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SPECIAL DYNAMICS OF EXOSOMES BY MEANS OF AN INFORMATIONAL MODEL

BY

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Abstract. Taking into account that, at the cellular level, exosomes contain and operate with explicit (deterministic) and implicit (potential) information, an informational model on the dynamics of exosomes is presented. The model has been developed based both on exosomes structure and on their functions in intercellular communication.

Keywords: exosome; information; invariant groups.

1. Introduction

Intercellular communication has been widely studied, as it allows the transfer of information between cells either through direct contact or through various secreted molecules. The secretion of extracellular vesicles (EVs) is a common process, as they have been identified in various biological fluids, including blood. They are cell-derived structures that allow the exchange of nucleic acids, lipids and proteins between cells, playing a role in cell signaling (Colombo *et al*., 2014).

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Cell communication and the microenvironment play a very important role in cancer development and tumor growth (Kahlert and Kalluri, 2013). Exosomes are a class of EVs secreted by almost all types of cells, involved in cell communication with other neighboring or distant cells, immune response, cancer developing and organ-specific metastasis (Liu *et al*., 2016). They are composed of phospholipid double layer and measure from 50 to 100nm in diameter (Wang *et al*., 2014), containing all molecular constituents of a cell, such as DNA, miRNA, mRNA or proteins. Although exosomes have been first described 50 years ago (Wolf, 1967), their emerging role in cancer development and as a potential biomarker has been intensively studied in the last decade.

Taking the above into consideration, in the present paper, a correlation between exosomes' biological structure and functions and a mathematical model based on information theory is presented.

2. Exosomes – General Considerations

Structure of exosomes

The biogenesis and release of exosomes is still not fully understood, various mechanisms involved in the process such as the endosomal sorting complex required for transport (ESCRT) (Williams and Urbé, 2007), but also ESCRT-independent pathways involving ceramids or tetraspanins have been described. The pathways involved in extracellular vesicle biogenesis may differ according to the producing cell type.

Exosomes consist of a lipid bilayer membrane and contain various molecular constituents of the cell of origin, such as various types of proteins, lipids or DNA and RNA material (Van der Boorn *et al*., 2013), but also a common set of protein molecules (Batista *et al*., 2011), such as heat shock and cytoskeletal proteins. Exosomes from various cell types contain proteins involved in the biogenesis of the multivesicular endosome, in adhesion (such as integrins or tetraspanins) or proteins involved in membrane transport and fusion. The particular role each protein plays in the genesis, secretion or communication with other cells is not yet completely understood. Exosomes from certain cell lines seem to be more enriched in miRNAs (Pigati *et al*., 2010) and KRAS has been suggested that it could play a role in miRNA sorting. Colorectal cancer with mutated KRAS release exosomes with a distinct miRNA profile compared to wild type colorectal cells (Cha *et al*., 2015).

After the release from originating cells, the exosomes, both in physiological and in pathological processes, enter the vascular system and are transported to distant sites, where they can interact with other neighboring or long-distance recipient cells and deliver their content, RNAs, proteins and lipids. Specific adhesion molecules such as integrins, expressed by EVs, may influence the selection of recipient cells. Exosomes released by intestinal epithelial cells that express CD9, CD81, CD82 and A33 have a specific affinity

towards binding with serum albumin. After binding, EVs may fuse with the membrane, be internalized or even remain attached to the cell's membrane.

Function of exosomes

i) Function on immune system

Most cells that constitute the immune system release exosomes, having the potential to express immunological effects both towards immune stimulation or tolerability. Exosomes released by dendritic cells that carry MHC-peptides or various antigens can stimulate a specific immune response by other similar cells (Chaput and Thery, 2011). Moreover, they can also promote an immune tolerance in situations where they express immunosuppressive cytokines. In cancer, exosomes released by tumor cells may both carry antigens that could be a target for the immune system (Wolfers *et al*., 2001), or they contain immunosuppressive molecules that alter the T lymphocyte response (Clayton *et al*., 2007).

Exosomes may pay a role in the autoimmune diseases, as normal immune pathways may be dysregulated in these situations. In rheumatoid arthritis, the released exosomes contain TNFα, contributing to the destruction of specific immune cells and phosphorylating Akt. The latter leads to increased severity of the disease due to increased phenotypic expression of NF-κ B (Zhang *et al*., 2006).

In physiological situation such as pregnancy, as placenta-derived exosomes were described in pregnant women's blood and they may be involved in the mother's tolerance to the fetus (Mincheva-Nilsson and Baranov, 2010) and thus, in fetus survival.

ii) Function in cancer promotion and metastasis

Tumor formation and progression to metastatic disease remains an area of continuous research. Exosomes are mobile elements, which manage to transport various proteins and miRNAs (some may be involved in promoting metastasis) from the primary tumor to distant locations. They are released by various types of tumors, such as breast, brain, colorectal, lung, kidney, prostate, ovarian, oral cavity, melanoma and bladder cancer (Zhang and Grizzle, 2011). As they carry specific signatures, there is currently a research interest regarding their potential role as biomarkers. Moreover, they may play a role in transferring information from cell to cell, induce hypoxia or be involved in the formation of pre-metastatic niche and developing metastasis (Kahlert and Kalluri, 2013).

As exosomes contain various proteins and RNAs (both mRNA and microRNA), they can induce tumor signaling by transferring the information to another recipient cells (Valadi *et al*., 2007). In both the primary tumor and metastasis, exosomes can modulate the microenvironment, supporting tumor growth and dissemination via autocrine effects, stimulate proliferation endothelial cells and angiogenesis by increasing the endothelial expression of

VEGF receptors. In tumor microenvironment, exosomes from melanomas increase endothelial cells formation and stimulate the expression of angiogenetic cytokines such as VEGF and TGFβ. Angiogenesis is also stimulated by hypoxia in primary tumor, by increasing the release of exosomes that contain pro-angiogenetic cytokines or that promote pro-metastatic behavior, such as increased expression of miR-21-rich, further increasing tumor invasion and favor tumor cell spread.

Local tumor growth, as well as metastasis, depends on the supportive microenvironment. As exosomes play a role in modulating the tumor environment, other microvesicles secreted by tumor itself and also by nonmalignant cells are involved. Activation of fibroblasts by inducing the expression of α-smooth muscle actin, can induce cellular motility and promote invasion. Exosomes manage to transfer its content to another recipient cell and thus, it can also induce an oncogenic phenotype (Al-Nedawi *et al*., 2009). Vesicles from glioblastomas can transfer EGFRvIII in other cells, which lack this receptor, its expression remaining stable once transferred. This could represent one mechanism of transferring a more aggressive phenotype to another tumor cell, modulating its behavior.

The immune system should play an important role in recognizing, eliminating cancer cells and prevent tumor progression through various types of immune reactions. However, the immune system's responses seem to be down-regulated both by the tumor itself and by various inhibitory signals promoted by tumor-released exosomes. Some of the mechanisms exosomes manage to increase immune tolerance refer to reduced cytotoxicity, decreased interleukin-2 mediated proliferation of natural killer and T cells and down-regulation of APCs expression (Zhang and Grizzle, 2011).

In order to promote metastatic events, the primary tumor plays an important role by secreting various cytokines and growth factors that contribute to an optimal metastatic microenvironment. In pancreatic cancer, tumor released exosomes that overexpressed macrophage migration inhibitory factor (MIF) can induce liver pre-metastatic niche formation in mice. Targeting MIF could block the pre-metastatic niche formation and inhibit metastasis. In prostate cancer, the release of exosomes containing TGFβ from both tumor and mesothelium cells can induce fibroblast differentiation to myofibroblasts, precluding the formation of metastatic niche. Myofibroblasts play a role in tumor growth, angiogenesis and metastatic events and their concentration is high in tumor microenvironment (Webber *et al*., 2010).

iii) Role in cancer and treatment resistance

The development of tumor resistance to radiation therapy or chemotherapy remains an important topic in cancer research. Some of the mechanisms involved in the process include switching to other tumor growth pathways when the primary is blocked (targeted therapies towards specific receptors or mutation), selection of highly resistant cell subpopulation with

increased plasticity or alteration of tumor microenvironment that leads to decreased drug penetrance. The potential involvement of exosomes in modulating the mechanisms involved in radiation and chemo-resistance is currently being researched. Increased release of exosomes in surviving cells during radiation therapy could be an intrinsic factor of resistance as well as their role in preventing membrane lysis by the complement system during cancer treatment (Pilzer and Fishelson, 2005).

Chemotherapy and targeted therapy resistance are one of the main issues concerning cancer treatment, as most tumors develop resistance at one point through mechanisms that are not yet completely understood. The involvement of exosomes in treatment resistance was suggested in several preclinical trials, as one of the mechanisms of chemotherapy elimination can be through exosome release. Some of the drugs that are exported include anthracyclines and platinum agents, two of the most commonly used drugs in cancer treatment. Multidrug resistance ATP binding cassette transporter A3 (ABC3 transporter) system activated in various types of cancer modulates the biogenesis of exosomes, expelling drugs in the extracellular compartments, playing a role in chemotherapy resistance. The involvement of exosomes in drug expulsion and its correlation to treatment sensitivity or resistance was documented, as vacuolar protein sorting 4A (VPS4a), a protein that aids exosome secretion, is correlated to doxorubicin expulsion. Platinum resistance in ovarian cancer could be exosome-modulated as resistant cells, as cisplatin concentrations were significantly reduced in the lysosomal compartment (Safaei *et al*., 2005). The exclusion of cisplatin in the extracellular compartment by various transporters seems to be one of the mechanisms involved. A similar model was described in Trastusuzumab resistant HER2-positive cell lines, where the intracellular drug concentrations were reduced. Drug expulsion was correlated with tumor aggressiveness and treatment resistance both to chemotherapy and targeted therapies.

iv) Role as biomarkers for cancer diagnosis and therapeutics

As one of the issues in cancer research and treatment is the lack of specific biomarkers, the possible utility of exosomes in cancer diagnosis and prognosis has been proposed. Among the molecules carried by exosomes, tumor cell-derived miRNAs profile and expression pattern has been researched in the last years, as they seem to be cancer-specific and could indicate cancer aggressiveness. Its utility as a diagnostic and prognostic tool is still not completely understood. However, exosome miRNAs levels seem to be increased in squamous cell carcinoma of the esophagus and also be correlated with tumor type and stage (Shi, 2016).

As exosomes carry both a common set of proteins involved in exosome formation and secretion, and also specific proteins linked to the cell of origin, their role as a biomarker has been suggested and is currently under research. Exosomes and the tumor of origin can express similar receptors, a significant

percentage of receptors being expressed on the exosomal membrane. Current trends tend to identify methods of minimally invasive techniques for diagnosis, monitoring disease recurrence or treatment response. The concept of liquid biopsies is currently being under development in a series of solid tumors, with a potential utility using exosomes.

Exosomal surface receptors can also be a target for various drugs, acting as a drug delivery system for recipient tumor cells. A phase I trial used autologous exosomes pulsed with MAGE 3 peptides for the immunization of stage III/IV melanoma patients. The toxicity profile was favorable and one patient presented with partial response according to RECIST criteria. Another similar trial in metastatic lung cancer patients showed potential survival benefits of exosomes pulsed with MHC class I peptides (Michael *et al*., 2005).

Future directions

Although there is important emerging data regarding exosome function in cancer and potential role as biomarker for cancer diagnosis or treatment, several limitations need to be overcome in order to translate the preclinical research into clinical applicability. The technology and available resources in identifying, isolating the exosomes represent one important limitation. The heterogeneity of the methods used to quantify miRNAs translate into data that is difficult to compare and more difficult cu apply in the clinical practice. Further research into a better and a more accurate exosome classification is needed, considering the primary tumor, metastatic sites and also surface receptor expression. The potential role of liquid biopsy in exosome research could open less invasive alternatives to identify early recurrences or metastasis and even treatment response or resistance. Its possible clinical utility in treatment strategies and medical decision could help better tailor treatment for each individual patient.

Understanding better the mechanisms involved in cell communication and microenvironment adaptation and metastatic niche development via exosomes could provide new strategies to overcome treatment resistance and cancer progression. Future studies will also focus on the heterogeneity of exosomes in cancer and how this information could clarify the process of clonal expansion in cancer and how it is influenced by cancer treatments.

The concept of precision medicine in cancer has emerged in the last decade both in the preclinical and clinical studies. The transition from one tumor-one treatment in cancer to personalized medicine according to tumor biology and individual markers. The role of exosomes is now being unraveled and, although some questions have been answered, more questions also have risen. Their potential in cancer personalized diagnosis and treatment is currently under research.

3. Mathematical Model

Plane Homogeneous Quadratic Forms

Let us consider a phase space of variables *x*, *y* as the exosomes dynamics space. In the following, *x* willl be identified with the exosomes impulse and *y* with their postion. For geometrical visualization of both dynamics in this space and the second fundamental form of a surface, we have the notion of homogeneous quadratic forms in two variables. Such a quadratic form will represent the set of points written as

$$[Q]_{a,b,c} \equiv \left\{x, y;\ ax^2 + 2bxy + cy^2 = 1\right\} \tag{1}$$

Here *x* and *y* are the coordinates in plane, as referred to the center of representative conic, for the moment being left undetermined. The parameters *a*, *b*, *c* reflect the size and orientation of that conic. They are determined up to a normalization factor, and can therefore be treated as projective coordinates.

We are obviously taking now into consideration the case $\left(ac - b^2\right) > 0, \quad a, c > 0$ when Eq. (1) gives ellipses. Even though referred to its center, the ellipse is otherwise in a general position with respect to it. The group that possibly transforms these quadratic forms into one another – if there is one at all – must be a group *acting in three variables a, b, c*. Suppose now that we measure the position of the revolving material point with the outcome (*x, y*), and we have a set of possible alternatives for such a measurement. The group acting upon these alternatives – if there is one at all – must be *acting in two variables*, not three. Certainly, the two actions cannot be identical, but they should be realizations of the very same algebraic structure. Their closest relation, we may think of, can only be an isomorphism. This can be easily seen by supposing two locations of the revolving material point: the alternative (*x*, *y*) located on $[Q]_{a,b,c}$ given by equation

$$x = K_1^{-1}(y - y_1 e)(y - y_2 e) \tag{2}$$

and the alternative $\left(\mathrm{x}', \mathrm{y}'\right)$ located on

$$[\mathrm{Q}]_{\mathrm{a}',\mathrm{b}',\mathrm{c}'} \equiv \left\{\mathrm{x}', \mathrm{y}';\ \mathrm{a}'\mathrm{x}'^2 + 2\mathrm{b}\mathrm{x}'\mathrm{y}' + \mathrm{c}\mathrm{y}'^2 = 1\right\} \tag{3}$$

given by

$$a'x'^2 + 2b'x'y' + c'y'^2 = 1 \tag{4}$$

Now suppose, as we certainly always can do, that the two alternatives are related by the real homogeneous transformation – a SL(2, R) transformation

$$x' = \alpha x + \beta y \quad y' = \gamma x + \delta y \tag{5}$$

It is easy to see that between the quadratic forms we have the following linear transformation (Mercheș and Agop, 2016):

$$\begin{aligned} a' &= \delta^2 a - 2\gamma\delta b + \gamma^2 c \\ b' &= -\beta\delta a - (\alpha\delta + \beta\gamma) b - \alpha\gamma c \\ c' &= \beta^2 - 2\alpha\beta b + \alpha^2 c \end{aligned} \tag{6}$$

This shows that *a*, *b*, *c* are the components of a mixed tensor of SL(2, R).

From this moment on we can forget about this particular example, and look at the two sets of Eqs. (5) and (6) as characterizing two *different* isomorphic groups. They are both representatives of the known SL(2, R) algebraic structure. As continuous groups they always have three real parameters no matter of the number of variables involved in the action that realizes their transformations – one, two or three variables – and therefore the universal *structure equations* are given by the commutation relations:

$$[X_1, X_2] = X_1, [X_2, X_3] = X_3, [X_3, X_1] = -2X_2 \tag{7}$$

which we take as standard for this structure throughout the present work. Here X_k are the infinitesimal generators of those actions. Specifically, in the case of group (5) we have the *differential realization*

$$X_1 = y\frac{\partial}{\partial x} \quad X_2 = \frac{1}{2}\left(x\frac{\partial}{\partial x} - y\frac{\partial}{\partial y} \right) \quad X_3 = -x\frac{\partial}{\partial y} \tag{8}$$

while in the case of group (6) we have the *differential realization*

$$X_1 = -a\frac{\partial}{\partial b} - 2b\frac{\partial}{\partial c}, X_2 = -a\frac{\partial}{\partial a} + c\frac{\partial}{\partial c}, X_3 = 2b\frac{\partial}{\partial a} + c\frac{\partial}{\partial b} \tag{9}$$

These differential realizations characterize particular geometries, each describing the corresponding *actions* of SL(2, R). The geometries are related to classical aspects of the problems in the plane of motion for any dynamics.

Joint Invariant Functions in 2D theoretical physics

After this brief description of the main aspects of the two SL(2, R) actions we are considering here, let us come back to our main problem: the *joint invariant functions*. The transformations related to the two realizations (8) and (9) do correspond to some fundamental aspects of physical dynamics. The

question is: are the joint invariants of those realizations telling us something new over we already know? May be not, but they surely can tell us what to take as essential from what we already know. Let us illustrate this statement.

The Stoka system for the actions given by the operators (8) and (9) is:

$$\begin{aligned} & y\frac{\partial F}{\partial x}-a\frac{\partial F}{\partial b}-2b\frac{\partial F}{\partial c}=0 \\ & \frac{1}{2}\left(x\frac{\partial F}{\partial x}-y\frac{\partial F}{\partial y}\right)-a\frac{\partial F}{\partial x}+c\frac{\partial F}{\partial c}=0 \\ & -x\frac{\partial F}{\partial y}+2b\frac{\partial F}{\partial a}+c\frac{\partial F}{\partial b}=0 \end{aligned} \tag{10}$$

The rank of the matrix of coefficients is 3, so we have two independent integrals. They are

$$\frac{1}{2}\left(ax^2+2bxy+cy^2\right),\quad ac-b^2 \tag{11}$$

Consequently we can construct physical quantities related to any dynamics only as functions of both algebraic expressions above. This is a clear gain of the application of Stoka theorem (Mazilu and Agop, 2012), having far reaching implications. The first, and most important among these, is that if one of the expressions (11) is missing in the final equations of our theory, then this is indication of the fact that it is a *constant*. Case in point: the classical conservation of energy for any dynamics of conservative systems. It is not a law as long as we consider the frequency constant. In general, *i.e.* if the frequency varies, the physics is discussed in term of the ratio between energy and frequency, which is a joint invariant in the phase plane of the dynamics.

An even better known classical case, explicitly containing both of the expressions (11), is the Gaussian probability density function, as given by the equation

$$w\left(x,y\,|\,a,b,c\right)=\frac{\sqrt{ac-b^2}}{2\pi}\exp\left[-\frac{1}{2}\left(ax^2+2bxy+cy^2\right)\right] \tag{12}$$

This appears to be the objective reason for the fact that the Gaussian is so important for human knowledge in general. Regarding the present subject, it is harder to interpret (12) as a probability density in the case of any dynamics.

In such conjecture, a specific differential geometry based on a Poincaré – type metric of the Lobacevski plane (which is invariant to the homographic group of transformations) and also a specific variational principle (whose field equations represent a harmonic map from the usual space into the Lobacevski

plane) occur (Mercheș and Agop, 2016). In the following we will show how the Gaussian (12) and Shannon's informational entropy can be correlated.

Shannon's informational entropy

Let us consider Shannon's informational $\rho(y,x)$ entropy in a space of *x, y* coordinates (for example the phase space), with the constraints

$$\begin{aligned}
&\iint x\rho(y,x)\,dydx = \langle x\rangle,\\
&\iint y\rho(y,x)\,dydx = \langle y\rangle,\\
&\iint (x-\langle x\rangle)\rho(y,x)\,dydx = (\delta x)^2,\\
&\iint (y-\langle y\rangle)\rho(y,x)\,dydx = (\delta y)^2,\\
&\iint (x-\langle x\rangle)(y-\langle y\rangle)\rho(y,x)\,dydx = \operatorname{cov}(y,x),
\end{aligned} \tag{13}$$

where $\langle x\rangle$ is the mean value of *x* (for example the position), $\langle y\rangle$ is the mean value of *y* (for example the momentum), δx is the standard deviation of *x* (for example the standard deviation of position), δy is the standard deviation of *y* (for example the standard deviation of momentum) and $\operatorname{cov}(y,x)$ is the covariance of the random variables (y,x) (for example the covariance of the position and momentum variables).

We now introduce Shannon's informational entropy by means of relation (Cristescu, 2008)

$$I = \iint \rho(y,x)\ln\left[\rho(y,x)\right]dydx \tag{14}$$

Through the principle of Shannon's maximum informational entropy

$$\delta I = 0 \tag{15}$$

with constraints (13), the normalized Gaussian distribution is obtained

$$\rho(y-\langle y\rangle, x-\langle x\rangle) = \frac{\sqrt{ac-b^2}}{2\pi}\exp\left[-I(y-\langle y\rangle, x-\langle x\rangle)\right] \tag{16}$$

with

$$I(y-\langle y\rangle, x-\langle x\rangle) = \frac{1}{2}\left[a(y-\langle y\rangle)^2 + 2b(y-\langle y\rangle)(x-\langle x\rangle) + c(x-\langle x\rangle)^2\right] \tag{17}$$

and

$$a=\frac{(\delta x)^2}{D},\ b=-\frac{\mathrm{cov}(y,x)}{D},\ c=\frac{(\delta y)^2}{D},$$
$$D=(\delta y)^2(\delta x)^2-\mathrm{cov}^2(y,x) \tag{18a-d}$$

We observe that the set of parameters (a,b,c) has a statistical significance given by relations (18a-c). In these conditions, the statistical hypotheses are specified through a particular choice of the set of parameters (a,b,c) of the quadratic form (17).

If both $I=ax^2+2bxy+cy^2$ and $ac-b^2$ are constant, then it results that a representative point from space (y,x), which is in motion on a surface of constant energy, can also be found on a surface of constant probabilistic density (ergodic condition) in Stoler's sense (Mazilu and Agop, 2012):

$$\frac{\sqrt{a'c'-b'^2}}{2\pi}e^{-I(y',x')}=\frac{\sqrt{ac-b^2}}{2\pi}e^{-I(y,x)} \tag{19}$$

In this way, the "class" of statistical hypotheses associated to the Gaussians having the same mean is given by the ergodic condition. This is important and highlights the strong relationship between the energetic issues and the probabilistic ones.

Onicescu's informational energy and uncertainty relations

For the informational energy we shall use Onicescu's relation (Mercheş and Agop, 2016)

$$\varepsilon=\int_{-\infty}^{\infty}\int\rho^2(y,x)\,dydx \tag{20}$$

In such context, the informational energy corresponding to the normed Gaussians (12), which is subject to conditions $ac-b^2>0$, becomes

$$\varepsilon(a,b,c)=\int_{-\infty}^{\infty}\int\rho^2(y,x)\,dydx, \tag{21}$$

where $I(y,x)>0$ is a condition imposed by the existence of the integral (20).

We thus get

$$\varepsilon(a,b,c)=\frac{\sqrt{ac-b^2}}{2\pi} \tag{22}$$

Therefore, if I has energetic significance, it results the following:

i) the informational energy is an indication of the dispersion distribution since the quantity

$$A = \frac{2\pi}{\sqrt{a\,c - b^2}} \tag{22}$$

is a measure of ellipses' areas of equal probability $I(y,q)x = const$, in the manner that the normed Gaussians are even more clustered the more their informational energy is higher;

ii) the class of statistical hypothesis that are specific to the Gaussians having the same mean is given by the constant value of the informational energy. In the particular case of an oscillator, the constant value of Onicescu's informational energy implies $\varepsilon/\nu = const$ *i.e.* the first quantization;

iii) the constant informational energy is equivalent to the ergodic condition;

iv) if the informational energy is constant, then the relations (18d) give the egalitarian uncertainty relation

$$(\delta y)^2 (\delta x)^2 = \frac{1}{4\pi^2 \varepsilon^2 (a,b,c)} + \mathrm{cov}^2 (y,x) \tag{23}$$

or the non-egalitarian one

$$\delta y \delta x \geq \frac{1}{2\pi\varepsilon(a,b,c)} \tag{24}$$

In such conjecture, by specific values of ε, various uncertainty relations can be obtained. In particular, for $\varepsilon = 2\pi/h$, with *h* the Planck constant, the standard uncertainty relation from quantum mechanics can be found.

4. Conclusions

The main conclusions of the present paper are the following:

i) Firstly, the structure and functions of exosomes are presented: function on immune system, function in cancer promotion and metastasis, role in cancer and treatment resistance, and role as biomarkers for cancer diagnosis and therapeutics.

ii) Due to the fact that any study, be it *in vivo* or *in vitro*, implies dyamics in a fictional phase space, we develop a model based on dynamics in the phase space on conic-type curves. By means of such a procedure, a potential/implicit and deterministic/explicit Shanon-type information has been obtained, in such a manner that an generalized uncertainty relation results. The later shows that biological structures, in particular exosomes, contain and transmit information.

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DINAMICI SPECIALE ALE EXOSOMILOR PE BAZA UNUI MODEL INFORMAȚIONAL

(Rezumat)

Luând în considerare atât structura, cât și funcțiile exosomilor, în prezenta lucrare se dezvoltă un model teoretic pentru dinamicile acestora. Întrucât exosomii conțin și operează cu informație explicită și implicită, acest model teoretic este unul de tip informațional.