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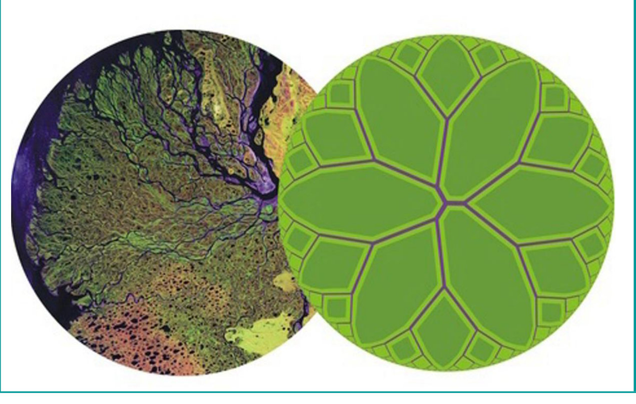


UNISINOS JESUÍTAS BRASIL

SHAPES AND HEAT TRANSFER IN CANCER: THE CONSTRUCTAL RESONANCE

Umberto LUCIA[a] and Giulia GRISOLIA[b]

[a] Dipartimento Energia "Galileo Ferraris",Corso Duda degli Abruzzi 24, 10129 Torino, Italy, umberto.lucia@polito.it
[b] Dipartimento Energia "Galileo Ferraris",Corso Duda degli Abruzzi 24, 10129 Torino, Italy, giulia.grisolia@polito.it

1. INTRODUCTION

Life is no more than an organisational process, which tends towards the maximum conversion of available energy. From a thermodynamic point of view, a living system is no more than an open system, in non-equilibrium thermodynamic states with its environment. Cancer cells were proved to be fermentative, as consequence of a metabolic injury and genetic processes. Differentiated cells are hyperpolarized as compared to quiescent or cycling cells, and the hyperpolarization increases the efflux of some ions (Ca^{2+}, K^+, Zn^{2+} etc.). If proliferation and invasion is out of control then a new behaviour occurs and cancer emerges as a disease of abnormal growth. From a thermodynamic point of view, living systems are no more than complex systems, open with a control of fluxes. Moreover, the analysis of the chemical species and of their reactions in the living cells have led to some sequences which start with nutrient molecules and end with the formation of living cells substance and waste molecules and waste heat. In this paper, we consider the energy injury in the following way: any cell process requires energy and mass fluxes, so a control of the energy conversion in the cell can represent a way to control the cell processes. So, Constructal Law represents a powerful approach to develop the analysis of the biosystems, just in relation to the energy and mass fluxes in order to design a possible control on the influxes and outfluxes. The Constructal law is distinct from the Second Law because the Second Law outlines the irreversibility, which is no more than the one-way nature of flows, while the Constructal law points out the generation of flow configuration, structure, and geometry as a consequence of dissipative processes, flows that overcome resistances and constraints, entropy generation, and nonequilibrium thermodynamics. Last, in physics and chemistry, resonance is the phenomenon in which a vibrating system or external force drives another system to oscillate with greater amplitude at specific frequencies. At resonant frequencies, small periodic driving forces have the ability to produce large amplitude oscillations, due to the storage of vibrational energy. So, in this paper we will show how a characteristic time of the biosystems exists and it holds to a frequency of electromagnetic or mechanical waves able to generate a resonant effect: this frequency can be evaluated by a Constructal law approach, so we name it "constructal resonance", due to its behaviour related to the fundamental structure of the nature of the living cells.

2. METHODOLOGY

The system considered is a single cell or as the cooperative system of all cells in a culture, and it is no more than an open system from a thermodynamic point of view, so, energy and matter flow through the border of the system, while biochemical and biophysical transformations occur within the system, with a related net production of entropy. But, any reaction generates a waste of heat towards the environment. So, we can consider cells as small systems which continuously dissipate energy. So, cells live in a continuous non-equilibrium steady-state, with heat wasted towards the environment.

To simulate this process Constructal law represents the fundamental approach, and we consider any cell as an adaptive thermal engine, which converts energy into work by coupling metabolic and chemical reactions with transport processes and wasted heat into environment. Here we focus our analysis on the wasted heat fluxes in order to consider the irreversibility of the life process. From the First Law of thermodynamics, we can evaluate the heat wasted by the cell, considering the usual equation of heat exchange between a solid (soft matter) system and the fluid around it. It follows:

$$\rho c V \frac{dT}{dt} = \alpha A \left(T - T_a\right) \qquad (1)$$

where r is the density, c is the specific heat capacity, V is the cell volume, T is the temperature, t is time, a is the coefficient of convection between the blood and the cell membrane, and A is the area of the surface cell. From equation (1) the Constructal frequency just the frequency of resonance obtained as:

$$\nu = \frac{1}{\tau} = \frac{\alpha A}{\rho c V} \qquad (2)$$

which represents the natural frequency of a cell which maintain a normal behaviour. So, when we apply a perturbation to a cell with a mechanical or electromagnetic wave at its constructal frequency, we expect to force an amplification of the heat exchanged. Consequently, when we excite a cell with a mechanical or electromagnetic wave at its constructal frequency we expect to force a normal behaviour. The constructal frequency is expressed in terms of physical properties of the systems but also by the geometrical characteristics V/A, the shape of the bio-system. This quantity results the fundamental property in the numerical evaluation because the numerical results are particular sensitive to any approximation of this quantity. This approach has been theoretically evaluated by some cells lines and also experimentally verified. In each experiment different cells lines have been exposed to an electromagnetic field, with the constructal frequency.

3. CONCLUSIONS

The results are summarized in Table 1 and in Figure 1. It is possible to point out that:

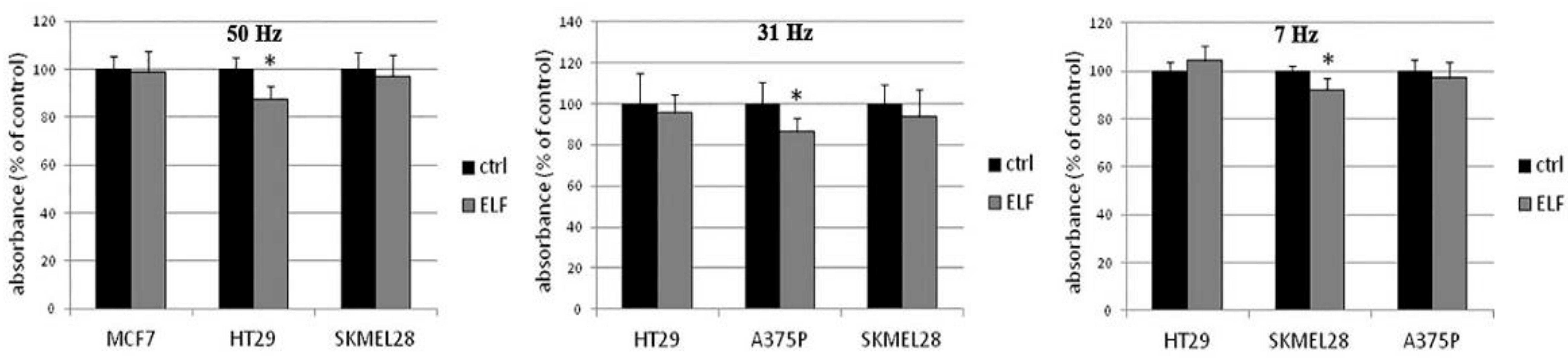
i) The constructal frequency is characteristic of each cell line;
ii) It depends on the shape and the volume, so the experimental results can consider only mean values due to the change of shape and volume of the cells during their life;
iii) Each cancer cell line decreases its growth at its proper constructal frequency, showing that the cancer is forced towards a normal behaviour by this bio-constructal resonance.

Last, the results point out the fundamental role of the cell volume-area ratio in relation to the fluxes control.

Table 1. Cell parameters and calculated ELF-EMF frequencies.

cell line	cell size [μm^2]	cell volume [μm^3]	Volume-area ratio	mean frequency [Hz]
MCF7	1,993 ± 16	16,468 ± 793	8.26 ± 0.46	5.0 ± 0.7
	1,051 ± 13	17,303 ± 1,040	16.45 ± 1.18	
	2,604 ± 21	42,284 ± 2,068	16.24 ± 0.93	
SKBR3	1,033 ± 11	1,795 ± 97	1.74 ± 0.11	8.0 ± 2.0
	2,066 ± 17	29,048 ± 1,301	14.06 ± 0.74	
	2,454 ± 20	47,594 ± 2,168	20.21 ± 1.05	
GTL16	1,042 ± 11	1,300 ± 80	1.25 ± 0.09	14.0 ± 3.0
	1,873 ± 15	2,630 ± 140	1.40 ± 0.09	
	1,059 ± 12	1,260 ± 77	1.19 ± 0.09	

Figure 1. Decreasing of growth at the proper frequency.



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