FULLERENES AS AGENTS FOR CHEMOTHERAPEUTIC DRUG DELIVERY

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Abstract - In a world where the scale of technology is continuously shrinking, from phones to cars to solar panels, nanotechnology is seeing a rise in applications. Recently, increased use of nanotechnology in the medical industry brought fullerenes, sometimes referred to as Buckyballs, to the forefront. Fullerenes are currently being developed by engineers to encapsulate a chemotherapeutic drug and deliver it directly to the cancerous cell. This improved treatment minimizes interactions outside of the intended cell, consequently reducing some of the harsh effects typically observed with chemotherapy.

Fullerenes are developed as an alternative method in the delivery of docetaxel and doxorubicin, medications used in breast and lung cancer chemotherapy. While chemotherapy is the most widely used method of cancer treatment, there remain a myriad of difficulties including low efficacy, or effectiveness, with the way the medicine enters the body, whether orally or intravenously. Fullerenes deliver the same medication using a unique capsule delivery method that minimizes the effect on non-cancerous cells and reduces unwanted side effects, a significant task for chemical engineers. After diffusing through the skin and travelling through the bloodstream without releasing the drug, fullerenes minimize problems such as hypersensitivity and reduce the number of treatments required, contributing to overall higher patient quality of life. Therefore, this technology is extremely relevant to engineers around the world who are looking to use fullerenes as methods for drug delivery. They seek to offer better treatment options that will reduce side effects normally associated with chemotherapy. The development of fullerenes demonstrates the benefits of nanotechnology in medicine by improving efficacy while reducing risk, consequently achieving social sustainability and reducing environmental impact.

Key Words – buckyballs, chemotherapy, docetaxel, drug delivery, fullerenes, nanotechnology

INTRODUCTION: DEMONSTRATING A NEED FOR IMPROVEMENT

Throughout society, cancer is a continuous problem that affects many people. Due to the number of different cancers and the number of individuals diagnosed with cancer each year, death from cancer is second to heart disease as the leading cause of death in the United States [1]. The far-reaching effects of the disease demand a sustainable and efficient treatment. While the ultimate goal of cancer treatment is to eradicate the disease, it also serves the additional functions of palliating side effects, improving patient quality of life and prolonging survival. There exist multiple options for the treatment of cancer, the most popular being chemotherapy.

Researchers interested in improving the effectiveness of chemotherapy intend to increase efficacy of drug delivery methods to minimize side effects that cause permanent damage to bodily function, often for prolonged periods of time. To treat cancer effectively and comprehensively without compromising patient well-being, alternate methods are being developed that focus on the delivery of chemotherapeutic drugs within the body. Specifically, attention has been given to nanotechnology such as fullerenes that delivers pre-existing medications to cancerous cells within the body. The development of fullerenes has shown potential to improve the ability of the drug to treat the cancerous cells without compromising the overall health of the patient. Effective drug delivery is as important as the medication itself in chemotherapy because without it chemotherapy fails to sustain the goals of improving the quality of life and prolong survival of recovering cancer patients. These goals are integral to researchers and engineers involved who strive to promote sustainable healthcare.

Understanding Cancer and Chemotherapy

As common as cancer is, many people still do not hold a basic understanding of the disease. Stated most clearly,
cancer is caused when reproduction of cells occurs too rapidly. The fragile balance between mitosis, the division of cell nuclei, and apoptosis, the death of cells that is a normal part of cell reproduction, becomes disrupted [2]. As a result, the cancerous cells grow very rapidly and disrupt bodily function by causing harm to other cells. Cancer takes all different forms in different areas of the body but the fundamental problem stems from the rapid reproduction of the cells. Because of the tendency of cancer cells to reproduce very rapidly, the best way to stop them is to keep them from growing. This need has led to the development of chemotherapy, the most widely used method of cancer treatment. Like cancer itself, chemotherapy takes on many different forms and involves the use of medications that target different types of cancer or make use of certain characteristics of cancer cells to kill them. At the core, however, is the goal of targeting the rapidly growing cancer cells and preventing them from reproducing [2]. Because chemotherapy treatment destroys cells, however, it comes with many side effects that differ in severity and can cause additional health problems for the patients.

In adults, cytotoxic chemotherapy is the main definitive treatment or adjuvant therapy [3]. Drugs are classified as cytotoxic because they are toxic to living cells. Taken orally or intravenously, chemotherapeutic drugs target cells at different phases of cell formation, specifically cells that grow at fast rates [4]. However, in traditional chemotherapy, a lack of efficacy arises as a consequence of not having exact control of where the medication is being released in the body because, in addition to killing healthy cells, the medication unintentionally affect normal, healthy cells that are fast-growing as well [4]. This lack of efficient drug delivery causes unwanted side effects that can vary in severity. For example, hair growth cells reproduce rapidly and are often killed unintentionally by chemotherapeutic drugs. This is the reason why hair loss is such a common side effect. Often, these side effects are severe to the point of causing both short term effects such as immune system depression and long term effects such as heart problems that may cause permanent damage to patients.

The evidence of the severity of side effects are a pressing issue of traditional chemotherapy. Normal cells most likely to be damaged by chemotherapy include blood-forming cells in the bone marrow, hair follicles, cells in the mouth, digestive tract, and reproductive system [4]. These side effects can result in fertility issues, and permanent damage in the immune system. Other short-term side effects include fatigue, easy bruising and bleeding, infection, anemia, nausea and vomiting, appetite changes, constipation, diarrhea, sores and pain within the mouth, tongue, and throat, kidney problems, mood change, and “chemo brain” which can affect concentration and focus [4]. There are over one hundred different types of chemotherapeutic drugs are used to treat cancer (either alone or with other drugs) that differ in chemical composition and their usefulness in treating certain types of cancer. Practitioners prescribe these drugs based on the type and severity of the cancer that the patient has [4]. These drugs work in different ways to destroy cancerous cells. Each drug has various side effects and because these drugs are often taken in combination with others, the risk and variance of side effects only increases.

In healthcare, researcher and engineers strive to contribute to social sustainability by focusing research on treatment methods that prolong and improve the quality of life. In order to achieve this, the primary goal of cancer treatment is to hinder the growth of the cancerous cells while promoting healthy recovery. The Department of Oncology, Northern Sydney Cancer Centre, conducted a study to get conclusive answers about the contribution of curative or adjuvant cytotoxic chemotherapy to survival in adult cancer patients [5]. The five-year relative survival rate for cancer patients diagnosed in Australia was 63.4%. Under cytotoxic chemotherapy the relative rate of survival only increased by 2.3% [5]. The effectiveness of cytotoxic chemotherapy on prolonged survival is minimal especially when 39.6% of patients did not survive in only a five-year period. These staggering results contribute to the conclusion that traditional cytotoxic chemotherapy is not effectively prolonging and improving the quality of life for cancer survivors. It is imperative to focus funding and research towards a more effective method of drug delivery for chemotherapy.

This study also compared the survivals relative to the different types of malignancies or tumors. It was found that of the small group of five year survivors, the successful impact of cytotoxic chemotherapy was limited to small subgroups of patients with the least common malignancies such as testis, Hodgkin’s disease, cervix, and ovarian cancers that only made up 8.4% of the test sample which experienced a 14% survival rate increase [5]. This increase in survival rate looks astronomical compared to more common malignancies. Malignancies that made up 56.6% of the sample including breast, prostate, lung, and melanoma only experienced an increase of survival of 1.6% [5]. Not only is traditional chemotherapy failing to substantially increase vitality, the most common tumor types have experienced poor improvement in cytotoxicity, indicating the need for a more efficient delivery method to allow the drugs to destroy the cancerous cells more efficiently.

NEW TECHNOLOGY TO IMPROVE TRADITIONAL CHEMOTHERAPY: FULLERENES

As with all areas of medicine, technology is constantly evolving to promote sustainability by improving the methods used to treat different diseases. Engineers and researchers have developed many different possible ways of
using nanotechnology to deliver drugs. Nanotechnology can be especially useful drug delivery agents because they have the ability to be developed in ways that target certain weaknesses in other methods of drug delivery, such as cytotoxicity or bioavailability. One specific nanotechnology that has shown enormous potential in drug delivery is fullerenes.

First discovered by professors Curl, Kroto, and Smalley in 1985, fullerenes are a spherical allotrope of carbon [6]. After observing the spherical shape of the fullerenes which strongly resembles a soccer ball, the scientists chose to name the nanotechnology after Buckminster Fuller, the designer of the geodesic dome [6]. Sometimes called Buckyballs, buckminster fullerenes can be isolated using a laser evaporation on graphite, another carbon allotrope. The fullerenes are essentially fused benzene rings each containing six carbons that link in a spherical shape.

Fullerenes are related to other types of nanotechnology, such as carbon nanotubes, that are also used in medical applications but are especially important because some of their unique properties. Carbon nanotechnology is both extremely durable and incredibly elastic, making it useful for applications. Fullerenes are stable in both air and aromatic solvents and are not inherently toxic. Additionally, due to their organic structure, fullerenes can be functionalized to carry medications and only appropriately react with certain aspects of the body using a series of reactions. Their unique properties also make them ideal imaging agents and antibacterial and antiviral agents, a function that will be utilized to make them useful drug delivery agents for cytotoxic chemotherapeutic drugs [6].

**Fullerenes as Drug Delivery Agents**

Given their useful properties, fullerenes exhibit high potential as drug delivery agents. To test their effectiveness and determine their potential, researchers have spent time functionalizing these groups. The functionalism of the groups is done by reacting the fullerene in the way shown in Addendum 1 below.

The fullerenes are conjugated with docetaxel using a multistep synthesis. Initially, fullerenes are prepared by carboxylating and acylating reactions that prepare the fullerene to react with the docetaxel. This is done in a twenty-four-hour period in solution with sulfuric and nitric acid between temperatures of 60-70°C [8]. These are very attainable lab conditions and reactions that are common in many organic syntheses, making the reaction very practical to implement into healthcare. The docetaxel is then reacted with the carboxylated/acylated fullerene to form the conjugated fullerene. This process is done also in 24 hours at a temperature of 35°C in solution with pyridine [8]. Again, these conditions for reaction are extremely practical and attainable in any industrial environment. This is the way that the fullerene will be treated and tested in the body. Fullerenes’ chemical composition and reactivity make conjugation of chemotherapeutic drugs a straightforward synthetic process. The conjugation of docetaxel exemplifies versatility of fullerenes. Versatility is valuable especially in healthcare when treatment requires heightened specificity according to the individual being treated. Fullerenes chemical composition make them viable chemotherapeutic drug delivery agents in hopes to create more efficient delivery through increasing bioavailability, cytotoxicity, and by decreasing effects of the drug on non-cancerous cells.

**IMPROVING UPON STANDARD TREATMENT: WHY FULLERENES HAVE THE POWER TO IMPROVE PATIENT CARE**

As a result of the negative side effects that accompany treatment, traditional chemotherapy does not successfully fulfill the goals of prolonging and improving the quality of life for surviving cancer patients. Many of the efficacy problems associated with chemotherapy such as short and long term side effects are a direct result of poor drug targeting through traditional drug delivery methods. The chemical composition of fullerenes make them ideal and viable options in transporting medication to targeted areas. Targeted drug delivery applied in cancer treatment poses promising potential in the goal of improving the quality of life for cancer patients. Fullerenes, like polymeric drug delivery, are versatile in the fact that they can be engineered in ways that specifically correspond to the environment they are in and the tasks they must perform [7]. Implementation of nanotechnology such as fullerenes in chemotherapeutic drug delivery increases the ability to destroy cancerous cells without the patient experiencing side effects by only delivering the medication to the desired area of the body [7]. Numerous innovations including “on-off” state increase targeting capabilities through the versatility of the chemical composition of fullerenes [8]. Conjugation of chemotherapeutic drugs with fullerene derivative C₆₀ promises increased efficacy and decreased suffering from side effects [8].

The goal of engineers developing new drug delivery methods remains to provide the best possible care to patients in order to encourage sustainability in healthcare. The potential of fullerenes to increase biotoxicity while decreasing toxicity to the surrounding cells proves to be a tremendous feat that demonstrates their value in the medical field. In considering the effects on patients, the three highest areas of highest concern are the bioavailability of the medication, the toxicity to cancerous cells, and the toxicity to areas outside the targeted cells.
Bioavailability

A common goal for pharmacists and engineers when developing pharmaceuticals is to create an efficient drug. The most effective drugs serve their purpose efficiently, with a minimal number of treatments and maximum effects of the medication when entering the bloodstream. Chemotherapy is no different. In delivering chemotherapeutic drugs, researchers aim to increase the availability of docetaxel so that it is able to treat the targeted cells more efficiently. One way this is measured is by analyzing the bioavailability of the drug. Bioavailability is defined as the percentage of the drug that enters into circulation when introduced into the body and so it is able to have an active effect.

Rapid development of nanotechnology in biomedical applications has resulted in promising new innovations to steer disease treatment in a more efficient direction. In cancer treatment, docetaxel is a common drug. It is classified as a mitotic inhibitor, defined by its ability to stop cells from dividing to form new cells by preventing enzymes from making proteins needed for cell reproduction [4]. While these capabilities are attractive to researchers, side effects such as nerve damage cause it to be given in small dosages. Docetaxel also has low bioavailability or poor tissue penetration as well as aqueous solubility [9]. Docetaxel delivery by traditional methods results in severe side effects as well as poor reception of docetaxel by the targeted cancerous cells. Results from a study performed by the Central University of Rajasthan, India show promising results for better bioavailability as well as a better pharmacokinetic profile for the release of docetaxel through this conjugation of fullerene C60. The versatility of fullerenes allows them to be carboxylated, acylated, and conjugated with docetaxel as shown in Addendum 1. From tests performed on rats, fullerene conjugation increased bioavailability to 81.42%, about 4.2 times higher than the non-conjugated fullerene [9]. Pharmacokinetic stability is also important because it is desirable to have substantial concentrations of the drug at the targeted location for a long amount of time so that the targeted cells are completely destroyed. Figure 1 demonstrates how fullerene conjugated docetaxel (shown in red) offers a release of 84.32% of the drug in a 120-hour period [9]. This is more desirable than docetaxel without fullerene conjugation which takes less than 30 hours to release the same percentage. Having a better pharmacokinetic profile is very desirable because of the potential it shows in improving social sustainability by improving the overall impact of the drug without increasing side effects, which increases the chance of the patient of advancing to remission without long-term side effects from the treatment. Having substantial concentrations of the chemotherapeutic drugs at the cancer site for a long amount of time (desirable pharmacokinetic condition) increases the chances of the drug to completely kill the cancerous cells. Having the ability to completely kill cancerous cells then increases the chances of remission as well as decreases the chances of relapse.

In demonstrating the ability to circumvent various challenges associated with docetaxel delivery, this approach has demonstrated the potential to enhance cancer cell cytotoxicity and provide a better pharmacokinetic profile [9]. These findings indicate a need to continue research of implementation of fullerenes with the ultimate goal of maximizing the bioavailability of the drugs used in chemotherapy.

Cytotoxicity

Increasing the cytotoxicity of the drugs is also an integral part of improving patient care. As previously mentioned, cytotoxicity is the ability of the medication to be toxic to the cancerous cells. Better cytotoxicity creates more effective treatment because patients will not need as many rounds of treatment and will consequently be less susceptible to relapses. This aspect of cancer treatment is important because common anti-tumor drugs present concerns from their ability to permanently damage the heart if they are given in high dosages [4].

The chemical composition of fullerenes that allows them to be conjugated with substituents to form different derivatives of C60 promises potential in increasing cytotoxicity. Recently, the derivative C60 has been researched in its ability to enhance chemotherapeutic susceptibility of cancer cells by modulation of autophagy [10]. Autophagy is an evolutionarily conserved intracellular process that consumes cytoplasmic proteins and organelles for recycling [10]. In other words, it is the cell's natural process of

![Figure 1: Percent Drug Release versus Time](image_url)
controlled self-digestion and recycling of damaged organelles. This process is very intriguing to engineers in cancer treatment research because it is a natural process that has potential to be focused and accelerated to kill cancerous cells. In this experiment, cytotoxicity of C₆₀ as a carrier of doxorubicin (displayed as “dox”) is tested on cells within extracted mouse embryos over an extended period of time [10]. Doxorubicin is a common chemotherapeutic antibiotic that works by changing the DNA inside cancer cells to keep them from growing and multiplying [4]. In this experiment, two types of cells were assessed: HeLa cells, and doxorubicin resistant cells [10]. An HeLa cell is a common agnomen for very strong cancerous cells used in medical research. Figure 2 illustrates time versus cell death percentage comparatively between carriers C₆₀ and C₆₀(Nd).

![Figure 2](image)

**FIGURE 2 [9]**

*Cell Death by Delivery Method*

Figure 2 shows the percentage of cell death was compared using a bar graph for various treatment methods ranging from doxorubicin alone to the fullerenes conjugated with Doxorubicin.

These results are consistent with the assumption that C₆₀ derivative, is more potent than doxorubicin alone in the enhancement of chemotherapeutic susceptibility. The substituent enhances the induction of autophagy in cancerous cells. Due to the distinctive physical and chemical characteristics, fullerenes enhance cytotoxicity with water-soluble conjugates. Different conjugations allow the cell to reach the desired toxicity level more efficiently and kill not only the cancerous cells but more specifically the doxorubicin resistant cancer cells [10]. The dramatic increase in cytotoxicity experienced by the C60 fullerene conjugation compared to doxorubicin alone is imperative in patient care because it promises fewer rounds of chemotherapy to get more efficient results. Less frequent treatment improves patient care by decreasing the amount of drugs in the body causing a lower probability of experiencing severe long-term side effects. This discovery is paramount in developing alternative strategies for delivering chemotherapeutic drugs through fullerenes. It also helps promise the overall goal of increasing the sustainability of healthcare by reducing side effects that come along with the low efficacy of current drug delivery methods.

**Targeted Drug Delivery Systems: Effects on Remaining Cells**

The final goal of engineers and researchers is to decrease the effect of the drug on cells outside of the cancerous cells. As discussed previously, the targeting of rapidly growing cells, even noncancerous ones, is the reason for many of the side effects typically observed with chemotherapy. Although drugs such as docetaxel and doxorubicin are still used, conjugating these drugs with fullerenes allows them to be delivered directly to the cell, decreasing many of the side effects.

Current drug delivery systems for chemotherapeutic drugs are often hindered by unexpected drug release during circulation to unwanted areas, consequently causing side-effects. These side effects as discussed earlier have harmful long-term effects that can be as severe as death. Targeted drug delivery is the key to eliminating unwanted side effects of cancer treatment drugs. When the side effects of chemotherapeutic drugs are as severe as the examples listed in previous sections it is essential to focus research on development of targeted drug delivery systems. The School of Pharmaceutical Sciences in China has devoted research to enable fullerene based tumor targeting nanoparticles with “off-on” state [8]. The goal in this experiment is to control the release of the drugs from the carrier and limit that release to cancerous cells only [8]. If this is achieved, chemotherapy through use of C₆₀ nanoparticles has the potential to eliminate most side effects. The diversity of fullerenes in chemical properties allow them to be the optimal drug delivery system. Their chemical properties allow for conjugations of drugs such as docetaxel and doxorubicin to be attached via a reactive oxygen species (ROS) linker [8]. The drug release is completely controlled by a photodynamic laser that triggers the ROS linker in order for the drug to be released in a desirable location [10]. Figure 3 below shows a schematic of the process of controlled drug release through a lab rat.
Effect of On-Off State on Drug Delivery

Figure 3 above represents a schematic of controlled drug release. From the IV injection, the drug travels in C60 in the “off-state” until it arrives at the tumor site where it passes under a laser that triggers the reactive oxygen species linker that then releases the drug in that location only.

In this experiment, the chemotherapeutic drug doxorubicin was successfully covalently conjugated to C60 via a ROS with a hydrophilic shell to provide excellent stability in physiological solutions and active tumor targeting capacity [8]. This chemical construct of the conjugation of C60 successfully encapsulates doxorubicin without commanded release efficiently in pH ranging from 5.5 to 7.4 as shown in figure 4 [8]. This range of pH is remarkable because it allows this drug delivery system to be effective in many different environments throughout the body. The process of on demand doxorubicin release is important because of the preciseness demanded at the cellular level that diminishes any release of doxorubicin to healthy non-cancerous cells. Instead of relying on spontaneous degradation of nanocarriers, researchers have developed a way to control the release of the drug. The “on state” of this fullerene conjugation drug delivery system is controlled through photodynamic radiation [8]. Photodynamic radiation is a process used in chemotherapy that involves triggering a reaction through photosensitizing a substance in order for it to react [8]. A 532-nm laser of 100 mW/cm² was used to trigger the ROS linker in the conjugate in order to release doxorubicin to the desired cells [8]. Performing this technique at time intervals of 10, 15, and 5 minutes produced the doxorubicin release percentages below in two different pH solutions [8].

According to these results, 42.6% of drugs were released (pH 7.4) after laser irradiation for 10 minutes [8]. In sharp contrast, C60 conjugate without laser irradiation showed negligible drug release (0.79%) during the same period of time [8]. This concludes that laser irradiation was helpful controlling the release of doxorubicin. Irradiation of C60 conjugate for 15 minutes resulted in a slight increase in doxorubicin release (57.4%). The similar results were observed in the more acidic condition. However, when sodium azide (a ROS scavenger) was added, the drug release was significantly reduced, thus further confirming the doxorubicin release was controlled by ROS [8]. These results confirm the ability for photodynamic radiation to control the release of chemotherapeutic drugs attached by ROS when conjugated to C60 fullerene. These conclusive results show the potential of drug delivery release to be controlled. This potential represents a benchmark to cancer treatment research because current chemotherapeutic strategies have failed to target cancerous cells efficiently. Because of this, many cancer survivors experience life-long health issues that were developed during their cancer treatment. The goal of cancer treatment is to increase the sustainability of healthcare by prolong and improve the life of the patient. Targeted drug release helps achieve this by drastically reducing side effects by delivering the high caliber drugs to a specific location without harming non-cancerous cells along the way. C60 fullerene conjugation allows the possibility of drug targeting capability and promises future improvement of patient care and social sustainability.
SUSTAINABILITY: MAINTAINING QUALITY CARE FOR GENERATIONS TO COME

As technology continues to become a ubiquitous part of our lives, innovation has procured a goal of sustainability. Sustainability is the ability to meet the needs of the of the present without compromising the ability of future generations to meet their own needs. Healthcare is increasingly being held to the standard of being sustainable as health problems remain evident in society. Healthcare has the responsibility of upholding social sustainability by prolonging and improving the quality of life. The case studies above explicitly conclude that fullerenes have the potential to increase bioavailability, cytotoxicity, and efficient targeting of chemotherapeutic drugs. Increasing bioavailability and cytotoxicity poses the need for less dosages of treatment because the drugs are more able to destroy cancerous drugs to completion. This improves the quality of life because less doses gives a lower probability of experiencing harmful and uncomfortable side effects. Heightened bioavailability provides a better pharmacokinetic profile that also improves the quality of life by increasing chances of remission and decreasing chances of relapse. This has potential to promise circumvention of related health problems in the future for recovering patients. Finally, efficient drug targeting is paramount in improving social sustainability. Controlling the release of the drug to the desired area within the body diminishes the possibility of destroying non-cancerous cells. This capability reduces the possibility of side effects experienced by the patient. This is significant because common side effects experienced by a cancer patient undergoing chemotherapy are often permanently damaging.

Even though development of fullerenes as agents for drug delivery are in research stages and have not been implemented into healthcare, their potential offers encouragement in other scopes of sustainability. As engineers and researchers continuously work to improve the efficiency and quality of life, environmental sustainability becomes a more pressing priority. Environmental sustainability is defined as the ability to maintain rates of renewable resource harvest, pollution creation, and nonrenewable resource depletion that can be continued indefinitely. Proven case studies discussed previously show that fullerene conjugation to docetaxel and doxorubicin increases cytotoxicity and bioavailability. This alone makes the drug (and therefore the treatment) more effective. This means that patients will need less dosages and treatments to get the quality care they need. Reducing the number treatments has the potential to decrease waste of medical supplies. Looking to the future, implementation of nanotechnology into medicine, alternative methods of drug intake will be able to decrease medical waste and help promote environmental sustainability.

The ability of fullerenes as chemotherapeutic drug delivery agents to increase bioavailability, cytotoxicity and efficient targeting encourages social sustainability. Dramatically reducing severe side effects and improving the effectiveness of chemotherapy in general contributes to the overall goal of prolonging and improving the quality of life for cancer patients. Improving the effectiveness of the drugs calls for need of less treatments per patient, therefore decreasing medical waste. This improves environmental sustainability not only by decreasing waste, but it also helps maintain rates of the renewable resource usage from the natural resources that many pharmaceuticals are synthesized from. Improving chemotherapeutic drug delivery meets the current needs of cancer patients while maintaining the quality of health for the future of the patient’s life. As a result of their encouragement of sustainability, fullerenes in drug delivery systems show the potential to improve the quality of cancer treatment without compromising the wellbeing future generations.

ETHICAL CONCERNS

As engineers and scientists continue to search for improved treatments for a myriad of diseases, it is important to uphold the highest ethical and safety standards possible to ensure the best outcomes for the patients and the highest degree of integrity when performing testing.

The first canon of the engineering code of ethics states the importance of holding paramount the safety, health, and welfare of the public [11]. This is the cannon that becomes the most critical when look at the effects of fullerenes in medicine. While improvement is important and always strived for in medicine, it remains crucial that engineers and researchers make sure that they are always presenting data honestly, not simply pushing for better results. The Markkula Center for Applied Ethics evaluates these case studies comprehensively, especially those compared to medical research and data collection, ultimately reaching a conclusion regarding the importance of clarity and repeated testing to ensure the highest level of accuracy [12]. In all engineering fields, especially medicine, this pressure is immense and crippling. Researchers may feel the need to always be improving but by doing so they are hindering development. It is crucial that researchers present data in an honest fashion, even when the results are not consistent with the predicted desired outcome. By only honestly presenting data researchers ensure that patients will receive the best care possible in time rather than rushing new treatments before they are safe and effective.

Additionally, there are certain ethical concerns specifically related to using nanotechnology. Because using nanotechnology in medicine involves introducing synthetic materials into the body, there are many concerns that arise about the safety of the materials and their place in the human...
body. In an article on ethics in nanomedicine, researchers David Resnick and Sally Tinkle evaluate the ethics and policy of nanotechnology and present the different testing methods used to determine the safety materials as well as possible ways for improving testing and treatment [13]. After presenting data, the researchers conclude that there is never a way to eliminate all of the uncertainty involved in using nanotechnology in medicine but through safe and careful testing and close analysis of results side effects can be minimized [13]. The same results must be considered with working with fullerenes. As with any medication or delivery method, there are possible unintended consequences that can be magnified when the procedure is done incorrectly, making it even more important to carefully consider all aspects of testing and implementation. As development of fullerenes for chemotherapeutic drug delivery continues, taking the ethics into consideration by ensuring that all trials are recorded and evaluated based on safety will help to minimize ethical issues with the nanotechnology.

FULLERENES IN THE FUTURE: MOVING FORWARD WITH DRUG DELIVERY IMPROVEMENT

Medicine can be compared to a classic team analogy, no matter how strong any one member is, a team will never be successful if the other members are not doing their jobs correctly. The same goes with the engineering around important pharmaceuticals. Even the drugs that will do the best job destroying and preventing further growth of cancerous cells will not be effective if they also destroy the patient’s immune system because they are unable to specifically target cancerous cells. For this reason, the area of drug delivery remains incredibly important. Researchers who are working with fullerenes understand this importance and are working to develop better solutions. Fullerenes, though in the development process, show incredible potential for further improvement in the future. By increasing the bioavailability of the drug, augmenting its cytotoxicity to cancerous cells, and decreasing the toxicity to other cells, the conjugated fullerenes are able to have a stronger effect on the cancer cells while being more gentle on the other parts of the body. As researchers and engineers press on in the development, they show the potential to improve the quality of patient care while continuing to fight to eradicate a pervasive disease.

SOURCES

types/medanim/chemotherapy/

ADDITIONAL SOURCES

M. Diener. “Fullerenes for Bioscience & Photovoltaic
http://thwink.org/sustain/glossary/Sustainability.htm

ACKNOWLEDGMENTS

We would like to thank our Conference Co-Chair, Kelly Donovan, for her helpful comments and inspirational dog photos. We would also like to thank Dr. Mahboobin and our writing instructor, Emelyn Fuhrman, for answering all our questions and reminding us to turn the paper in as a Word document, not a PDF.
ADDENDUM 1 [8]
Conjugation of Fullerenes with Docetaxel

The graphic is a visual representation of the reaction to conjugate the fullerene with the chemotherapeutic drug.