CANCER DIAGNOSIS AND IMAGING

BACKGROUND OF THE INVENTION

[0001] Conventional cancer imaging is inaccurate and imprecise. Typically a patient has a marker, or other chemical compound, injected into their circulatory system, waits about 1 hour and is then imaged using Positron Emission Tomography (PET). The 1 hour time frame is quite short and may not be representative of the general activity of the entire number of cancer cells.

[0002] The reason why conventional cancer imaging is inaccurate and imprecise is because, in part, the metabolic uptake of an imaging marker has a cell cycle-specific mechanism of action. More specifically, uptake of the imaging marker is a function of which part of the cycle targeted cell are in. During any given hour, which is the typical wait time between marker administration and imaging, the cancer cells to be imaged may be at any stage of the cell cycle and may uptake and absorb the marker at different rates and amounts. This variance, which exists between all of the cancer cells throughout the patient, can cause misleading results and improper diagnoses.

[0003] The cell cycle is the series of events occurring in a cell leading to its division and duplication. In eukaryotic cells, the cycle can be divided into two periods, interphase and mitosis. Transit through these two periods of the cell cycle is known as proliferation. During interphase, the cell grows, accumulates nutrients needed for mitosis and duplicates its DNA. During mitosis, the cell splits itself into two distinct daughter cells. Interphase includes three distinct phases, Gap 1 (G_1) phase, S phase and Gap 2 (G_2) phase while mitosis includes two processes. G_1 phase includes the cell increasing in size, biosynthetic activities of the cell increasing and the synthesis of enzymes needed for DNA replication in the subsequent step. S phase includes the beginning of DNA synthesis and replication of all of the chromosomes. G_2

phase lasts until the cell enters mitosis and includes protein synthesis including the production of microtubules for mitosis. Mitosis includes a process where the cell's chromosomes are divided between the two daughter cells and a cytokinesis process where the original cell's cytoplasm divides forming two distinct daughter cells. The cell cycle also includes a resting phase, typically referred to as G_0. The boundaries between the various phases, for example the boundary between the G_1 and S phase is referred to as a cell cycle checkpoint.

[0004] The progression of the cell cycle can be inhibited, so that a particular cell stops the cycle at a point, a cellular checkpoint, before proceeding to the next phase. Cell cycle checkpoints are located between the different phases of the cell cycle, with two of the checkpoints being at the interface between the G_1 and the S phase (G_1/S) and the interface between the G_2 and M phase. A cell cycle inhibitor can stop the progression of a cell from passing to the next phase, for example a cell can be inhibited at the G_1/S cell cycle checkpoint, which forces the cell to remain in the G_1 phase until the inhibitor is removed.

[0005] In any particular cancer cell population or tumor in an individual, the length of the cell cycle is variable. This variability is due to differing periods spent in G_1 of G_0 while the length of time from the beginning of S phase to the end of M phase is relatively constant.

[0006] Imaging using traditional markers relies on the increased uptake of the marker because of the increased metabolic activity of the cancer cells. This increased uptake is most noticeable once the cancer cells are in the S phase as opposed to the other cell cycle stages. If the majority of cancer cells to be imaged are not in the S phase during the typically one hour time span between administration and imaging, the image result may not be representative of the actual concentration and location of cancer cells.

[0007] What is desired is a treatment to arrest the cell cycle for a clinically relevant fraction of cells at the G_1/S cell cycle checkpoint, so that the efficacy of imaging markers can be enhanced.

SUMMARY OF THE INVENTION

[0008] The present invention provides a method for imaging a disease or condition in a mammal which includes the steps of: administering a therapeutically effective amount of a cell cycle inhibitor to effectively stop proliferation of eukaryotic cells at a cell cycle checkpoint between the G_1 and S phase, stopping administration of the cell cycle inhibitor for a period of time, administering a marker to the mammal and imaging the mammal.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Figure 1 is a schematic representation of the cell cycle. The outer ring includes the interphase (I) and mitosis (M) stages, with the duration of mitosis in relation to the other phases being exaggerated. The inner ring includes the Gap 1 (G_1), Gap 2 (G_2) and synthesis (S) phases. Gap 0 (G_0) or resting phase is not shown.

[0010] Figure 2 is a graphical representation of the ability of several chemical agents to inhibit calcium influx as compared to the same chemical agent's ability to inhibit cell proliferation.

[0011] Figure 3 is a schematic representation of the cell cycle and the influence several calcium channel blockers have on the progression of the cell cycle.

[0012] Figure 4 is a graphical representation of data measuring the impact of mibefradil on cell cycles.

[0013] Figure 5 is a graphical representation of data measuring the impact of mibefradil on cell cycles.

[0014] Figure 6 is a graphical representation of data measuring uptake of an image marker after administration of mibefradil.

[0015] Figure 7 is a graphical representation of data measuring uptake of an image marker after administration of mibefradil.

DEFINITIONS

[0016] In describing and claiming the invention, the following terminology will be used in accordance with the definitions set forth below.

[0017] As used herein, the term "pharmaceutically acceptable carrier, vehicle or diluent" includes any of the standard pharmaceutical carriers, such as a phosphate buffered saline solution, water, emulsions such as an oil/water or water/oil emulsion, and various types of wetting agents. The term also encompasses any of the agents approved by a regulatory agency of the US Federal government or listed in the US Pharmacopeia for use in animals, including humans.

[0018] The term "therapeutically effective amount" means an amount of a compound of the present invention that ameliorates, attenuates, reduces or eliminates a particular disease or condition or prevents or delays the onset of a particular disease or condition.

[0019] By "mammal" it is meant to refer to all mammals, including, for example, primates such as humans and monkeys. Examples of other mammals included herein are rabbits, dogs, cats, cattle, goats, sheep, mice, rats and horses. Preferably, the mammal is a female or male human.

[0020] The expression "pre-cancerous condition" refers to a growth that is not malignant but is likely to become so if not treated. A "pre-cancerous condition" is also known as "pre-malignant condition" by one of ordinary skill in the art.

[0021] It is understood to one skilled in the art that "T type calcium channel blockers" are also known as "T type calcium channel inhibitors".

DETAILED DESCRIPTION OF THE INVENTION

[0022] The method for imaging a disease or condition in a mammal includes several steps. The method can be conducted for many reasons including diagnosis of a suspected disease or condition, screening for the impact of various treatments and the monitoring of the progress of treatment. Based on the images generated from the described method, a health care administrator can more easily determine a diagnosis, an impact of a treatment and the progress of a current treatment.

[0023] The method can be used to image various diseases or conditions, including unstable angina, hypertension, epilepsy, neuropathic pain, petit mal seizure, absence seizure, age related macular degeneration, cancer and pre-cancerous conditions. In other embodiments, the method can be used to image tumors and pre-cancerous tumors.

[0024] In the method for imaging a disease or condition, a cell cycle inhibitor is first administered in a therapeutically effective amount to stop proliferation of eukaryotic cells at the cell cycle checkpoint between the G_1 and S phase (G_1/S). Varying lengths of the cell cycle are determined predominately by the time spent in the G_1 phase. The lengths of the S, G_2 and M phases are relatively invariant. Because of this, any particular cell in a population will reside in G_1 for a period of time before the cell enters the S phase of the cell cycle. To stop the cell cycle from continuing past a cell cycle checkpoint, a cell cycle inhibitor can be administered.

[0025] The administration of a cell cycle inhibitor causes asynchronously proliferating cancer cells in a population to accumulate at G_1/S as they proceed through the cell cycle because their

ability to proceed to the S phase is arrested by the cell cycle inhibitor. For a cell to move from G_1 phase to S phase through the cell cycle checkpoint, the cell requires influx of extracellular calcium to trigger biochemical cascades that are necessary for the progression. Removal of calcium from the extracellular medium blocks cell cycle transit for each cell. Thus, each cell persists in G_1 phase as long as it would in the presence of extracellular calcium, but becomes locked in place when G_1/S is reached without calcium, thereby synchronizing cells at G_1/S. Calcium influx to a cell is necessary for proliferation and transit through the cell cycle. This is further described in Example 1 below.

[0026] The administration of the cell cycle inhibitor increases the percentage of cells at G_1/S. To take advantage of the increase of cells at G_1/S, administration of cell cycle inhibitor to the mammal persists for a period of time before imaging. This period of time can be between about 1 day and about 10 days, inclusively. In another embodiment, this period of time can be between about 5 days and about 7 days, inclusively. Although the upper limits of these embodiments are 10 days and 7 days, the cell cycle inhibitor can be administered for longer periods of time. The dosage of cell cycle inhibitor creates a concentration in a mammal's plasma of about 1 μM to about 10 μM.

[0027] The cell cycle inhibitor can be administered through several routes including parenteral, intravenous, intramuscular, intraperitoneal, intrathecal, suppository, transdermal, topical, or oral. Oral administration of the cell cycle inhibitor is most preferred. An oral administration can be administered as a dosage unit, typically a pill or capsule along with a pharmaceutically acceptable carrier.

[0028] The cell cycle inhibitor can be one or many of several cell cycle inhibitors. For example, mibefradil, efonidipine, ethosuxamide, TTL-1177 (a proprietary compound, described in reference: Gray, L.S., Perez-Reyes, E., Gomora, J.C., Haverstick, D.M., Shattock, M., McLatchie, L., Harper, J., Brooks, G., Heady, T., and MacDonald, T.L. (2004) *Cell Calcium* **36**, 489-497) and nickel.

[0029] These cell cycle inhibitors inhibit the influx of extracellular calcium into the cell which is critical for a number of vital cellular processes. The calcium necessary for these processes comes from the extracellular milieu via influx through calcium channels. Calcium channels are grouped into several families based upon sequence analysis, biophysical characteristics and pharmacological sensitivity. Among these is the T type calcium channel family. These calcium channels have been implicated in regulation of blood pressure, cardiac rhythm and cellular proliferation. Studies also suggest that T-type calcium channels may play an important role in age related macular degeneration. At least one pharmacological agent, mibefradil, has been proven to be clinically effective because of inhibition of T channel function. Inhibitors of calcium entry are useful for treating hypertension, cardiac arrhythmia and clinically deleterious cellular proliferation.

[0030] T type calcium channels are present in cells, cell lines and specifically cancer cell lines. Specifically, the Cav3.2 isoform of T type calcium channels has been shown to be aberrantly expressed in breast cancer tissue as compared to normal adjacent breast tissue in Japanese women, as discussed in reference Asaga, S., Ueda, M., Jinno, H., Kikuchi, K., Itano, O., Ikeda, T., and Kitajima, M. (2006) *Anticancer Res* **26**, 35-42.

[0031] Cell cycle inhibitors effectively stop proliferation of eukaryotic cells at cell cycle checkpoints, including G_1/S, which is further explained in Examples 2-4 below.

[0032] Subsequent to the administration of the cell cycle inhibitor, an imaging marker is administered that is targeted to be uptaken in the S phase of the cell cycle. The period between the first administration of the cell cycle inhibitor and the imaging marker allows the accumulation of cells at G_1/S of the cell cycle. This method increases the percentage of the cells which are in the S phase, thereby increasing the uptake of imaging marker into those cells.

[0033] Subsequent to administration of the cell cycle inhibitor, there is a period during which no cell cycle inhibitor is added. This period can range from about 30 minutes to about 72 hours. This period allows the cells which have accumulated at G_1/S to enter the S phase of the cell cycle. About 5% to about 25% of cells will have accumulated at G_1/S. The increase in number of cells in the S phase makes a subsequent administered dose of an imaging marker more effective because a large percentage of cells will uptake the imaging marker in each dose.

[0034] Subsequent to the period where no cell cycle inhibitor is added, an imaging marker is administered to be uptaken or absorbed by cells in the S phase. The specific imaging marker will be dictated by clinical experience of one skilled in the art, where different diseases are imaged with different imaging markers. The same dose of an imaging marker is uptaken more readily and more specifically as compared to an imaging marker when used alone. The increase in imaging marker being uptaken is further described in Example 5 below.

[0035] Cancer cells can be located within the living body by administering a substance that binds to T type calcium channels or T type calcium channel accessory proteins. The location within the body of the drug can then be determined by tagging it with substances that are

detectable from outside the body. For example, radioactive atoms can be localized within the body by measurements taken outside of it and examples of such atoms useful for this purpose include 99mTc, 125I, 131I, 18F, 11C, 13N, 15O, 3H, 68Ga, 67Ga and 16F, among others. Some of the examples of the many possible imaging markers include 11C Methionine, 2-deoxy-2-(^{18}F)fluoro-D-glucose (FDG), tritiated FDG (3H-FDG) and fluoro deoxythymidines such as [18F]-3'-fluoro-3'-deoxy-L-thymidine). Additionally, deuterium, for example, can be similarly localized using Nuclear Magnetic Resonance (NMR) and various dyes, fluorescent as well as non-fluorescent, are localized using optical techniques. Additionally, one or more imaging markers may be combined and administered to the mammal prior to imaging of the mammal.

[0036] The administration of a cell cycle inhibitor followed by stopping that administration allows for a greater percentage of cells in a particular phase of the cycle. Various cellular metabolic activities proceed to differing extents in the various phases of the cell cycle. By altering the proportion of cancer cells in a particular phase of the cell cycle, an altered proportion will exhibit the metabolic activities most characteristic of that phase. One example of an imaging marker is FDG which is accumulated in cells that require this energy source for the particular metabolic state they are in. Thus imaging of FDG from outside the body would localize those cancer cells that responded to T type calcium channel active agents by an alteration in the fraction of cells in that part of the cell cycle most in need of glucose. Because, as an example, cancer cells preferentially express T type calcium channel function compared to non-cancerous cells, cancer cells will be preferentially affected by T type calcium targeting agents and detected.

[0037] After the imaging marker is administered to the mammal, the mammal is then imaged. The imaging marker can be administered at any suitable dose, for example about 100 mBq to about 600 mBq. The mammal can be imaged using any suitable imaging apparatus, for example an apparatus capable of gathering a magnetic resonance image (MRI), a positron emission tomogram (PET scan) or a computer tomogram (CT scan). The images gleaned by a suitable imaging apparatus will be more sensitive than images taken of mammals with no pre-treatment of a cell cycle inhibitor. The scans taken after administration of cell cycle inhibitors will be more sensitive because the diseased cells will have a higher uptake of the imaging markers as compared to uptake of imaging markers of cells that have not had an administration of a cell cycle inhibitor.

[0038] The above described method can be repeated as desired for each instance the mammal is to be imaged. For example, after the mammal received the administrations of cell cycle inhibitor, stopped administration of the cell cycle inhibitor, was administered an imaging marker and was imaged, the mammal can then again begin the process by receiving another administration of a cell cycle inhibitor. This method can be repeated as many times as desired, according to the requirements and advice of a qualified health care administrator.

[0039] The above described method is not only useful for imaging diseases and conditions such as cancer during treatment or diagnosis, the above described method could be used to aid in screening for which types of tumors are more and less affected by T-type calcium channel blockers and which types of tumors are more and less affected by a treatment. For instance, T-type calcium channel blockers are variably efficient at halting the cell cycle based on the type of tumor being targeted. For instance a pancreatic cancer tumor may react differently as compared

to a pancreatic tumor in response to a dosage of T-type calcium channel blockers. Using the above described regimen for screening, it can be determined which types of tumors respond more efficiently to the regimen and what types of tumors do not respond as efficiently to the regimen. This information can be determined for each individual prior to undergoing a treatment regimen and can be used to plan the treatment regimen in the most efficient and advantageous way.

Example 1

[0040] To measure the correspondence between calcium influx inhibition and proliferation, the ability of several chemical agents to inhibit calcium influx was plotted against the ability of the same agent to inhibit proliferation, as can be seen in FIG. 2 below. These agents were proprietary chemical entities synthesized at the University of Virginia. A least squares correlation line with a slope of 0.98 and R^2 value of 0.92 was obtained. Conventionally, a correlation cannot be used to infer causality, but in this case, a Bayesian approach is warranted because calcium influx is necessary *a priori* for proliferation, such that blocking calcium entry will correspondingly block proliferation. A regression line with a slope very near 1 means that essentially all of the variation in the variables is accounted for by variation in the other, meaning that there is no action of these agents on proliferation other than inhibition of calcium entry.

Example 2

[0041] Cell cycle analysis was performed using flow cytometry and BUdR staining. In FIG. 3, "Con" represents untreated, control cells. All other cell cultures were treated with nocodazole, which interferes with microtubule polymerization and blocks the cell cycle during M phase. Treatment of A10 cells with nocodazole alone blocked cell cycle transit through M phase as determined by flow cytometry. Because A10 cells reside primarily in the cell cycle checkpoint between G_0 and G_1 (See "Con" in FIG. 3), evaluating the possibility that a pharmacologic agent inhibits transit out of that phase is not as straightforward as determining blockade at other cell cycle checkpoints. Therefore, cell cultures were treated for 24 hours with T channel calcium channel blockers mibefradil (mib), nickel (Ni) or TTL-1177 (a proprietary compound owned by the assignee Tau Therapeutics), before adding nocodazole. Absent an effect on the T channel

blockers, cells would be locked at the cell cycle checkpoint between G_2 and M by nocodazole as happened with cells treated with it alone. Instead, treatment with the T type calcium channel blockers arrested cells at the cell cycle checkpoint between G_0 and G_1 and prevented accumulation at the cell cycle checkpoint between G_2 and M that would otherwise have resulted from nocodazole. This shows that T type calcium channel blockers arrest cycling cells at G_1/S.

Example 3

[0042] To measure the efficacy of the cell cycle inhibitor mibefradil at stopping progression through the cell cycle, human lung cancer cells of cell line A549 and human prostate cancer cells of cell line were incubated with 10 μM mibefradil for 48 hours (M48H). As can be seen in FIG. 4, the mibefradil increased the proportion of cells in the G1 phase of the cell cycle by not allowing progression to the S phase, for both cell lines. Further data was collected by incubating the same cell lines with 10 μM of mibefradil for 18 hours followed by a 12 hour washout followed by another 8 hour incubation with mibefradil (M18-12-18h). These results also show a greater proportion of cells in the G1 phase as compared to control cells not incubated with mibefradil.

Example 4

[0043] To measure the effect of mibefradil on the cell cycle of human prostate cancer cells of cell line PC3, PC3 cells were incubated with varying concentrations of mibefradil for varying times. The PC3 cells were incubated with either a 5 μM concentration or a 10 μM concentration for either 24 hours or 48 hours. As can be seen in FIG. 5, an increase in concentration and contact time of the mibefradil increases the proportion of cells in the G1 phase.

Example 5

[0044] The efficacy of the uptake of imaging markers after treatment with a cell cycle inhibitor was determined. Human colon cancer cells, cell line HT29, were first incubated for 24 hours with the cell cycle inhibitor mibefradil at concentrations of 5 μM (5uM-FDG-HT29) and 10 μM (10uM-FDG-HT29). After 24 hours of incubation with the mibefradil, the HT29 cells were removed from mibefradil contact. After 60 minutes of being removed from mibefradil contact, the imaging marker 2-deoxy-2-(^{18}F)fluoro-D-glucose (hereinafter, "FDG") was administered.

[0045] As can be seen in FIG. 6, uptake of the imaging marker FDG into the HT29 cells increased in the cells incubated with mibefradil as compared to the cells that were not incubated. With a concentration of 10 μM of mibefradil, the increase in uptake of FDG was about 100% as compared to uptake of cells not incubated with mibefradil.

[0046] The uptake of an imaging marker was also determined in human lung cancer cells of cell line A549. A549 cells were incubated with 5 μM, 10 μM and 15 μM concentrations of the cell cycle inhibitor mibefradil for 24 hours. After 24 hours of incubation with the mibefradil, the A549 cells were removed from mibefradil contact. After 30 minutes of being removed from mibefradil contact, the imaging marker tritiated FDG (hereinafter "3H-FDG") was administered. As can be seen from FIG. 7, uptake of the 3H-FDG was maximal at 5 μM, with an increase in uptake being observed at all concentrations of mibefradil incubation. Although not shown, incubation of human prostate cancer cells of the PC3 cell line with 10 μM mibefradil for 72 hours increased uptake of the subsequently introduced imaging marker 3H-FDG by about 60%.

Example 6

[0047] As a descriptive example, the method for imaging a disease or condition in a mammal will be described as it would be undertaken in a clinical setting. Initially a mammal, in this embodiment the mammal is a human, is chosen to be imaged. This choice can be made based on various factors including past treatment for a disease, in this embodiment prostate cancer, or as a possible confirmation of a diagnosis. The human initially receives an administration of a cell cycle inhibitor in a therapeutically effective amount, in this embodiment an oral pill delivering a dosage of mibefradil twice daily for 6 days prior to a scheduled imaging session. After the 6 days of dosages are administered, the administration of mibefradil is ceased. After ceasing administration, there is a period of time before the imaging procedure is undertaken. In this example, 6 hours pass between ceasing administration of the mibefradil and administration of an imaging marker, which in this example is FDG. After 6 hours have passed, FDG is injected into the human at a sufficient dosage. The human is then imaged with a PET scan. The data produced from the PET scan is more precise and more accurate than data available from PET scans wherein the patient did not receive a cell cycle inhibitor.

CLAIMS

What is claimed is:

1. A method for imaging a disease or condition in a mammal which comprises the steps of:
   (a) administering a therapeutically effective amount of a cell cycle inhibitor to effectively stop proliferation of eukaryotic cells at a cell cycle checkpoint between the G_1 and S phase;
   (b) stopping administration of the cell cycle inhibitor for a period of time;
   (c) administering an imaging marker to the mammal; and
   (d) imaging the mammal with an imager.

2. The method of claim 1, wherein the disease or condition is selected from the group consisting of unstable angina, hypertension, epilepsy, neuropathic pain, petit mal seizure, absence seizure, age related macular degeneration, cancer, and pre-cancerous condition.

3. The method of claim 2, wherein the disease or condition is a tumor.

4. The method of claim 3, wherein the tumor is a cancerous or pre-cancerous tumor.

5. The method of claim 1, wherein the mammal is a human.

6. The method of claim 1, wherein the cell cycle inhibitor comprises mibefradil, efonidipine, ethosuxamide, TTL-1177, nickel and combinations thereof.

7. The method of claim 1, wherein the imaging marker comprises 11C Methionine, 2-deoxy-2-(^{18}F)fluoro-D-glucose, tritiated FDG 2-deoxy-2-(^{18}F)fluoro-D-glucose, fluoro deoxythymidines, deuterium, and combinations thereof.

8. The method of claim 7, wherein the fluoro deoxythymidine is [18F]-3'-fluoro-3'-deoxy-L-thymidine.

9. The method of claim 1, further comprising a method for extended treatment by repeating steps (a) –(d) one or more times.

10. The method of claim 9, wherein the disease or condition is a tumor.

11. The method of claim 10, wherein the tumor is a cancerous or pre-cancerous tumor.

12. The method of claim 1, wherein the cell cycle inhibitor is administered between about 1 and about 10 days, inclusively, prior to stopping administration of the cell cycle inhibitor.

13. The method of claim 12, wherein the cell cycle inhibitor is administered between about 5 and about 7 days, inclusively, prior to stopping administration of the cell cycle inhibitor.

14. The method of claim 1, wherein the administration of the cell cycle inhibitor is stopped for about 30 minutes to about 72 hours prior to administration of the imaging marker.

15. The method of claim 1, wherein the imager is selected from the group consisting of a magnetic resonance imager, a positron emission tomograph and a computer tomographer.

16. The method of claim 1, wherein the cell cycle inhibitor is administered to a concentration in a mammal's plasma of about 1 μM to about 10 μM.

17. The method of claim 1, wherein the method for imaging diagnoses a disease or condition in a mammal.

18. The method of claim 1, wherein the method for imaging screens for the efficacy of a treatment in treating the disease or condition.