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Cover Page Footnote

I would like to thank Dr. Jason T. Haraldsen for all of his help and guidance. Without his support, I would not have the pleasure of publishing in this journal.

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Abstract

Positron Emission Tomography (PET) scans can utilize a radioactive tracer, in this case 2-deoxy2-[fluorine-18] fluoro-D glucose (^{18}F-FDG), to visualize malignant tumors in cancer patients. The uptake was compared to glucose to understand the difference in thermal properties, which contribute to the ability to image the cancerous cells. The uptake of ^{18}F-FDG by cancer cells and the imaging process of positron emission tomography were reviewed from a thermodynamic perspective. Gastrointestinal and neurological imaging techniques were reviewed to understand the role of PET imaging in different areas of the human body.

I. Introduction

One of the greatest challenges that humanity is currently facing is that of cancer. In the year 2019, 1,762,450 new cancer cases and 606,880 cancer deaths were projected in the United States alone [1]. The loss of life and hardship suffered is staggering and has resulted in a dramatic push for early diagnosis and treatment. One of the most profound methods of early diagnosis is that of positron emission tomography (PET) scan imaging. This imaging technique has been groundbreaking as a result of the unique thermodynamic properties it utilizes to take compelling images of malignant tumors. When making the diagnosis of cancer, the patient is being asked to put their life into the hands of their physician. Therefore, in patient diagnosis, accuracy and precision are key to quality care. As seen in Figure 1, image (C) provides a diagnostic that is readable even for the layperson, given slight direction. In (C), the ease in readability is due to the combination of PET (B), and magnetic resonance imaging or MRI (B). The PET image shown appears fuzzy and unreadable to the untrained eye; however, the brighter region corresponds to increased ^{18}F-FDG uptake at the cellular level. The benefit of fusing PET with MRI comes from considering the PET image to be of cellular processes,

and the MRI to be macroscopic structures such as bones and organs. In this case, the increased uptake corresponds to a malignant growth, more commonly referred to as cancer. This fusion of scans allows for not only patient education, but also a better understanding for the physician, especially when considering surgical approaches.

PET scan imaging utilizes the labeling of important biological molecules with positron-emitting radionuclides.

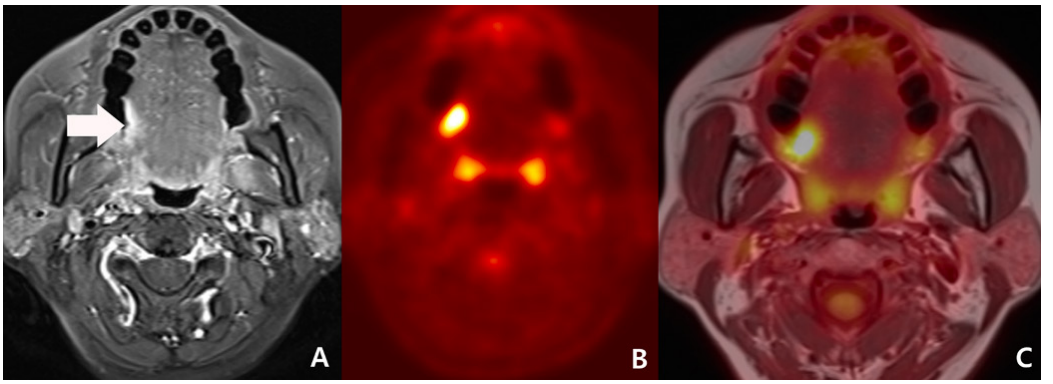

Figure 1: Diagnostic imaging comparison for a patient presenting with right tongue cancer and bilateral cervical metastasis. (A) Contrast enhanced MRI image of region of interest (ROI). (B) PET image of ROI with ^{18}F-FDG. (C) PET/MRI image fusion formed from (A) and (C). [2]

These radiolabeled compounds are then introduced to the region of interest, typically intravenously, and are delivered to the biological target (e.g., cancerous cells). It is once they reach their target, and their disguise of their analog compound is unable to undergo normal cellular processes, where they undergo radioactive decay. The radioactive decay, where in the case of ^{18}F-FDG is β^+ decay, can then be identified by the PET scanner. The most commonly used, and relevant to our discussion is that of 2-deoxy-2-[fluorine-18] fluoro-D-glucose or ^{18}F-FDG. FDG or fluro-D-glucose is an analog of glucose that utilizes the high consumption of glucose in cancer cells, opposed to normal cells, for imaging purposes. The images produced by the PET scanner are able to visually pinpoint the locations of malignancies and aid physicians in diagnosing both the stage and infiltration of the cancer. PET scan images can even be layered with CT images using a PET/CT scanner, as shown in Figure 2, to drastically improve the quality in structure and definition. It is worth mentioning that PET images are typically layered with magnetic resonance imaging (MRI) when the high levels of radiation from the CT scan are a patient concern.

The PET imaging seen above is nothing short of a miracle for the detection of cancer. The reason as to why this works has to do with the metabolic properties of cancer cells. Cancer cells are by default starved of glucose due to their metabolic pathways being eighteen times less efficient than that of normally functioning cells [3]. The consequence of such inefficiency is an incredibly high consumption of glucose when compared to normally functioning cells. One can think of this incredibly high metabolism of glucose with the following analogy. Consider two individuals at a cruise ship buffet: individual a, who has just been rescued from a deserted island, and individual b, who is just enjoying their cruise ship vacation. In this analogy, cancer cells are individual a, and normal functioning cells are individual b. Individual a would clear the entire buffet before individual b gets the chance to grab their plate. This analogy characterizes the relative glucose consumption of the two metabolisms. This high consumption of sugar is key for PET scan imaging in oncology as the ^{18}F-FDG uptake concentrates in regions with high glucose metabolism.

Figure 2: A PET/CT scanner capable of taking both a PET and CT scan and generating a single, layered image of high resolution.

Various types of cancer can be imaged by PET scans depending upon the radionuclide utilized. The radionuclide ^{18}F-FDG alone is capable of imaging the following cancers: colorectal, lymphoma, ovarian, brain, soft tissue sarcoma, and many more [4]. ^{18}F-FDG, at the time of this review, is the only PET tracer approved by

the Food and Drug Administration (FDA). Other PET tracers have been identified, such as radiolabeled choline, that have had considerable results in PET scan imaging. Regardless, ^{18}F-FDG is the most commonly used and is the radiotracer of importance for the purposes of this review. From a thermodynamic perspective, the process of obtaining these images is investigated from the cellular level of microscopic cell structures to the macroscopic 400 lb. PET scanner which is seen in Figure 2 [5].

II. The Metabolism of Glucose

A. Normal Cells

After consuming a meal, various chemical processes in your body begin. The gastrointestinal system breaks the meal down further and further, and in the case of carbohydrates, into their monomer subunit glucose. Glucose, which is absorbed by the small intestine, is absorbed into the blood stream and undergoes either glycogenesis or metabolization. Glycogenesis is the process of storing glucose as glycogen all throughout the body, particularly in the liver. Metabolism, referring to the conversion of glucose to Adenosine Triphosphate or ATP, drives cellular processes. The metabolization of glucose begins when it crosses the cellular membrane and undergoes cellular respiration, which occurs in all cells of the body, regardless of cell type [6]. The process of cellular respiration occurs through various pathways such as: glycolysis, oxidation of pyruvate, citric acid cycle, pentose phosphate pathway, etc. Relevant to this review is the overall process known more generally as metabolism. While there are interesting thermodynamic considerations to be made at the individual steps of metabolizing glucose, the key consideration for PET is in the overall process. Therefore, the overall metabolization of a single glucose molecule through the below pathways, see equations 1 and 2, produces generally 32 – 38 molecules of ATP.

Table I: Standard biological conditions.

Temperature	310 K
pH	7.4
Partial Pressure (O_2)	2×10^4 Pa
Partial Pressure (CO_2)	38 Pa
Glucose Concentration	5×10^3 M

The fluctuation in the total number of ATP produced is due to individual enzymatic activity. The overall cellular respiration reaction is given below.

$$\text{Glucose} + 6O_2 + 36\text{ADP} + 36\text{P} \rightarrow 6CO_2 + 6H_2O + 36\text{ATP} \quad (1)$$

Rather, from a thermodynamic consideration, a further simplified form of the same reaction can be given as:

$$\text{Glucose} + 6O_2 \rightarrow 6CO_2 + 6H_2O, \quad (2)$$

where under typical biological conditions, given in Table 1, the following standard values for the changes in Gibbs free energy, enthalpy, and entropy, are calculated to be -2945.2 kJ mol^{-1}, -2820.0 kJ mol^{-1}, and 403.9 J K^{-1} mol^{-1}, respectively [3].

The above thermodynamic values are calculated from the following equation:

$$\Delta S = (\Delta H - \Delta G)/T \quad (3)$$

in which they refer to the metabolization of a single glucose molecule, see equation 2. The overall change in these thermodynamic parameters indicate that cellular respiration is a spontaneous, exergonic, and exothermic reaction. The overall result is the entropy of the system being increased. These thermodynamic properties are logical, given that the overall process is breaking down glucose into various intermediates that then result in the formation of ATP. This thermodynamic process is characteristic of normal cell function in which the body produces the driving force, ATP, for all activity, (e.g., thinking, breathing, walking, etc.) from glucose, largely through cellular respiration. Therefore, it can be seen why glucose is vital for normal biological processes as human beings would not be able to survive, at least for long periods of time, without it. It is worth noting that the human body does have other systems to generate some type of energy for cells, e.g., ketone bodies resulting from ketogenesis. In fact, ketogenesis is the biological process that puts an individual into a 'ketosis' state. Many refer to this type of metabolism as the 'Keto Diet' and is commonly used. It is especially popular amongst cancer patients, who utilize this alternative metabolic pathway as a way of starving their cancerous cells of glucose. A further elaboration of why this is possible can be found in the next section.

B. Cancerous Cells

Cancerous, or malignant, cells are defined by their uncontrolled cell growth and metastatic characteristics [7]. Such metastatic characteristics consist of irregular shape, malformed organelles, large varying nuclei, and variable cellular arrangement. Key to understanding how to image cancer cells is to understand how and why they form. The formation of cancerous cells begins through the process of carcinogenesis, which is the initiation of cancer formation. It is activated through genes that have the potential to cause cancer (oncogenes) and/or the deactivation of the very genes that control the formation of cancer (tumor suppression genes). For the purposes of PET, the main parameter of cancer that is important has to do with its metabolism. Cancer has unique metabolism methods that it prefers that result in its high demand for glucose. Opposed to normal functioning cells, cancerous cells prefer low cellular respiration and high lactate fermentation rates; otherwise known as the Warburg effect [3]. Lactate fermentation is a process of glucose metabolism to ATP given as:

$$\text{Glucose} + 2\text{ADP} + 2\text{P} \rightarrow 2\text{Lactate} + 2\text{H}^{+} + 2\text{ATP} \tag{4}$$

However, one can look at this reaction strictly from a thermodynamic point of view. Therefore, this reaction can be reduced further to:

$$\text{Glucose} \rightarrow 6\text{Lactate} + 2\text{H}^{+} \tag{5}$$

This change in the predominant metabolic pathway results in a drastic shift in the changes observed in the Gibbs free energy, enthalpy, and entropy of the overall reaction. Considering the values given in Table 1 and the concentration of lactate, 2.9×10^{-3} M, the before mentioned thermodynamic parameters are given as: -220.8 kJ mol^{-1}, -109.4 kJ mol^{-1}, and 359.4 J K^{-1} mol^{-1}, respectively [3]. These values indicate that the metabolism of cancer is still a spontaneous, exergonic, and exothermic reaction, compared to normal cells. It also still results in an overall increase in the system's entropy. However, for cancerous metabolism, there is a significant decrease overall amongst these thermodynamic parameters. Particularly notable is the decrease in the entropy of the system, which can possibly be described by the Prigogine theorem. Considering that cancer cells have high proliferation rates, and no mechanism of programmed cell death (apoptosis), the result of significantly less ATP produced appears incorrect. However, justification for the loss in ATP production may lie in this decrease in entropy. In reference to the Prigogine theorem, this reduction in entropy

could be that cancerous cells are minimizing their rates of entropy production through modified replicating cells [3].

For the purposes of PET, the result of favoring lactate fermentation is that for every mole of glucose, only two moles of ATP are formed. Compared to normal cells which produce 36 ATP moles per mole of glucose, the demand for glucose in cancer cells is eighteen times higher. Nonetheless, the key consideration to be made from this analysis is the result of this massive glucose consumption by cancerous cells opposed to normally functioning cells. Referring to the previous values obtained, cancerous cells require eighteen moles of glucose to achieve the same ATP production normally functioning cells can achieve with just a single mole of glucose. This difference results in high metabolic activity in cancerous cells opposed to noncancerous cells, which PET uses to differentiate between the two to image cancer and not the surrounding tissue.

III. Positron Emission Tomography (PET)

A. The Principles

The analytical imaging diagnostic, positron emission tomography, uses compounds radiolabeled with positron emitting capabilities [8]. Radiolabeling ensures detection of the compounds by the PET scanner in order to produce images of the absorption in relation to the body. In reference to ^{18}F-FDG, it utilizes the significant increase in glucose consumption seen in cancerous cells, opposed to noncancerous cells [9]. The way in which PET scans take advantage of this property begins with ^{18}F-FDG (^{18}F as a positron emitting label).

^{18}F-FDG, 2-deoxy-2-[fluorine-18] fluoro-D-glucose, is the key compound used to detect many different types of cancer. ^{18}F-FDG is synthesized from the glucose analog FDG and the nucleophilic ^{18}F ion. It can be synthesized by either reaction: electrophilic fluorination or nucleophilic fluorination [10]. The latter synthesis mechanism is most commonly used. The ^{18}F is produced with a cyclotron, typically by proton irradiation of ^{18}O [11]. The cyclotron is a large circular chamber that subjects particles to a constant magnetic field, and an alternating electric field. This propels the particle and through this acceleration, one is able to achieve radioactive compounds as mentioned above. Most hospitals capable of producing PET scans have a cyclotron onsite or within city limits as the half-life of ^{18}F-FDG is about 110 minutes [12].

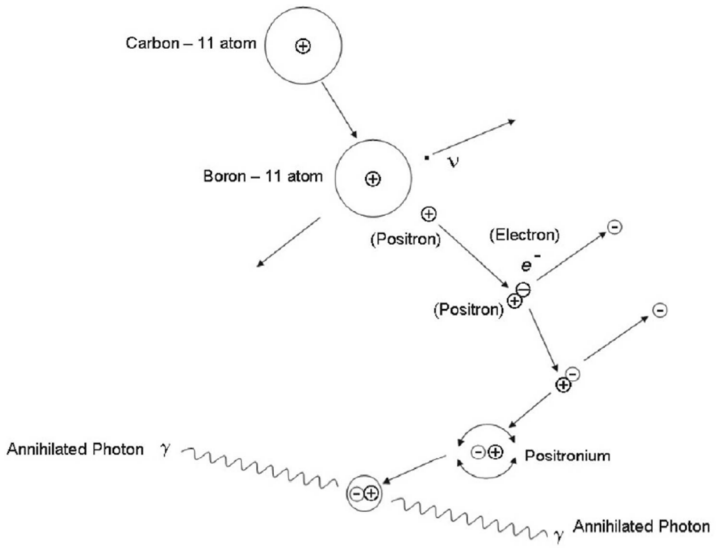

Figure 3: Schematics of positron annihilation. [9]

More on the characteristics of ^{18}F-FDG: it undergoes 97 percent β^+decay and possesses 637 keV positron energy [11]. The production of ^{18}F results in two forms, one typically used in electrophilic methods and the other used in nucleophilic methods, the latter will be of importance. The latter reaction, the efficient nuclear reaction ^{18}O(p,n)^{18}F, produces a high level of radioactivity of 370 GBq/reaction, and the specific activity of which is 102 GBq/μmol. The key takeaway, in terms of the thermodynamics of ^{18}F-FDG, is that upon its nuclear decay the positron has an energy of 637 keV. This will be used in the PET imaging process.

B. ^{18}F-FDG Uptake and Positron Emission

After being intravenously administered the ^{18}F-FDG travels through the blood to the highest consumption of glucose near the administration site: the cancer. It is then taken up by the same secondary active membrane transporters glucose utilizes at the cancerous cellular membrane. However, after entering the cellular membrane, ^{18}F-FDG is not able to undergo gluconogenesis or glycolysis. This inability to undergo gluconogenesis or glycolysis is due to the ^{18}F ion being where the carbon atom is supposed to be located. Since these processes are highly specific, the ^{18}F-FDG is instead trapped within the cellular membrane in the cytoplasm of the cancer cell. This trapping results in a localization of ^{18}F-FDG in the cancer cells which is the perfect positioning for the compound prior to its positron emission. The positron is itself the antiparticle

of the electron, equivalent mass and charge, and is capable of emitting a maximum energy of 0.63 MeV. After the ^{18}F-FDG is trapped within the cancer cells, the positron is emitted as seen in Figure 4. The emission releases the positron with a kinetic energy that is eventually lost in recombining with nearby electrons, resulting in the formation of positronium. The positronium is then annihilated through converting all of its mass into energy, resulting in the emission of two photons, each equal to the rest energy of the electron (511 keV). This energy conversion is the result of the classic equation derived by Albert Einstein, where c is the speed of light, 299,792,458 m sec^{-1}.

$$E = mc^2 \tag{6}$$

The photons emit in opposite direction from the source. Considering the first law of thermodynamics, energy is always conserved and cannot be created or destroyed, the before mentioned process of annihilation affirms that this is true. The overall process described above can be seen in Figure 3. This process is not perfect in that energy losses before undergoing annihilation can and will occur. The distance traveled by positrons for ^{18}F is somewhere in the range of 2-3 mm. Thus, the trajectory of the point of emission to annihilation is somewhere within a sphere of possibility (radius between 2-3 mm). The energy lost after annihilation but before emission has the potential to deliver energy to any surrounding tissue within that sphere of potential trajectory. This results in a slight loss of image resolution.

C. Imaging Procedures

After annihilation, the two photons are separated by 180° and are detected by the PET scanner. The detectors are composed of scintillation detectors and photomultiplier tubes and are placed opposite to emission in a ring. The detectors need to be able to receive the gamma rays, so they are fitted with characteristics such as: stopping power, amount of light produced against each absorbed photon, and time taken for the decay of light [9]. These characteristics permit or allow a complete transfer of energy from the gamma rays into the detector. This is achieved by using a scintillator with a high effective atomic number and linear attenuation coefficient. The gamma ray signals are then received as a coincidence event, pinpointing the source of radiation. For a typical PET scan, hundreds of such points are generated to render the entire scan of the patient. Attenuation corrections are also performed to enhance the quality of the image.

IV. Applications of PET Scans

From the cellular level to the macroscopic level, the general overview of PET scans and their thermodynamic properties have so far been analyzed. In furthering this analysis, examples of specific systems will be given: the brain and the stomach.

A. Application: The Brain

The use of PET scans to examine the brain has been a remarkable advancement in the neurology community. Functions of the brain that can be analyzed by PET scans include cerebral blood flow, metabolism, and receptor binding [13]. The particular tracers used to image these functions vary, for example, ^{18}F-FDG is used to image the cerebral metabolic pathways of glucose whereas H2^{15}O is used to image cerebral blood flow. Interestingly, even receptors, such as dopamine D1 and D2, can also be visualized through PET scans and their respective tracers. These tests in particular can be carried out while the patient performs a certain task to better understand the receptor's role. This is pivotal for the neurology community in that many of the maladies they need to image are not produced in a stagnant environment. For example, the patient may need to be performing a task in order to measure the activity of the brain.

In Figure 4, the PET images displayed show three different patients. Image one, two, and three each show a patient that is normal, diagnosed with Parkinson's disease, and diagnosed with progressive supranuclear palsy, respectively. The tracer used in this figure is still ^{18}F; however, the analog that it is attached to is Dopa rather than FDG. This is related to what the PET image is trying to visualize, in this case, the receptors in the brain. This is another type of technique in PET imaging where the swapping of the analog attached to the tracer can image different properties of the human body.

Considering the thermodynamics of PET scan imaging the brain, it is interesting to note the complexity in the transfer of energy required to image such a PET scan. You could begin by considering the cognition of the task being instructed to follow through, let's say picking up a puzzle piece, which in turn would require further cognitive efforts. You could break this apart into essentially three different thermodynamic situations: cognition, mechanical work in completing the task, and the imaging of the brain throughout.

In regard to cognition alone, studies have shown that cerebral blood flow and glycolysis increase more than needed for metabolism while the opposite is true for the oxygen fraction [14]. However, when considering the basic thermodynamics of metabolism,

these results are sound. The agreement arises out of the conservation of entropy in the system. The metabolic rates and cerebral blood flow are a result of this conservation.

Now consider the transfer of energy from the performance of the task. Specific to this example, consider the transfer of energy from the processes before mentioned: the function of the brain in understanding the task. The brain is then responsible for signaling through the central nervous system via motor neurons to tell your muscle to perform work (e.g., on a puzzle). In terms of entropy, the entropy of the puzzle would decrease as it is assembled while the bodily entropy is increased in performing the task.

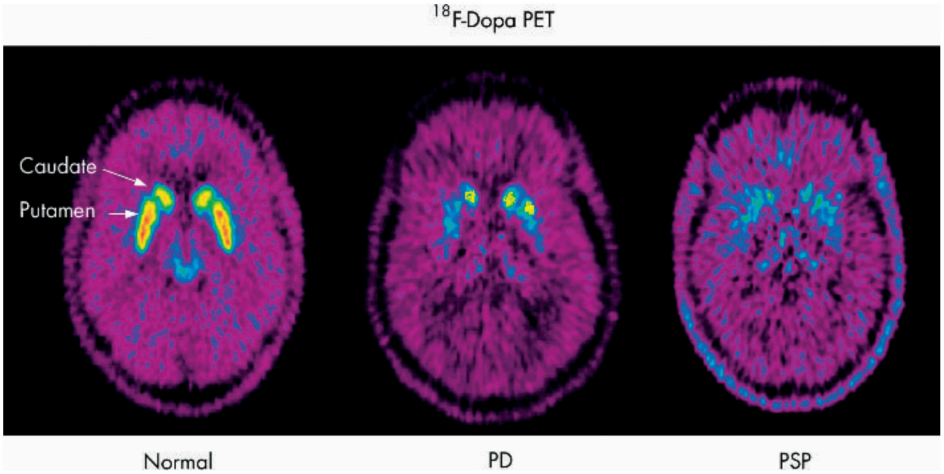

Figure 4: Image I. ^{18}F-Dopa PET in a normal patient. Image II. Patient with Parkinson's disease (PD). Image III. Patient with progressive supranuclear palsy (PSP). [13]

These intricacies in cognition and mechanical work are also greeted with those of receptor-tracer thermodynamics, which has been covered in greater detail in previous sections of this review. Considering the PET scan imaging, the overall process has not dramatically changed. The process of annihilation and emission from the tracer at the absorption site has already been well defined before in this review. Therefore, the cognition in performing the task to the work performed to achieve said task (e.g., completing a puzzle) all being imaged from the annihilation and emission of gamma rays read by the PET scanner is a highly complex thermodynamic process. The energy transfer in completing such a simple task is remarkable.

B. Application: The Stomach

Another application of PET scan imaging is for gastrointestinal maladies: specifically, gastric cancer. Gastric cancer is second in cancer-related deaths worldwide, therefore the importance of its early diagnosis is critical [15]. As before mentioned, the high cellular metabolism of glucose in cancer cells is of great importance for PET scan imaging with ^{18}F-FDG. The thermodynamics of which have been well defined in previous sections of this review. Through the use of PET imaging, the physician is able to visualize the development of gastric cancer. Specifically, PET imaging in gastric cancer uses the common ^{18}F-FDG tracer to locate highly metabolically active tissue. As with all other PET scans, administration of the ^{18}F-FDG is through injection [16, 17]. The process through which the ^{18}F-FDG is brought into the cell and later annihilated and emitted is the same as before. However, there are distinct complications that can arise due to the metabolically active nature of the stomach. The images produced, even with CT coupling, are not nearly as refined as other areas of the body. When observing Figure 5, one is able to note the distinct differences in ^{18}F-FDG uptake [17].

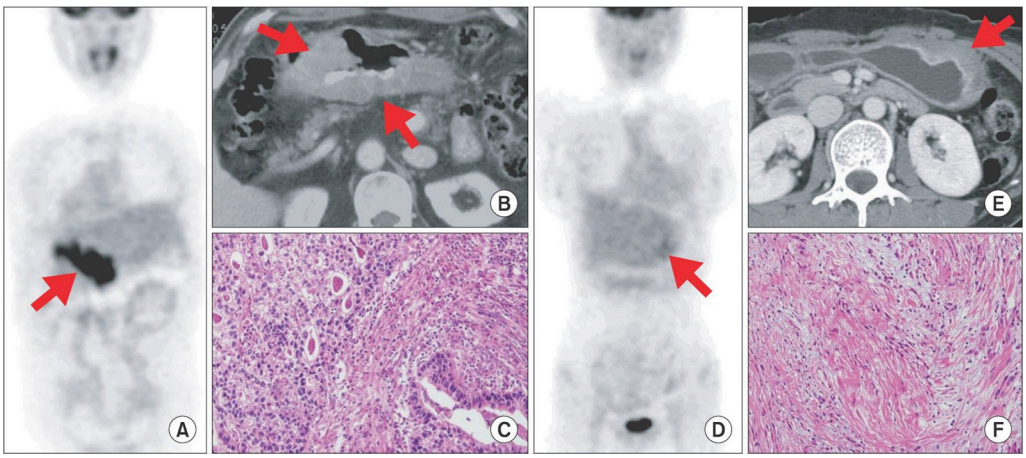

Figure 5: Fluorodeoxyglucose (^{18}F-FDG) uptake in advanced gastric cancers (AGCs). [17]

Both patients visualized have been diagnosed with acute gastric cancer and the quality in the imaging produced is staggering [15]. A, B, and C show significant ^{18}F-FDG uptake (red arrows) in the regions of interest. However, D, E, and F only show some ^{18}F-FDG uptake (red arrows). This discrepancy is concerning and can be attributed to the high metabolic activity of the stomach leading to this loss of imaging.

V. Discussion

It is humbling to think of the trillions of cells in our bodies, of all different types, operating together to enable the life of a single human being. This orchestra on the cellular level is exactly that, an orchestra of specialized units performing unique functions coming together to achieve the common goal of human life. The timing and achievement of all of these individual cells is key to what allows us to lead normal lives. Unfortunately, in the case of the millions fighting cancer, this orchestra can falter. Cancer is the six-letter word no one wants to hear while awaiting their results at their physician's office; however, too many do. When they do, it could not be more important to have all of the information possible on how to proceed. Patient education is vital in keeping spirits high, for the difficult path that follows diagnosis can bring about mental anguish and despair. Therefore, for those diagnosed, being able to see their adversary plain as day on an image is everything. Imaging is perhaps even more critical for doctors and staff whose sole job is to cure their patients of this insidious disease. When planning a tumor resection, understanding the malignancy's boundaries is crucial. Therefore, information is key, which is why the development of positron emission tomography scan imaging is so important. Patients are educated, while physicians are better informed in their treatment planning.

Specifically, this groundbreaking achievement for oncology of positron emission tomography is only achievable due to the unique metabolism of cancer. This thermodynamic process resulting in the increased glucose consumption of cells is the type of distinction scientists can capitalize on in diagnostics. Reflecting on the uniqueness of cancer metabolism, it is interesting to consider the entropy. As previously discussed, cancer metabolism is lower in terms of entropy per reaction compared to normally functioning cells. Cancer as a whole brings disorder to the entire biological system, disrupting normal cell and organ function, altering the lymphatic system, etc. For instance, in the case of a malignant brain tumor, the intricate neural network becomes compromised and can even result in hallucinations. Such a disruption of normalcy, thus increase in system disorder or entropy, introduces an interesting consideration. In considering the conservation of energy: if cancer is causing such an increase in system entropy, is it possible that this is a result of its lowered metabolic entropy, or vice versa. Future research should concentrate on this thermodynamic, interesting situation of overall entropy in cancer patients.

Moreover, beyond the cellular level, the transfer of energy in performing such a PET scan image is quite spectacular. Beginning with the radioactive compound, ^{18}F-FDG, you have the creation of a substance capable of sending X-rays and gamma rays out in all directions from the point source. To image with such a volatile compound, thick steel doors, massive concrete walls, Geiger counters, and so much more is required to ensure limited exposure to personnel. Said exposure to these emitted X-rays and gamma rays can result in the disruption of cellular DNA, even this miracle of a diagnostic could give one cancer! Beyond the radioactive compound itself, the thermodynamics of uptake and decay within the cancerous target cells is quite impressive. Once the ^{18}F-FDG is within the cell, a time-sensitive decay process begins where the compound becomes more and more unstable. This instability eventually leads to the annihilation of a positron with a kinetic energy of 637 keV, which through conservation of energy and the collisions with neighboring electrons leads to the formation of positronium. It is then that the positronium emits two photons in opposite directions of 511 keV each. These photons are then captured by the PET detectors, and through various processes, are able to generate the compelling images seen in Figures 1, 4, and 5.

From the emitted photons to the metabolic pathways, if it were not for this thermodynamic process these scans would not be achievable. This conversion of energy from one form to another allows for this overall process to take place. If it were not for this conversion, everything from the imaging of the brain's receptor pathways to gastric cancer would not be possible. Such an achievement allows for the progression of scientific understanding and the bettering of the world we live in. In future studies, further applications of PET imaging should be considered and studied. ^{18}F-FDG is just one compound, and yet it is able to achieve so much. By taking advantage of the metabolism of glucose, scientists were quite literally able to shed light on cancer. Other essential biological molecules should be investigated for their relativity in thermodynamic importance. Cancer is just one of the many battles we face. Efforts to better understand and cure neurological conditions such as Parkinson's or Alzheimer's, should investigate further the role PET can play.

VI. Conclusions

The thermodynamic considerations relative to PET imaging are due in large part to the cellular metabolism of cancerous cells and the radioactive decay of the ^{18}F-FDG compound. Both metabolisms, cancerous and noncancerous, were found to be

spontaneous, exergonic, and exothermic processes with overall increases in entropy. However, cancerous cells were found to have overall lower thermodynamic parameters of Gibbs free energy, enthalpy and entropy when compared to normal functioning cells. Further, the transfer of energy from the radioactive compound ^{18}F-FDG was evaluated from formation to detection of annihilated photons. Overall, PET imaging is a highly interactive, thermodynamic process that results in highly specific scans of many maladies.

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