection and also treatment of infected cases and for the second one we proposed the previous model for transition dynamics in the frame work of fractional dynamics. The approach introduced in this work can be applied in future research on the physics and biology of viruses and modeling of dynamic of the transmissions.

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