

Nanotechnology Method Comparison for Early Detection of Cancer

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Abstract — Since 1999, cancer has been the leading cause of death under the age of 85 years and the eradication of this disease has been the long sought-after goal of scientists and physicians. Cancer is a disease in which abnormal cells divide uncontrollably. These abnormal cells have the ability to invade and destroy normal body cells, which is life threatening. One of the most important factors in effective cancer treatment is the detection of cancerous tumour cells in an early stage. Nanotechnology brings new hope to the arena of cancer detection research, owing to nanoparticles' unique physical and chemical properties, giving them the potential to be used in the detection and monitoring of cancer. One such approach is quantum dots based detection which is rapid, easy and economical enabling quick point-of-care screening of cancer markers. QDs have got unique properties which make them ideal for detecting tumours. On the other hand, Gold nanoparticles have been in the bio-imaging spotlight due to their special optical properties. Au-NPs with strong surface-plasmon-enhanced absorption and scattering have allowed them to emerge as powerful imaging labels and contrast agents. This paper includes the comparative study of both the methods. Compared with quantum dots, the gold-nanoparticles are more than 200 times brighter on a particle-to-particle basis, although they are about 60 times larger by volume. Thus, Gold nanoparticles in suspension, offers advantages compared with quantum dots in that the gold appears to be non-toxic and the particles produce a brighter, sharper signal.

Index Terms— Cancer, Nanotechnology, Gold Nanoparticles, Quantum Dots

I. Introduction

According to the US National Cancer Institute (OTIR, 2006), "Nanotechnology will change the very foundations of cancer diagnosis, treatment, and prevention". We have seen how nanotechnology, an

extremely wide and versatile field, can affect many of its composing disciplines in amazingly innovative and unpredictable ways. In fact, nanotechnology and the ideas and methods that it encompasses can be applied to almost any problem that leading researchers face today. Even the most seemingly impossible problems like HIV and cancer become only obstacles in the path to solutions, if we take an imaginative approach. Of course, this is quite logical, since everything around us is made up of atomic and molecular matter, and all of our problems are ultimately rooted in atomic and molecular arrangements. Current cancer detection methods rely on the patient contacting their provider when they feel ill, or relying on non-specific screening methods, which unfortunately often result in cancers being detected only after it is too late for effective treatment. Cancer treatment paradigms mainly rely on whole body treatment with chemotherapy agents, exposing the patient to medications that non-specifically kill rapidly dividing cells, leading to debilitating side effects. In addition, the use of toxic organic solvents/excipients can hamper the further effectiveness of the anticancer drug.[5] Nanotechnology has at last provided a way for us to rearrange and restructure matter on an atomic scale, allowing us to reach down to the very roots of any problem. Provided that we can thoroughly understand the problem on an atomic scale and develop the know-how to turn our innovative ideas for the perfect solution into reality, we now have all the tools that we need.

This paper contains a brief introduction of cancer and the role of nanotechnology in early diagnosis of cancer. Gold nanoparticles and quantum dots are discussed concisely and a comparative study is performed which resulted in support of gold nanoparticles.

The focus of this paper is cancer. It is one of the most widely researched diseases in today's medical and scientific community. The purpose of this paper is to discuss some of these recent and innovative solutions that have been made possible by the arrival of nanotechnology in early diagnosis of cancer.

1.1 Cancer

The word cancer was first applied to the disease by Hippocrates (460–370 B.C.), the Greek philosopher, who used the words *carcinos* and *carcinoma* to refer to non-ulcer forming and ulcer forming tumours. The words refer to a crab, probably due to the external appearance of cancerous tumours, which have branch-like projections that resemble the claws of a crab.[12]

In non-cancerous tissues growth is limited in the sense that cell reproduction is tightly controlled. After a certain number of cells have developed, feedback control (contact inhibition) limits cell division, allowing for tissue repair but not expansion. Cancer or neoplasm, on the other hand, involves tissues composed of cells that divide and/or grow abnormally. Cancer is a genetically rooted disease that involves the simultaneous occurrence of two general categories of cellular malfunctions. The precise number of genetic changes required for these malfunctions remains unresolved for any cancer, but for adult cancers it is generally believed to range from 5 to 15.[12]

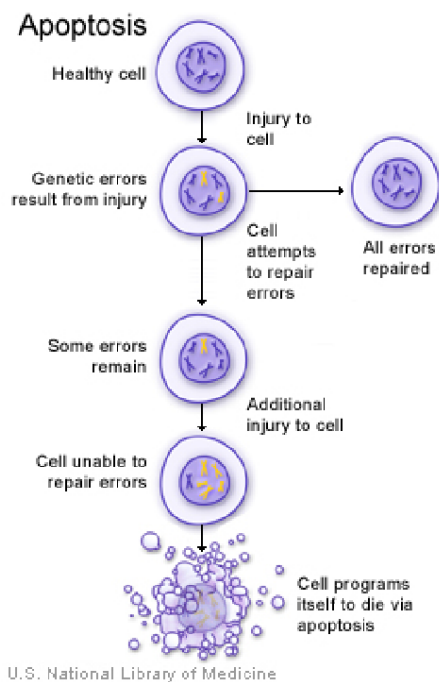


Fig. 1: Apoptosis

The first category causes the replication of a cell to become permanently enabled due to a natural or carcinogen-induced genetic mutation, chromosome translocation or gene amplification (genetic instability). The second category is also due to genetic mutations, and causes the apoptosis complex, also known as the suicide complex, to become permanently disabled (Figure 1). As stated, both of these problems must occur in the same cell, at the same time, in order to cause cancer. Under normal circumstances, the cells carefully control their divisions using apoptosis complex activated by the p53 tumour suppressor

protein. There are other mechanisms triggering the apoptosis complex, including receptor mediated death, which is dependant to chemical messengers, especially tumour necrosis factors. But, when both of these mechanisms malfunction, the body has no other option.[12]

As the uncontrolled cell division continues, a cluster of fairly unspecialised cells committed to dividing develops and becomes larger and larger. In addition, the cluster of cells releases chemicals to promote abnormal capillary growth into the tumour. This kind of a cell cluster is known as a malignant tumour, and can severely damage the surrounding tissue as it sucks up essential nutrients and displaces healthy cells. Eventually, when the tumour grows large enough, some of the tumour cells can find their way into the bloodstream, forming tumours in other parts of the body. This latter phenomenon is known as metastasis. It effectively multiplies the cancer as well as its effects, and eventually will prove fatal to the patient.[12]

Survival of a cancer patient depends heavily on early detection and thus developing technologies applicable for sensitive and specific methods to detect cancer is an inevitable task for cancer researchers.

1.2 Nanotechnology

Nanotechnology has the power to radically change the way cancer is diagnosed, imaged and treated. Currently, there is a lot of research going on to design novel nanodevices capable of detecting cancer at its earliest stages, pinpointing its location within the body and delivering anticancer drugs specifically to malignant cells. Nanoscale devices smaller than 50 nanometres can easily enter most cells, while those smaller than 20 nanometres can transit out of blood vessels. As a result, nanoscale devices can readily interact with bio molecules on both the cell surface and within the cell. Nanoscale devices are already proving that they can deliver therapeutic agents to target cells, or even within specific organelles. Yet, despite its small size, a nanoscale device is capable of holding tens of thousands of small molecules, such as a contrast agent or drug.

1.3 Quantum dots

Quantum dots (QDs) are a promising alternative to organic immune-fluorescent probes for cancer detection. They are nanometer-size luminescent semiconductor crystals and have unique chemical and physical properties due to their size and their highly compact structure. They emit different wavelengths over a broad range of the light spectrum from visible to infrared, depending on their size and chemical composition.[3] They have excellent optical properties, including high brightness, resistance to photo-bleaching and tunable wavelength. Recent developments in surface

modification of QDs enable their potential application in cancer imaging. Conjugation of QDs with bio-molecules, including peptides and antibodies, could be used to target tumours in vivo. Compared with the traditional small-molecule fluorophores, QDs have the following distinct features.

First, QDs have extremely high brightness when excited, owing to their high quantum yield and high molar-extinction coefficient values. Second, QDs are highly resistant to photo-bleaching, which is crucial for long-term real-time image tracking. Third, the emission spectra of QDs can be tuned by the size and composition of their cores and shells.[9]

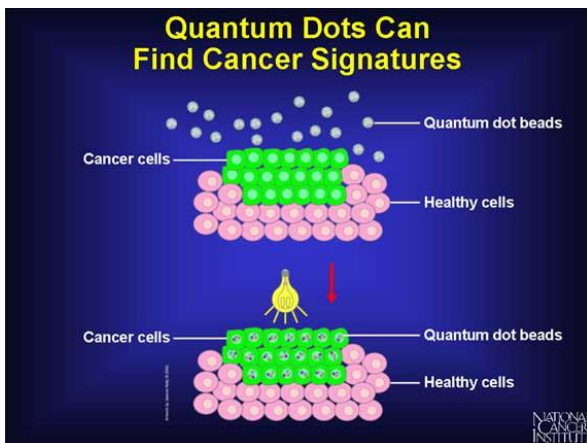


Fig. 2: Quantum dots detecting cancer cells

Finally, QDs have broad excitation and narrow and symmetric emission spectra, which make it feasible to perform 'multiplexing' (simultaneous detection of multiple signals) imaging using a single excitation source.[9]

1.4 Gold Nanoparticles

Nanoscale materials hold great promise for both industrial and biomedical applications. Toxicological studies suggest that nanoparticles may cause adverse health effects, but the fundamental cause-effect relationships are ill defined.[1] The diagnosis of cancer is an area in which the light absorption and emission characteristics of gold nanoparticles have become a key advantage. It has been proposed that these aspects of gold nanoparticles themselves can be utilized in the diagnosis of cancer. A currently developing technique involves attaching a specialized antibody that is attracted to cancerous cells to the end of gold nanoparticles, and mixing this compound with blood or tissue samples containing cancerous cells. The blood or tissue samples are then subjected to white light and examined using standard microscopy. Since each type of cancer has a unique protein on its cell surface, the gold nanoparticles will be oriented differently, depending on which type of cancer cells they have been attached to. This results in each type of cancer having its own unique pattern of scattered light. Doctors would

then be able to determine both the location and type of cancer with this method. Gold nanoparticles have a high usability level when compared to other similar methods of cancer detection[13].

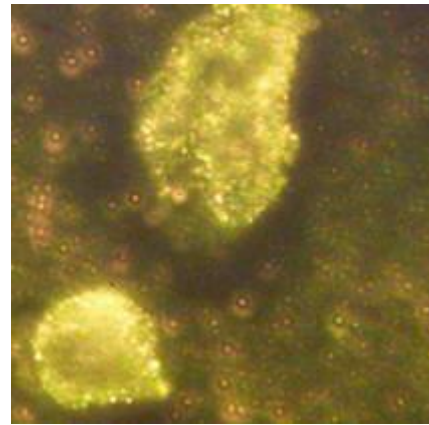


Fig. 3: Gold nanoparticles detecting cancer cells

The other method described is the use of quantum dots instead of gold nanoparticles to illuminate the location of cancerous tissue. The problem with these quantum dots, however, is that they burn out after extended exposure to light. Gold nanoparticles, on the other hand, will not burn out after extended light exposure, allowing them to illuminate cancerous cells for much longer periods of time than the quantum dots. Gold nanoparticles luminescence is also a more highly sensitive technique, permitting doctors to use fewer chemical markers in order to obtain the same information[13].

II. Methodology

2.1 Cytotoxicity

2.1.1 Gold Nanoparticles

Gold nanoparticles (GNPs) may serve as a promising model to address the size-dependent biological response to nanoparticles because they show good biocompatibility and their size can be controlled with great precision during their chemical synthesis.

Generally, gold NPs are considered to be benign, but they were also variously described as nontoxic or toxic. It was found that the increasing toxicity of gold NPs may result from the decreasing their dimensions rather than changing their chemical structure, since very small (1 nm in diameter) can penetrate both the cell and nuclear membranes and become attached to DNA. However, they are similar in size compared to biological matters, such as cellular components and proteins, and the size similarity could lead to undesired cellular entry which might be detrimental to normal cellular function. However, a number of questions remain unanswered for the fate of gold NPs upon their entrance into the living cells. It is now well demonstrated that the main route for the gold NPs

entrance into living cells is through the endocytosis and there are several studies indicating size, shape and surface property dependent cellular uptake of gold NPs. The latest studies indicate that the gold NPs mostly remain in the endosomes, spherical double layer of membrane lipids, in the living cells. Due to the fact that the fate of the gold NPs in living cells is not evidently known, there is a need for clear understanding of their destinations and possible interactions with the cell components.

Nanoparticles could have many adverse effects at the cellular level by interacting with vital cell components such as the membrane, mitochondria, or nucleus. Adverse outcomes could include organelle or DNA damage, oxidative stress, apoptosis (programmed cell death), mutagenesis, and protein up/down regulation. Since it is simpler to perform, most nanotoxicological screening studies are done *in vitro*, on cell cultures in plates. Even though these results may not accurately predict the *in vivo* toxicity, it does provide a basis for understanding the mechanism of toxicity and nanoparticle uptake at the cellular level.[2]

Gold nanoparticles have been found to be “nontoxic” according to many reports. Using a human leukaemia cell line, gold nanospheres of different sizes (4, 12, and 18 nm in diameter) and capping agents (citrate, cysteine, glucose, biotin, and cetyltrimethylammonium bromide) were found to be nontoxic based on the MTT assay. Similar results were obtained using gold nanoparticles (spheres, 3.5 nm in diameter) on immune system cell lines. In this study, gold nanoparticles entered the cell by (presumably) endocytosis, did not induce any toxicity, and reduced the level of reactive oxygen species. Villiers et al. studied the toxicity of citrate-capped gold nanoparticles (spheres, 10 nm in diameter) on dendritic cells (part of the human immune system, which process and present antigens on their surfaces for other cells). They found that nanoparticles were not cytotoxic, did not induce activation, and did not change phenotype of the cells.[2]

In contrast to these results, other groups have found that gold nanoparticles are “toxic”. These results highlight possible size-dependent toxicity of gold nanoparticles. In particular, gold nanoparticles less than 2 nm in diameter show evidence of chemical reactivity that does not occur at larger sizes.[2]

2.1.2 Quantum Dots

Quantum dots or qdots are a new breed of nonorganic nanocrystalline fluorescent probes, which have recently caught the interest of many biologists and generated much hope, some hype, but also skepticism. A consensus has emerged concerning their superior photophysical properties, but mixed reports on their stability or compatibility with long-term live imaging might be attributed to the fact that there are currently almost as many quantum dots as there are reports about

them. This diversity has multiple origins. First, qdots can be synthesized using different materials and protocols, leading to various final products. Second, qdots need to be solubilized in aqueous buffers using additional chemical steps. At this stage too, a vast number of solutions have been proposed and tested. Finally, biological functionalization adds a third level of diversity. Whereas initial reports have described successes in areas including single-molecule detection, single cell tracking, and whole embryo or animal *in vivo* imaging, the need for a serious assessment of QD's potential long-term cytotoxicity has garnered much needed attention in recent publications. Although limited to cadmium (Cd) chalcogenide materials (CdS, CdSe, or CdTe cores, with or without a ZnS shell), these studies have globally shown (1) that qdots become toxic to cells when present at micromolar concentrations in the growth medium, and (2) that toxicity is directly related to the accessibility of the core surface cadmium atoms to the surrounding medium.[7]

The potential toxicity of the binary QDs is a cause for concern because they are made of heavy metals. The toxicity could be caused by the release of cadmium ions. Although such QDs should not be acutely toxic as long as their polymer coating is stable enough to restrain the release of cadmium, both short- and long-term safety of QDs will need to be established in toxicological studies in clinically relevant animal models. Studies in cell lines have shown that QDs do not affect cell growth under normal media conditions and short-term administration of QDs into animals, such as pig or mice, seems not to affect the metabolism and behavior of the animals. However, under all these conditions, cadmium is quarantined but not eliminated from the body, which might cause substantial regulatory concerns when QDs enter clinical trials in the future. To pave the way for clinical use, important questions, such as how rapid QDs in the tumor can be eliminated and whether QDs are excreted or remain resident in the body, and, if yes, which tissue(s) and organ(s) they reside, need to be answered. If QDs are retained in the body, careful toxicological studies in appropriate animal models must be carried out to establish the long-term safety profile of QDs.[9]

2.2 Fluorescence

2.2.1 Gold Nanoparticles

Because of their photo-optical distinctiveness and biocompatibility, gold nanoparticles (AuNPs) have proven to be powerful tools in various nanomedicinal and nanomedical applications.[4]

Gold nanoparticles characteristically have dimensions which range from 1-100 nm. From the figure given below it is evident that these dimensions are similar to many cellular objects, which includes, cell surface receptors, DNA and viruses.

We all know that metals are good conductors of electricity because their electrons are not bound to individual atoms instead forming a “cloud” around the atomic cores. This cloud of electrons is mobile allowing metal to transport charge (electrons) easily.

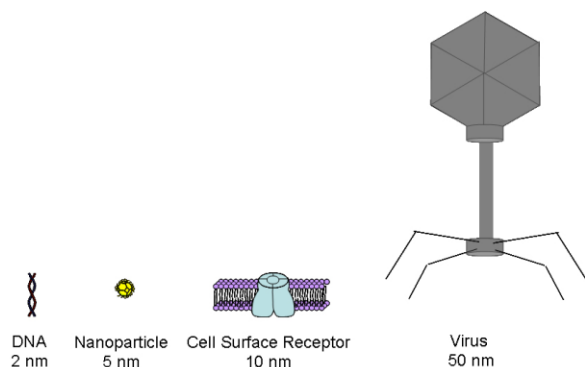


Fig. 4: Comparison of dimensions

Also, experience tells us that metals are shiny. This is because light is reflected off their surfaces back to the eye. The reason for this reflection has to do with the electron cloud that surrounds metals. Photons (individual units) of light cannot be absorbed by the atomic cores because they are blocked by the electron cloud. Consequently, photons are reflected back to the eye producing the sheen associated with metals. However, we also know from quantum mechanics that electrons can behave as either a wave or a particle. If we imagine electrons in the electron cloud as a wave with a certain energy value, we can envision a situation where it is possible for light of the same wavelength to be absorbed by the electron cloud, producing resonance. When a metal absorbs light of a resonant wavelength it causes the electron cloud to vibrate, dissipating the energy. This process usually occurs at the surface of a material (as metals are not usually transparent to light) and is therefore called surface plasmon resonance.

A currently developing technique involves attaching a specialized antibody that is attracted to cancerous cells to the end of a gold nanoparticle, and mixing this compound with blood or tissue samples containing cancerous cells. The blood or tissue samples are then subjected to white light and examined using standard microscopy. Since each type of cancer has a unique protein on its cell surface, the gold nanoparticles will be oriented differently, depending on which type of cancer cells they have been attached to. This results in each type of cancer having its own unique pattern of scattered light. Doctors would then be able to determine both the location and type of cancer with this method. Gold nanoparticles have a high usability level when compared to other similar methods of cancer detection. One of these other methods employs quantum dots instead of gold nanoparticles to illuminate the location of cancerous tissue[13].

2.2.2 Quantum Dots

Since QDs are composed of inorganic semiconductors, they contain electrical charge carriers, which are negatively charged electrons and positively charged holes (an electron and hole pair is called an exciton). Bulk semiconductors are characterized by a composition-dependent band-gap energy, which is the minimum energy required to excite an electron to an energy level above its ground state. Excitation can be initiated by the absorption of a photon of energy greater than the band-gap energy, resulting in the generation of charge carriers. The newly created exciton can return to its ground state through recombination of the constituent electron and hole, which may be accompanied by the conversion of the band-gap energy into an emitted photon, which is the mechanism of fluorescence. Due to the small size of QDs, these generated charge carriers are confined to a space that is smaller than their natural size in bulk semiconductors. This quantum confinement of the exciton is the principle that causes the optoelectronic properties of the QD to be dictated by the size of the QD. Decreasing the size of a QD results in a higher degree of confinement, this produces an exciton of higher energy thereby increasing the band-gap energy. The most important consequence of this property is that the band-gap and emission wavelength of a QD may be tuned by adjusting its size, with smaller particles emitting at shorter wavelengths. Importantly for use as biological probes, QDs can absorb and emit light very efficiently, allowing highly sensitive detection relative to conventionally used organic dyes and fluorescent proteins. Combined with the fact that QDs can have quantum efficiencies similar to that of organic dyes (up to 85%), individual QDs have been found to be 10-20 times brighter than organic dyes, thus enabling highly sensitive detection of analytes in low concentration, which is particularly important for low copy-number cancer markers. In addition, QDs are several thousand times more stable against photo-bleaching than organic dyes, and are thus well suited for monitoring biological systems for long periods of time, which is important for developing robust sensors for cancer assays and for in vivo imaging[14].

The problem with these quantum dots, however, is that they burn out after extended exposure to light (Birch, 2009a). For single-particle tracking, the irregular blinking of quantum dots is a minor drawback. Gold nanoparticles, on the other hand, will not burn out after extended light exposure, allowing them to illuminate cancerous cells for much longer periods of time than the quantum dots (Birch, 2009a). Gold nanoparticle luminescence is also a more highly sensitive technique, permitting doctors to use fewer chemical markers in order to obtain the same information (Birch, 2009a; Soppimath et al., 2008)[13].

2.3 Accuracy

2.3.1 Gold Nanoparticles

Gold nanoparticles are very good at scattering and absorbing light. It has scattering property in a living cell to make cancer detection easier. Many cancer cells have a protein, known as Epidermal Growth Factor Receptor (EGFR), all over their surface, while healthy cells typically do not express the protein as strongly. By conjugating, or binding, the gold nanoparticles to an antibody for EGFR, suitably named anti-EGFR. It is able to get the nanoparticles to attach themselves to the cancer cells. "If you add this conjugated nanoparticle solution to healthy cells and cancerous cells and you look at the image, you can tell with a simple microscope that the whole cancer cell is shining," "The healthy cell doesn't bind to the nanoparticles specifically, so you don't see where the cells are. With this technique, if you see a well defined cell glowing, that's cancer".[6]

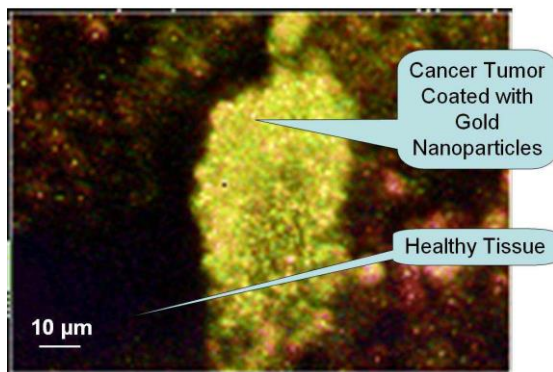


Fig. 5: Gold nanoparticles targeting cancer cells leaving healthy tissues

The gold nanoparticles have 600 percent greater affinity for cancer cells than for noncancerous cells. The particles that worked the best were 35 nanometers in size. Technique using cell cultures of two different types of oral cancer and one nonmalignant cell line. The shapes of the strong absorption spectrum of the gold nanoparticles are also found to distinguish between cancer cells and noncancerous cells. Another benefit is that the results are instantaneous. "If you take cells from a cancer stricken tissue and spray them with these gold nanoparticles that have this antibody you can see the results immediately. The scattering is so strong that you can detect a single particle." A similar technique using artificial atoms known as Quantum Dots uses semiconductor crystals to mark cancer cells, but the semiconductor material is potentially toxic to the cells and humans. Thus, use of gold nanoparticles is making cancer detection easier, faster and less expensive.[6]

2.3.2 Quantum Dots

Cancer can be extremely difficult to locate, as symptoms do not show until the cancer has been present for several months. By this time a tumour may have developed and even metastasised, which lowers

the chance of the patient surviving. The production of quantum dots has provided the potential to transform diagnostic techniques. By attaching these quantum dots to antibodies which detect certain antigens on cancer cells, they can be used as biomarkers to show the doctors where the exact location and nature of the cancer cells. Nie's polymer coating (shown in figure 3) improves the solubility of quantum dots in water which not only protects the dots from the environment, but also provides functional groups for bonding with the probe molecules.

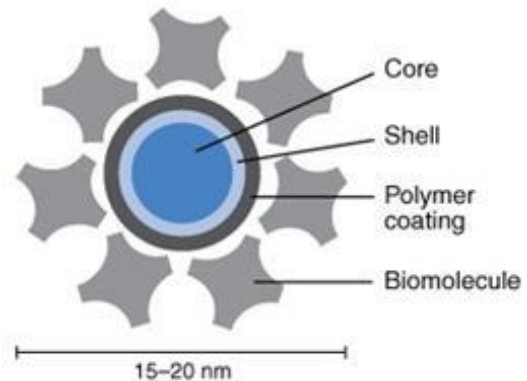


Fig. 6: Structure of a quantum dot

By combining different coloured quantum dots with different antibodies, it is possible to find out precisely what kind of cell is present in biopsies, which can be extremely useful for diagnosing specific cancers. For the stereospecific blockade effect, it is not clear how many functional molecules can conjugate to one QD, which holds back the quantification in molecular detection. The combination of the different colours in varying amounts on the cell surface would inform the doctor with the exact nature of the cell and even which specific cancer it is. By using this idea of "multiplexing", the doctors would only have to look at an image of the biopsies and process the different colours present to find out which cancer it is, how advanced it is and what treatment is needed. The use of quantum dots provides better imaging than organic dyes due to their bright optical characteristics (see figure 7) and as they would be specific, the images would be more precise and accurate.



Fig. 7: Quantum dots

III. Conclusion

It has been almost 4 decades since the "war on cancer" was declared. It is now generally believed that personalized medicine is the future for cancer patient

management. Possessing unprecedented potential for early detection, accurate diagnosis, and personalized treatment of cancer, nanoparticles have been extensively studied over the last decade.[8] As medicine has developed, the understanding of the importance of individual cells and how they are affected by molecules in nanoscale has increased. By controlling these substances that are used in cell signalling, it is possible to prevent damage to the cells and help heal them. This would help find, prevent and cure diseases which would otherwise be extremely difficult to treat.

Furthermore, the advancement of nanotechnology has led researchers to generate nanostructures that can be conjugated to several kinds of biological molecules, including hormones and antibodies, which can reach targeted cells expressing the receptors. One particularly exciting field of research involves the use of gold nanoparticles in the detection and treatment of cancer cells. AuNPs find significant exploitations in biomedical field due to (i) their comparative chemical stability, making them less hazardous, (ii) simple and straightforward synthesis and fabrication process, and (iii) genuine biocompatibility and noninterference with other labeled biomaterials (e.g., antibody and other biomarkers). More and more research shows that gold nanoparticles based technologies are becoming promising approaches in cancer research. The exploitation of unique and characteristic properties of AuNPs such as surface plasmon resonance (SPR), surface enhance Raman scattering (SERS), magnetic properties (MRI), and fluorescence behavior shown upon conjugation with biological and biocompatible ligands provides us a faster, easier and inexpensive method for early diagnosis of cancer.[10]

One of these other methods employs quantum dots instead of gold nanoparticles to illuminate the location of cancerous tissue. The semiconductor nanocrystal quantum dots (QDs) have excellent photo-physical properties, and the QDs-based probes have achieved encouraging developments in cellular and in vivo molecular imaging.[11] The production of quantum dots has provided the potential to transform diagnostic techniques. QDs have unique optical and electronic properties such as size- and composition-tunable light emission, improved signal brightness, resistance to photobleaching and simultaneous excitation of multiple fluorescence colors. In addition, different colors of QDs can be simultaneously excited with a single light source, with minimal spectral overlapping, which provides significant advantages for multiplexed detection of target molecules.[11] However there are a few issues surrounding the use of quantum dots in vivo, particularly considering the long term effects that they may have inside the body. Due to their inert coating quantum dots cannot be broken down by the body and instead may build up within blood vessels or in the liver. There are also some concerns as to whether the continuous fluorescence of the quantum dots may cause

mutations or denaturing of cells and that they may otherwise disrupt normal cell function.

Alternatively, by remaining in circulation within the body quantum dots can be used in regular screening to check for the development or the status of any cancerous cells present. Quantum dots may even be developed so that they repel each other slightly, reducing the risk of their accumulation. There may also be further discrepancies of its effect in the body, so further research is required into their application and usage. Thus, gold nanoparticles are “promising probes” for biomedical applications because they can be easily prepared & unlike other fluorescent probes such as quantum dots or organic dyes; don't burn out after long exposure to light.

IV. Future Enhancement

Nanoscience has had a huge impact in medicine in recent years due to its non-invasive applications. It is clear that AuNPs offer various advantages over bulk structures; their characteristic properties make them ideal for diagnostic purpose and several biomedical applications. A number of techniques applying with AuNPs such as surface chemistry mainly by conjugating them with biological molecules have been playing a great role in 21th century for the diagnosis and treatment of various diseases like cancer.[10] Surface plasmon resonance (SPR) is significant for the absorption and scattering properties of AuNPs. While cancer detection using gold nanoparticles in common medical practice is just around the corner, treatment using gold nanoparticle photothermal ablation and nano-chemotherapy will be in clinical trials for some time before they are being used on patients regularly. With nanotechnology advancing as fast as it currently is, scientists will hopefully be able to utilize the characteristics of compounds such gold nanoparticles in the detection and treatment of many more deadly diseases in the years to come.

Similarly, with further research, quantum dots can be developed to deliver therapeutic drugs such as in chemotherapy to target and destroy the cancer cells. Such a targeted therapy can ensure that only the cancerous cells are destroyed without damage to normal tissue. It can also seek out micro-metastases and potentially reduce the risk of recurrence at a future date.

The quantum dot technology promises to open new avenues in the management of cancers. However, much more research is needed before the technique will become available for clinical application. The possibility of adverse events from any residual nanoparticles left in-situ side at the end of treatment will need to be considered. Perhaps in future we may be able to develop a technique through which the quantum dots can be extracted from the body once they have delivered the desired clinical effect as we learn to control and manipulate these nanoparticles.

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