Cancer as a Chronic Disease with which Human can Coexist

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Abstract

The aim of the current study is to establish new physical tumor-markers for the effectiveness of the cancer therapy upon which human can coexist with cancer as a chronic disease. Doubling Time-Energy Conversion (DT-EC) during tumor formation and cancer therapy were investigated in groups of mice i.p. injected with \((1 \times 10^6)\) HeyA8 MDR cells and \((2.5 \times 10^5)\) HeyA8 cells, and treated by cell cycle specific drug (docetaxel) one week after tumor cell injection. Therapy for HeyA8 tumor model consisted of three groups: (a) Phosphate Buffered Saline (PBS), (b) Maximum Tolerated Dose (MTD) for Docetaxel \((15 \text{ mg/kg every 2 weeks})\), (c) metronomic Docetaxel \((0.5 \text{ mg/kg thrice weekly})\). Therapy for HeyA8 MDR tumor model consisted of two groups: (a) PBS, (b) MTD Docetaxel \((15 \text{ mg/kg every 2 weeks})\) Mice were monitored for adverse effects and tumors were harvested after 3 to 4 weeks of therapy. Tumor of advanced stage (HeyA8 MDR model) was characterized by higher rate (1st derivative) of DT-EC (with respect to the doubling time) and faster deceleration (2nd derivative) of DT-EC (with respect to the doubling time). Energies yield by equivalent doses with same regimen (MTD) in both tumor models were identical regardless to tumor size or resistance. Metronomic regimen was more effective than the standard one in HeyA8 model. Despite the dose of the metronomic regimen \((147 \mu\text{g/mL})\) was about one fifth of that of the MTD of the standard one \((840 \mu\text{g/mL})\) the energy yield by the smaller dose was greater than that yield by the higher one with more reduction in the rate of DT-EC and more slowing for the DT-EC deceleration. Thus the effectiveness of the cancer therapy is assessed by how much the 1st derivative of DT-EC has been minimized and by how much the 2nd derivative of DT-EC has been slowed down to treat cancer as a chronic disease with which human can coexist as long as possible.

Keywords: Doubling time-energy conversion; Emad formula; Cell cycle specific chemotherapy drugs; Metronomic regimen.

Introduction

The process of cancer therapy is based mainly on the concept of Doubling Time-Energy Conversion (DT-EC) in which the conversion of doubling time into growth energy takes place \([1, 2]\). The concept of the equivalence of doubling time and energy is obvious in cancer therapy in which the change in doubling time is a relatively large fraction of the initial
doubling time [3]. This type of energy was named cell growth energy due to the increase of the rate of mitosis than the rate of apoptosis which leads to the growth of the population of the tumor cells [4]. The duration of the mitosis stage is defined by the cell doubling time or the division time and denoted by \( t_o \) [5].

The fundamental principle for the cell cycle duration in relation to the physical energy condition of a cell has been derived and confirmed. Growth energy \( E_g \) of the biological cell was expressed in terms of \( t_o \) by the DT-EC formula \( E_g = \ln (\frac{\ln 2\text{ (in) sec}}{t_o}) \) (Emad Eqt (1)) which is known by Emad formula referring to the unit used in identifying the converted energy [6, 7]. The DT-EC formula represents the total existence energy that the biological cell possesses through its cycle duration [1, 2]. The converting factors of the Emad unit of each of the biological cell and the Iodine-131 were taken equivalent as it is the commonest safely used radionuclide. i.e. 1 Emad = 23234.59 MeV Eqt (2) [8]. This important formula represents the total energy of a biological cell, suggesting that the biological condition for the existing cell is increasing along its whole domain as shown in figure (1).

Consequently the 2\textsuperscript{nd} derivative of the cell \( E_g \) as a function of cell \( t_o \) can be derived from Eqts (1) and (3) as follows:

\[
\frac{d^2E_g}{dt_o^2} = \frac{2}{t_o} \times e^{t_o} \left( e^{2t_o} - 2e^{t_o} + 1 \right) Eqt (4)
\]

which is always positive along the domain of \( E_g (t_o > 1\times e \text{ Sec}) \) to indicate that \( E_g \) is increasing along its whole domain as shown in figure (1).

\[
\frac{dE_g}{dt_o} = \frac{2}{t_o} \times e^{t_o} \left( e^{2t_o} - 2e^{t_o} + 1 \right) Eqt (3)
\]

Identifying the effectiveness of cancer treatment

The 1\textsuperscript{st} derivative of the cell \( E_g \) as a function of cell \( t_o \) can be derived from Eqt (1) as follows:

\[
\frac{dE_g}{dt_o} = -\frac{2}{t_o} \times e^{t_o} \left( e^{2t_o} - 2e^{t_o} + 1 \right)
\]

which is always negative expressing a deceleration along the domain of \( E_g (t_o > 1.884169385 \text{ Sec}) \) to indicate that \( \frac{dE_g}{dt_o} \) is decreasing along its whole domain to show that rate of DT-EC decreases by the increase of \( t_o \). Accordingly, it can be deduced that during tumor formation the rate of this conversion decreases gradually.

Methods and Materials

Identifying the effectiveness of cancer treatment

The 1\textsuperscript{st} derivative of the cell \( E_g \) as a function of cell \( t_o \) can be derived from Eqt (1) as follows:
Thus, as much the physical tumor-marker \( \frac{dE_{\text{tumor}}}{dt} \) decreases, whereas the other physical tumor-marker \( \frac{dE_{\text{cell}}}{dt} \) increases algebraically (slows) during therapy than their values during tumor formation as much the treatment would be more efficient.

**Influence of pharmacokinetic on the effectiveness of cancer treatment**

Half-life time of chemotherapy drugs (\( t_{1/2} \)) is considered one of the main parameters to distinguish between those drugs in investigating their suitability and approval to treat certain disease [9]. Thus the following proof is to investigate the influence of \( t_{1/2} \) on rate of DT-EC and the effectiveness of cancer treatment:

\[
\text{As } \frac{dE_{\text{tumor}}}{dt} = \frac{dE_{\text{cell}}}{dt} = \frac{dt_{1/2}}{dt} \quad \text{Eqt (6), then rate of DT-EC during therapy depends on two main factors; rate of the growth energy acquired by the cell (} \frac{dE_{\text{cell}}}{dt} \text{) and rate of increase of } t_{1/2} \text{. From Eqt (6), as much as } \frac{dE_{\text{cell}}}{dt} \text{ decreases and } \frac{dt_{1/2}}{dt} \text{ increases as much as rate of DT-EC during therapy decreases as well that implies the increase of the effectiveness of the treatment and conversely.} 
\]

Notably, growth energy (\( E_{g} \)) acquired by the cell during an efficient therapy would be equivalent to that yield by the used drug (\( E_{\text{dose}} \)) in the therapy duration [2]. Accordingly, the increase of \( \frac{dE_{\text{dose}}}{dt} \) contributes in the effectiveness of cancer treatment as follows:

\[
E_{\text{dose}} = E_{1 \text{Dose}} \times (1 - \text{e}^{-\frac{\ln 2}{t_{1/2}}}) \quad \text{Eqt (7)} 
\]

where \( E_{1 \text{Dose}} \) is the energy of the administered dose, \( t_{1/2} \) is the half-life time of the used drug and \( T \) is the time from initiating the treatment. Thus, rate of energy yield by the drug during therapy:

\[
\frac{dE_{\text{dose}}}{dt} = \frac{\ln 2}{t_{1/2}} \times E_{\text{dose}} \times \text{e}^{\frac{-\ln 2}{t_{1/2}}} \quad \text{Eqt (8)} 
\]

which increases by the increase of \( E_{1 \text{Dose}} \) and the decrease of \( t_{1/2} \).

From Eqts (3), (6) and (8)

\[
\frac{dt_{1/2}}{dt} = \frac{\ln 2}{t_{1/2}} \times \frac{\ln V_{\text{final}}}{\ln V_{\text{initial}}} \text{e}^{\frac{\ln 2}{t_{1/2}}} \quad \text{Eqt (9)} 
\]

which decreases by the decrease of \( t_{1/2} \) and the increase of \( t_{1/2} \). Thus, the opposite impacts of \( t_{1/2} \) on the rate of DT-EC during therapy shown by Eqts (8) and (9) demonstrate that \( t_{1/2} \) doesn’t influence that conversion and consequently the effectiveness of cancer treatment. Hereby it can be concluded that Eqt (3) is valid to express the rate of DT-EC during tumor formation and during therapy as well. On the other hand, it should be noted that during tumor formation or therapy the tumor \( t_{1/2} \) varies linearly with time as follows:

\[
\frac{dt_{1/2}}{dt} = \frac{\ln 2}{\ln V_{\text{final}} - \ln V_{\text{initial}}} \quad \text{Eqt (10)} 
\]

\[
\frac{dt_{1/2}}{dt} = \frac{\ln 2}{\ln V_{\text{final}} - \ln V_{\text{initial}}} \times t \quad \text{Sec Eqt (11)} 
\]

Where \( V \) is the tumor volume, and as much \( \frac{dt_{1/2}}{dt} \) increases as more as the treatment would be efficient.

**DT-EC kinematics in tumor models treated with cell-cycle specific drug**

Next, consider a basic cancer therapy in which drug acts as a cytostatic agent inducing cell cycle arrest to check the above mentioned hypothesis for the effectiveness of cancer treatment. Chemotherapy drugs which are known by cell-cycle specific are the most suitable for the following check because of their non linear effect. Those drugs affect cells only during mitosis such that as long as doubling time of the tumor prolongs as much as tumor cells affected by the drug [11]. The scheduling of such chemotherapy drugs is based on the type of cells, rate at which they divide, and consequently the time at which those drugs are likely to be effective [11]. Docetaxel belongs to this class of chemotherapy drugs [12], which was selected to check the hypothesis of the current approach. As conducted and described by Kamat AA, et al [13] for long-term experiments to assess tumor growth 200 \( \mu L \) of concentrations of 5x10^6/mL of HeyA8 MDR cells and 1.25x10^6/mL of HeyA8 cells were i.p. injected in female athymic nude mice. Groups of mice (n = 10 in each group) i.p. injected with (1x10^6) HeyA8 MDR cells and (2.5x10^5) HeyA8 cells were treated one week after tumor cell injection. Therapy for HeyA8 tumor model consisted of three groups: (a) PB S, (b) Maximum Tolerated Dose (MTD) for docetaxel (15 mg/kg every 2 weeks), (c) metronomic docetaxel (0.5 mg/kg thrice weekly). Therapy for HeyA8 MDR tumor model consisted of two groups: (a) PB S, (b) MTD Docetaxel (15 mg/kg every 2 weeks) Mice were monitored for adverse effects and tumors were harvested after 3 to 4 weeks of therapy. If animals in any group began to seem moribund and required sacrifice, all animals in the experiment were sacrificed together. Mouse weight, tumor weight, and distribution of tumor were recorded. Survival experiments were also done, which were initiated one week after tumor cell injection. Mice of HeyA8 tumor model were treated as described above and individually killed when moribund (unable to move or reach food). The date of death was recorded as the day a mouse was sacrificed.
Results and Analysis

Therapy with different doses was initiated one week after tumor cell injection at which the median weight of the injected tumors was 0.1g. The docetaxel-treated animals exhibited a tumor growth delay along the whole duration of the experiment which terminated after 3-4 weeks [13]. Survival data were compared for significance with the log-rank statistic. Treatment with MTD (P = 0.03) and metronomic Docetaxel (P = 0.002) both significantly prolonged survival [13].

Effect of the Maximum Tolerated Dose of Docetaxel in treating HeyA8 tumor model

While the median of control tumors grew to 1.2g at the end of the experiment, the MTD of docetaxel (15 mg/kg/ two weeks) resulted in a reduction in the median tumor weight to 0.42 g after 3-4 weeks of therapy (P < 0.001)[13].

A dose of 15 mg/kg/2 weeks of docetaxel for 3-4 weeks in human (70kg, 2.5L plasma) is equivalent to \( \frac{15 \times 2 \times 70}{2.5} = 840 \) \( \mu \) g/mL.

Tumors in the mice received the treatment of docetaxel (840 \( \mu \) g/mL) had a growth curve with \( t_D \) of 11.83352313 days [from 0.1g to 0.42 g in 3.5 weeks (p<0.001)], while \( t_D \) was 6.834102168 days only for the group of control tumors [from 0.1g to 1.2g in 3.5 weeks (p<0.001)]. Moawad presented a clinical staging model at the cellular level in which the tumor histologic grade (HG) can be identified as follows:

\[
H_G = \ln \left( \ln \left( \ln \frac{2.5}{0.1} \right) \right) \times 15 \times 2 \times 70 = 840 \text{ } \mu \text{g/mL}
\]

From Eqts (3) and (4), the 1st and the 2nd derivatives of \( t_D \) in those groups of tumor Model (2.5 \( \times \) 10^5 HeyA8 cells) were 3.13566995x10^-7 Emad/Sec and -1.19318468x10^-10 Emad/Sec^2 respectively, while values of those derivatives in those groups of tumor Model (1x10^6 HeyA8 MDR cells) induced by 840 \( \mu \) g/mL of Docetaxel was as follows:

\[
\ln \left( \ln \left( \ln \frac{2.5}{0.1} \right) \right) \times 15 \times 2 \times 70 = 840 \text{ } \mu \text{g/mL}
\]
with 840 \( \mu g/mL \) in standard regimen was 7.01519471x10\(^8\) Emad/Sec less than that of the control tumors of HeyA8 MDR cells (7.03154621x10\(^8\) Emad/Sec) by 0.23% only expressing the low effectiveness to decrease the DT-EC by the standard regimens of cell-cycle specific drug therapy in treating the tumors of high mitotic index as HeyA8 MDR tumor model.

**Effect of the optimal metronomic dose of Docetaxel in treating HeyA8 tumor model**

While the median of the control tumors grew to 1.2 g at the end of the experiment, all metronomic doses of Docetaxel were highly effective in reducing tumor growth. The metronomic dose of Docetaxel (0.5 mg/kg thrice weekly) resulted in a reduction in the median tumor weight to 0.288 g after 3-4 weeks of the therapy (P < 0.001) [13].

A dose of 0.5 mg/kg thrice weekly of docetaxel for 3-4 weeks in human (70kg, 2.5L plasma) is equivalent to \( 0.5 \times 3 \times 3.5 \times 70 = 147 \mu g/mL \).

Tumors in the mice received the treatment of docetaxel (147 \( \mu g/mL \)) had a growth curve with \( t_b \) of 16.05432194 days from [0.1g to 0.288g in 3.5 weeks (p<0.001)], while \( t_b \) was 6.834102168 days only for the control tumors [from 0.1g to 1.2g in 3.5 weeks (p<0.001)]. Accordingly, from Eqt (12), the difference in tumor energy in those groups induced by 147 \( \mu g/mL \) of docetaxel was as follows:

\[
\left[ \ln \ln \frac{6.91914942x10^{-8}}{6.65171488x10^{-8}} - \ln \ln \frac{2.31738213}{6.51186844x10^{-8}} \right] \times 2.5 \times 10^3 \times 23234.59 = 7.0477781x10^8 MeV.
\]

Thus from table 1 it is obvious that

1. The rate of DT-EC in the control tumor of HeyA8 MDR model was more than that of the control one of the HeyA8 model, while the deceleration of DT-EC in the control tumor of HeyA8 MDR model was faster (less algebraically) than that of the control one of the HeyA8 model.

This provides a clear cut criterion to accept the hypothesis of current approach that tumors of higher rates of DT-EC and faster deceleration of DT-EC which are represented here by HeyA8 MDR model would be more resistant to cell-cycle specific drug treatment.

2. The rate of DT-EC in the treated tumor was lower than that of the control one, while the deceleration of DT-EC in the treated tumor was slower than that of the control one in the three presented therapies.

This confirms the hypothesis of current approach that the targets of therapy are to minimize the rate of DT-EC and slowing the deceleration of DT-EC as minimum as possible. As the deceleration of DT-EC is always negative along the whole domain of \( E_g \) as previously shown then slowing its value as minimum as possible means to maximize its algebraic value.

3. Accordingly, the effectiveness of the presented therapies was ranked as follows:

```plaintext

t_{\text{16.05432194 days}} \quad 7.0477781x10^8 MeV

t_{\text{11.83352313 days}} \quad 4.5793223x10^8 MeV

t_{\text{6.834102168 days}} \quad 0.2789429457

t_{\text{6.91914942x10^{-8}}/\text{Emad/Sec}} \quad 0.2317382132

t_{\text{6.51186844x10^{-8}}/\text{Emad/Sec}} \quad 0.2242383242

t_{\text{6.51186844x10^{-8}}/\text{Emad/Sec}} \quad 0.2317382132
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Table 1. shows, docetaxel dose and regimen, energy yield, Cell Growth energy (\( E_g \)), Doubling time (\( t_b \)), rate of DT-EC, deceleration of DT-EC, rate of increase of \( E_g \), and rate of increase of \( E_g \) for control and treated tumors of HeyA8 and HeyA8 MDR Models.
The metronomic dose of 0.5mg/kg of docetaxel thrice a week in HeyA8 tumor model was the most effective one, then followed by the MTD of 15mg/kg/2weeks of docetaxel in HeyA8 tumor model with moderate efficiency and followed by the MTD of 15mg/kg/2weeks of docetaxel in HeyA8 MDR tumor model with lower efficiency.

This rank is consistent with the experimental results presented by Kamat AA, et al in which HeyA8 MDR tumor model was classified as the most resistant model to docetaxel therapy [13].

Discussion

The aims of this study are to investigate the kinematics of DT-EC during tumor formation and their therapeutic responses to establish new physical tumor-markers for cancer staging and effectiveness of cancer treatment. In-vivo tumor models in athymic mice were used to identify the treatment efficacy of docetaxel as a one of the cell cycle specific drugs through metronomic and standard regimens. From Eqts (8) and (9), the drug half-life time has equal and opposite impacts on the rate of drug energy yield and the rate of tumor doubling time. Thus, the resultant of those impacts vanished on the DT-EC kinematics to conclude that drug pharmacokinetic has no effect on the effectiveness of cancer treatment. The clinical methodology for staging tumors using Eqt (12) was conducted as described in earlier studies to determine the energy of tumor responses [3,8,14-25].

Estimating the energy yield by docetaxel doses was conducted by monitoring the difference in tumour responses and the accompanied alteration in the tumour H\textsubscript{g} before and after therapy as described before in earlier studies [14,17-19,22-25]. The most important issues regarding the use of cell-cycle specific drugs are optimal dosing and scheduling. Thus, selecting docetaxel to test the hypothesis of the current approach was because docetaxel has never demonstrated predictable outcomes yet because of its non aphid accumulative therapeutic effect as it affects cells only when they are dividing [6]. Accordingly it was more suitable to select docetaxel to investigate the kinematical targets of chemotherapy other than non-cell cycle specific drugs which characterized by aphid accumulative and predictable therapeutic effect. Thus, it was not surprisingly for the variation in energies yield by the equivalent doses of docetaxel (840 \( \mu \)g/mL) with the same schedule of standard regimen (15mg/kg/2weeks) in the treated HeyA8 and HeyA8 MDR tumor models that demonstrate the variation in the therapeutic action of cell-cycle specific drugs due to the variation in mitotic indices. HeyA8 MDR tumor model was faster in tumor formation compared by HeyA8 model. Hereby, the rate of mitosis in HeyA8 MDR model was higher than that in HeyA8 model before therapy. Such increase in the rate of mitosis resulted in a shorter doubling time compared to the schedule of MTD regimen that led to expose the drug dose to metabolism in non dividing periods and to substitute the portion of tumor cells that had been triggered to apoptosis by the first dose through mitosis before the second dose. The rate of DT-EC (\( \frac{dt}{dt} \)) in the treated tumor of HeyA8 model was lower than that induced in the treated tumor of HeyA8 MDR model. This was because of the greater increase in \( \frac{dt}{dt} \) and the greater decrease in \( \frac{dt}{dt} \) of the treated tumor of HeyA8 model (73.15% and 3.9% respectively) than that induced in the treated tumor of HeyA8 MDR model (3.18% and 0.23% respectively) as postulated for minimizing the rate of DT-EC as a therapeutic target in Eqt (6). This explains the greater resistance exhibited by HeyA8 MDR model than that of HeyA8 model to docetaxel therapy. Thus, regimens of cell cycle specific drugs can be designed according to the standards assessed by current approach which should cover the tumor doubling time by more frequent infusion to improve effectiveness of the treatment. Observations at table (1) demonstrated also that despite the dose of the metronomic regimen (147 \( \mu \)g/mL) was about one fifth of that of the MTD of the standard one (840 \( \mu \)g/mL), the energy yield by the lower dose was greater than that yield by the higher one as deduced from the tumor response in each therapy. Accordingly, metronomic regimen was more effective than the standard one as it induced a lower rate of DT-EC and slower deceleration of DT-EC as postulated in our model for the effectiveness of the cancer treatment. In addition, each of the metronomic and the MTD based regimen had a significant effect on the therapeutic survival [14]. This clarifies the evolution towards the metronomic administration of cell cycle specific chemotherapy drugs that attack the cells during various phases of division, or in case of administration of chemotherapeutic drugs when high-dose chemotherapy is not very effective and/or associated with high toxicity [26].

Thereby, these findings suggest that patients with tumors of advanced stages of low mitotic index may particularly more benefit from standard docetaxel regimens than those with tumors of early stages of higher mitotic index. On the contrary, metronomic docetaxel regimens would be more efficient for cases in early stages of higher mitotic index due to their lower histologic grade that needs lower doses of docetaxel. It was possible to correlate between the kinematics of DT-EC during tumor formation and the stage of the tumor model. Advanced stages are characterized by higher rate of DT-EC and faster deceleration of DT-EC (lower algebraic value) as shown for the control tumor of the resistant model (HeyA8 MDR) compared to that of HeyA8 one. Also, reducing the rate of DT-EC and slowing (increasing algebraically) the deceleration of DT-EC during therapy was confirmed in all the presented therapies of different regimens and tumor models. Thus through identifying the effectiveness of the presented treatments, it was possible to deduce the role of therapy which is minimizing the rate of DT-EC and slowing the deceleration of DT-EC as minimum as possible to prolong the survival period as long as possible. From Eqt (3), the rate of DT-EC is an increasing function along its whole domain. Thus, in cancer therapy there are no limits to slow the deceleration of DT-EC which can be continued also to infinity.
These optimistic findings give the hope to deal with cancer as a chronic disease with which humans can coexist with no survival period limit. DT-EC kinematics for cancer patients can be identified by clinical or pathological tests before therapy for cancer staging and grading [5, 16]. Also during therapy to check the effectiveness of the treatment, modify doses and regimens for optimal dosing and scheduling [7, 13-18,20,21-25]. Ranking the effectiveness of the presented therapies was consistent with the experimental results presented by Kamat AA, et al [13] that classified HeyA8 MDR tumor model as the resistant model to docetaxel therapy. Together with these findings and analysis that irrespectively of the treatment (untreated (control) vs. treated), origin of the cells (HeyA8, HeyA8 MDR), treatment regimen (metronomic, standard), provide a clear cut criterion to accept the hypothesis of the current thesis that during tumor formation the rate of DT-EC decreases, whereas the deceleration of this conversion slows (increases algebraically) gradually. Furthermore, the targets of the cancer therapies are to minimize the rate of DT-EC and slowing the deceleration of DT-EC as minimum and longer as possible. These therapeutic roles are considered physical tumor-markers for the effectiveness of the cancer treatment that helps to treat cancer as a chronic disease with which humans can coexist as long as possible with no survival period limit.

Conflict of interest

The author declares that there is no conflict of interest concerning this paper.

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