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Applications of quantum Zeno effect in cancer therapy

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ABSTRACT

In later stages of cancer therapy, active medical therapy like chemo-therapy poses a great risk of accelerating disease expansion rather than inhibition. This paper explores the idea of using the Quantum Zeno Effect and creating frequent perturbations in a quantum system to get the population of cancer cells to nearly 0.

Keywords: *Quantum Zeno Effect, Cancer Therapy, Quantum Physics, Molecular Biology.*

1. INTRODUCTION

Cancer, or the uncontrolled growth and abnormal division of cells in a part of the body is one of the leading causes of death in the world. It is caused by the detrimental variation in the human genome through sufficient genetic mutations.

There are two primary genes that can influence the formation of cancer : oncogenes and tumor suppressor genes. **Proto-oncogenes** are genes that enable cell growth. When mutated, they become permanently activated, forming oncogenes that promote cancer. **Tumor suppressor genes** are genes that slow down cell division or repair DNA damage, and they have the opposite effect of that of proto-oncogenes. These genes when mutated are inactivated and become tumorigenic.

Apoptosis, or the programmed cell death usually occurs when a cell undergoes cellular stresses or abundant DNA damage. However, in a cancer cell, the mutations cause the cell to continue dividing due to reduced sensitivity to the same factors.

Tumors, or swellings in a part of the body that are caused by uncontrolled growth of tissues, can be cancerous when malignant. Malignant tumors have the capability to spread to other parts of the body and metastasize. When tumors are benign, they are not cancerous due to the lack of ability to invade neighbouring tissues.

Metastasis is the process by which tumor cells move from the primary tumor to a different organ or region in the body through the lymph or blood. This is the property of malignant tumors that enables cancer. Metastasis occurs through various processes that are supported by the ten cellular hallmarks of cancer, which will be explored in detail later in this paper.

Imaging is used in oncology as a guide through the entire process of cancer screening, diagnosis, staging, treatment response and monitoring. Depending on the individual patient requirements and type of cancer, certain types of imaging like CT scans, MRI scans, ultrasounds, plain films and nuclear medicine are used.

Even the various types of **treatment** used, like surgery, radiation, chemotherapy, immunotherapy, targeted therapy and hormonal therapy vary between patients since each case is unique and requires individual assessment. Some of the most common types of cancer in the world are that of the lung, breast, prostate, colon, liver and stomach.

2. CANCER MANAGEMENT TECHNIQUES

The Cancer Management Techniques involve the processes to deal with individual situations. It consists of the following steps, of which steps 2-6 require some form of imaging in order to assess.

- **Cancer Prevention**
- **Cancer Screening** - screening tests are done using imaging to identify cancer at an early stage before the occurrence of symptoms, when cancer is easier to treat and possible to cure.
- **Cancer Diagnosis** - pathology and imaging are used together for diagnosis. One of the common ways cancers are diagnosed are using imaging of biopsies.
- **Cancer Staging** - used to determine how advanced the cancer is by predicting the course of the disease (prognosis) and then assessing treatment options. The invasiveness of the cancer is determined by the Tumor Lymph-Node Metastasis staging:

- ✓ Organ of origin - primary tumor
- ✓ Nearby lymph nodes
- ✓ Metastasis at any distant tissues

- **Assess Treatment Response** - used to assess change in tumor burden (tumor shrinkage in response to treatment).
- **Monitoring** - the imaging that worked best for each individual when the cancer was first diagnosed is used to monitor for recurrent cancer. The hallmarks 6 and 9 of cancer are often used to monitor patients after therapy.

3. OLIGOMETASTASES

The theoretical state of limited metastatic potential, or oligometastases suggests that:

- The conditions in a primary tumor are not too harsh
- Cells that break off from the primary tumor are less aggressive CTCs
- Less sloughed off CTCs survive in through circulation
- The sites of metastasis where these CTCs land are inhospitable

Oligometastasis can be diagnosed by staging with imaging. Oligometastasis diagnosis means treatment intent may be to cure.

4. CANCER TREATMENT

There are various methods of cancer treatment that are employed:

4.1 Surgery and radiation

Performing a surgery to remove tumors can be effective as they kill the cancer before it spreads. An external beam radiation is used, or radioactive seeds are implanted into the tumor to cause cancer cell death by DNA damage. Radiation is given in several doses over time and can be as curative as surgery. It can also be used to shrink a tumor (palliation).

4.2 Hormones

Hormones can contribute to the growth of cancer, for example estrogen stimulates breast cancer growth and testosterone promotes prostate cancer growth. Anti-hormone agents like anti-estrogen and anti-testosterone agents are used to treat cancer patients.

4.3 Chemotherapy

Chemotherapy drugs are designed to block cancer cells from division. Chemotherapy drugs not only kill cancer cells, but also normal cells like those of hair follicles and WBCs. This results in hair loss and risk of infection in patients. There are two classes of chemotherapy drugs:

- Agents that interfere with DNA replication:

1. Anti-metabolites: Base pair drugs that are included into the DNA strand and do not allow replication to occur
2. Topoisomerase inhibitors: Inhibit topoisomerase enzyme from unwinding and rewinding DNA strands during replication
3. DNA intercalation: metals, alkylators and antibiotics that prevent DNA strands from replicating

- Agents that interfere with cell division by inhibiting microtubules and blocking mitosis

1. Vinca alkaloids: Prevent microtubule assembly
2. Taxanes: Prevent microtubule disassembly

4.4 Targeted therapy

Targeted therapy inhibits proteins that have been mutated or overexpressed, and proteins that help cancer proliferation. This treatment is specific to cancer cells, and does not result in many side effects.

4.5 Immunotherapy

Immunotherapy is the use of medicines to promote the patient's immune system to effectively recognise and destroy cancer cells. The immune system normally prevents attacking itself using checkpoints that are switched on or off to generate an immune response. Checkpoint inhibition that targets PD-1 or CTLA-4 are generally used. PD-1 and CTLA-4 are proteins on the immune system cells (T-cells) that normally help prevent these cells from attacking other body cells. This will promote the response against cancer cells.

5. THE QUANTUM ZENO EFFECT

The quantum zeno effect is named after famous greek philosopher, Zeno of Elea. The Quantum Zeno Effect states that frequent measurements of quantum systems, inhibits the transitions between quantum states. Misra and Sudarshan conducted an experiment regarding the decay of an unstable state such as the radioactive nucleus. Traditionally, the decay of an unstable system can be modelled as an exponential function of time which is given by the radioactive decay of law. It can be expressed as:

$$N(t) = N(t_0)e^{-\lambda(t-t_0)}$$

Where N(t) is the number of undecayed nuclei after a time t, and $\lambda$is a constant. Quantum mechanics mostly agrees with this exponential decay and most quantum decay can be modelled using this, however, in cases of extreme timespan, i.e. very short lifespan and very long lifespan there can be a deviation from the familiar radioactive decay law. Now, let's model the decay of an unstable quantum state. Define, φ_0 to be the undecayed state of the system at time t=0, and $\varphi(t)$ to be the state of the system at

any time t later in the life cycle. The system evolution is dictated by an operator $U(t) = e^{-iHt}$, where H is the hamiltonian of the system.

Therefore, $\varphi(t)$ can also be expressed as follows:

$$\varphi(t)_{=}\varphi_{0}{}_{\times}U(t)$$

The survival probability which is the modulus squared of the survival amplitude can be given by:

$$P(t) = |\langle\varphi_0|U(t)|\varphi_0\rangle|^2$$

The survival probability for extremely short life times can be expanded to

$$P(t) \approx 1 - t^2(\triangle H)^2 + ...$$

If we create a new variable t_z, the zeno time which is defined as $\frac{1}{\triangle H}$, and on substituting this value in the previous equation we get:

$$P(t) \approx 1 - (\frac{t^2}{t_z^2}) + ...$$

Since the lifespan of this exponential decay is extremely short we can ignore the H.O.T and our new equation becomes:

$$P(t) \approx 1 - (\frac{t^2}{t_z^2})$$

From the above equation, we can infer that quantum decay is a quadratic function and not an exponential one.

Suppose, if we were to make N equally spaced measurements, over a time period T, then $T = N\tau$ where $\tau$is the time interval between each measurement. Essentially, the measurements are made at times $\frac{T}{N}, \frac{2T}{N}, \frac{3T}{N} .... \frac{(N-1)T}{N}$

Once these measurements are made, the wave function collapses and the new survival probability becomes:

$$[P(t)]^N = \left(1 - \frac{T^2}{N^2 T_z^2}\right)$$

From this it becomes clear that as N gets larger and approaches infinity, the denominator will become much greater than the numerator causing the second term to approach 0. We can infer that as the number of measurements increases of a quantum system, the probability of it not decaying approaches 1. (Note that probabilities are measured on a scale of 0 to 1, where 0 is least likely and 1 is most likely to occur).

6. APPLICATIONS OF THE QUANTUM ZENO EFFECT IN CANCER THERAPY

According to research conducted by Glavatović and Panković using quantum phenomena in the form of quantum zeno effect might be a more effective way of treating cancer than our existing methodologies. The underlying principle is inhibition of regulatory cells (the cells that play a part in suppressing the immune system) and allowing the effector cells (cells that appropriately respond to an external stimulus) and thereby playing a role in eliminating cancer cells.

Additionally, another important perspective is considering the evolution of cancer cells as a function of time.

$$p = p_0(1 + \alpha t)$$

Where p is the population at any given point and p_0 is the population that corresponds to an initial time of t_0. Suppose medical treatment is possible to be done in extremely short lifespans which would allow the quantum zeno effect to take place in the decay of the system. This leads to a new equation for the population:

$$p_r = p_0 k(1 + \alpha t)$$

And on performing the same treatment n times, we get:

$$p_{rn} = p_0[k(1+\alpha t)]^n$$

From this equation, we can note that as the value of n increases, the population of cancer cells at any given time approaches 0. Essentially, this describes the quantum zeno effect and the result obtained while understanding the decay process at a quantum scale in a way is very similar to the result obtained above.

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