ORIGINAL ARTICLE

Synthesis and Bio-imaging Applications of Silver Nanoparticles for Breast Cancer Imaging

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Abstract

Purpose: Timely detection of breast cancer is essential for improving treatment outcomes, particularly in the field of oncology. Several diagnostic techniques are available, and one promising approach is the use of Quantum Dots (QDs) for accurate and early detection. This study focuses on the utilization of cadmium selenium QDs with and without silver coating, which can modulate the transfer intensity of light sources.

Materials and Methods: Cadmium selenium QDs with silver coating ($CdSe@Ag_2S$) were synthesized and characterized. These QDs were then mixed with blood samples containing different concentrations of hemoglobin to simulate breast cancer conditions. The mixture was injected into phantom vessels representing breast tissue, and the transmitted light intensity was measured using a power meter. The light source used operated in the near-infrared range at a wavelength of 635 nm.

Results: The transmitted light intensity from vessels containing normal hemoglobin concentration was measured at 5.24 mW. However, in cancerous breast tissue, the intensity decreased to 4.56 mW and 3.34 mW for two and four times the hemoglobin concentrations, respectively. When the CdSe QDs were combined with different hemoglobin concentrations, the intensities of transmitted light were found to be 3.14 mW, 2.26 mW, and 1.22 mW for normal, twice, and four times the concentration of hemoglobin in turn. Furthermore, when the test was conducted using $CdSe@Ag_2S$ QDs, the intensities of transmitted light were 1.83 mW, 2.52 mW, and 3.31 mW for the same hemoglobin concentrations, respectively.

Conclusion: This study concludes that the combination of different hemoglobin concentrations with QDs enables the differentiation between healthy and cancerous blood, enabling the early detection of breast cancer during its initial stages of development. Early detection of breast cancer has significant potential for improving treatment outcomes in the field of oncology.

Keywords: Cadmium Selenium; Silver; Quantum Dots; Breast Cancer; Imaging.

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1. Introduction

Breast cancer is a significant concern for physicians, particularly oncologists, who are actively seeking new methods for early detection and identification of smaller, more treatable tumors. Breast cancer is one of the most critical and potentially fatal types of cancer affecting women [1]. Currently, various diagnostic methods are employed for breast cancer detection, including physical examinations, mammography, ultrasound, Magnetic Resonance Imaging (MRI), and optical mammography. These methods can be used individually or in combination, depending on the resources available at each imaging center [2]. However, each technique has its own strengths, limitations, and varying capabilities in detecting breast cancer. Mammography, for instance, utilizes ionizing radiation and has limited resolution. Although it demonstrates satisfactory sensitivity, its effectiveness is influenced by the age of the patient, with mammograms of 50-year-old women showing the highest sensitivity. Mammography is not recommended for women under 40 years old [3]. MRI requires a specialized coil and is associated with high costs, limiting its widespread usage [4]. Ultrasound imaging has lower sensitivity in detecting small nodules, while Computed Tomography (CT) imaging is costly and carries a risk of radiation exposure [5].

Given the drawbacks and limitations of current diagnostic techniques, there is a pressing need for new approaches that can overcome these challenges and enable early detection of breast cancer in a more accurate and accessible manner. Optical mammography, particularly when utilizing near-infrared wavelengths, shows promise as a more sensitive method compared to other diagnostic techniques [6]. Unlike mammography, optical mammography uses non-ionizing beams, which makes it safer for patients. Additionally, it is a less costly imaging modality and has the potential to provide vascular contrast by detecting variations in hemoglobin concentrations [7]. Therefore, research focused on developing methods for accurately and efficiently diagnosing breast cancer in its early stages remains a significant area of interest and a challenging endeavor. Such studies hold considerable potential for advancing our understanding of breast cancer detection and improving patient outcomes.

In recent years, nanomaterials have gained significant attention in various fields due to their unique applications [8, 9]. Nanoparticles (NPs) with high permeability and fast traceability have shown promise in detecting changes in hemoglobin concentration within tumor areas, making them valuable tools for early breast cancer detection [10]. Among the emerging NPs used for cancer detection, Quantum Dots (QDs) have garnered particular interest. QDs are NPs with exceptional optical properties, exhibiting characteristics similar to semiconductors. When stimulated by light, QDs emit radiation that is typically lower in energy, resulting in visible light emission, often in the red spectrum [11]. One notable advantage of QDs over other NPs is their stability against photo bleaching. These NPs can produce, reflect, scatter, or absorb light based on the wavelength of the incident light [12]. Additionally, QDs offer several other advantages, including tunable emission, high quantum yield, broad absorption range, long-term stability, and biocompatibility. These collective advantages position QDs as promising nanomaterials for various biomedical applications, such as cancer detection, imaging, drug delivery, and molecular sensing [13].

Among the different types of QDs, Cadmium selenide (CdSe) QDs have been extensively studied due to their unique optical properties. One of the advantages of CdSe QDs is their broad absorption spectrum, allowing them to be excited by a range of light wavelengths, including Ultraviolet (UV), visible, and Near-Infrared (NIR) light [14]. This flexibility enables their use with different imaging modalities and light sources. Moreover, when directed towards CdSe QDs, NIR light can be absorbed by them. However, when CdSe is coated with silver (Ag), it can produce NIR light, thereby enhancing the detection of NIR signals [15]. This property opens up new possibilities for utilizing CdSe QDs with a silver coating in the detection and imaging of breast cancer, particularly in the near-infrared range. This combination of CdSe QDs and silver coating offers improved sensitivity and specificity in the detection of breast cancer using NIR imaging techniques [15].

Previous studies have demonstrated that the use of 620-640 nm wavelengths can provide good vascular contrast, allowing for differentiation between hemoglobin concentrations that are two to four times higher [16]. Another study by Taroni et al. showed that contrast and differentiation between healthy and cancerous tissues in tumors measuring 1.5 cm in diameter are possible using a wavelength of 637 nm [17]. These wavelengths are also utilized in other methods, including functional NIR spectroscopy (fNIRs), to detect changes in the concentration of oxy-hemoglobin [18].

In this study, cadmium selenium with a silver coating ($CdSe@Ag_2S$) NPs was synthesized, and the changes in the intensity of transmitted infrared light were investigated as it passed through different concentrations of hemoglobin. Both cadmium selenium QDs and silver-coated cadmium selenium were employed as contrast agents. This study suggests that this approach holds potential as a candidate for the early diagnosis of breast cancer in areas exhibiting vascular variations. By analyzing the changes in infrared light intensity, it may be possible to detect and quantify variations in hemoglobin concentration, thereby providing valuable information for early breast cancer diagnosis.

2. Materials and Methods

2.1. Sample Preparation

In the experiment, three different concentrations of hemoglobin were prepared for testing. Firstly, the health of the blood donor was verified through hematologic laboratory analysis. From the blood samples, the hemoglobin was separated from the plasma. Subsequently, three concentrations of hemoglobin, labeled as ×1, ×2, and ×4, were prepared by adding Phosphate-Buffered Saline (PBS) to the hemoglobin solution. To simulate breast tissue, a phantom made of polyethylene ($(C_2H_4)\ nH_2$) was utilized. Polyethylene consists of hydrogen-carbon chains and exhibits properties similar to those of breast tissue.

Within the phantom, two types of vessels were placed: a minor vessel with a diameter of 5 mm and a major vessel with a diameter of 10 mm. These vessels were incorporated into the phantom to mimic the blood vessels found in breast tissue, allowing for the investigation of light transmission and absorption through different concentrations of hemoglobin in a controlled experimental setting.

2.2. Synthesis of QDs

First, $CdCl_2{\cdot}H_2O$ (0.12 mmol, 0.0805 g) was mixed with 70 µL of TGA (thioglycolic acid) as a stabilizer. The resulting solution was then purged with high-purity nitrogen for 30 minutes. To adjust the pH to 10.0, a 1.0 M NaOH solution was used. Next, 10 mL of a 20×10^{-3} M NaHSe solution was rapidly added to the mixture, resulting in a clear, light-yellow solution of CdSe precursors. The solution was heated to 95°C and kept at that temperature for one hour to allow the formation of TGA-modified CdSe QDs. To form a shell of Ag_2Se on the CdSe nanoparticle core, an $AgNO_3$ solution was added drop by drop to the mixture under vigorous stirring. The addition of $AgNO_3$ caused an immediate color change to dark red, indicating the formation of Ag_2Se NPs. The reflux process was continued at 95°C for 3 hours. The final molar ratios of $Cd_2+/Se_2-/TGA/Ag$ for the optimal QD preparation were 2:1:5:0.5. After cooling, the solution was washed three times with ethanol to remove any unreacted reactants, followed by centrifugation at 6000 rpm for 10 minutes. Finally, the QDs were dried at 50°C and stored in a dark place [19]. In order to obtain detailed information about the structure and morphology of the materials under investigation, the Transmission Electron Microscopy (TEM) and Scanning Electron Microscope (SEM) analysis were performed using a Philips CM10 microscope, with an accelerating voltage of 100 kV.

2.3. Optical Equipment

In this study, a NIR light source was utilized. The light source consisted of 45 LEDs with dimensions of 13.5 × 13.5 × 13 mm² and a power of 50 W, operating in continuous wave mode. The wavelength of the light emitted by the LEDs was 635 nm. To measure the Transmission Light (TI) intensity, an optical power meter (Model PM100D, ThorLabs GmbH, Dachau, Germany) was employed. For the experimental setup, blood samples with different concentrations of hemoglobin, both with and without NPs, were separately injected into the minor and major vessels of the breast phantom. The transmission light intensity for each sample, consisting of normal and cancerous blood, was measured using the optical power meter. To quantify the difference in transmission intensity of NIR light from various concentrations of hemoglobin in both vessels of the breast phantom, the following formula was used (Equation 1):

$$TI\% = \frac{(TI\ without\ the\ substance\ -\ TI\ with\ substance)}{TI\ without\ substance} \times 100 \quad (1)$$

The formula mentioned above is applied to both types of vessels, with and without NPs. In the formula, TI represents the transmission intensity of light through the phantom. The measurements of NIR transmission intensity were recorded using a power meter at three positions along the vessel surface: the middle point and one centimeter above or below the middle point.

2.4. Statistical Analysis

Each test sample underwent three repetitions of measurements to ensure accuracy and reliability. The collected data were analyzed using statistical software such as SPSS version 19.0. Data comparison was performed using appropriate statistical methods, including the Wilcoxon test for non-parametric data and the t-test for parametric data. The results were expressed as mean ± Standard Deviation (SD), and statistical significance was determined at a significance level of $P < 0.05$, indicating a statistically significant difference.

3. Results

3.1. Characterization of NPs

The morphology analysis of CdSe@Ag2S NPs was performed using TEM and SEM microscopy, providing valuable insights into the structure of the NPs. Figure 1 a-d clearly showed the presence of small particles with a diameter below 12 nm. These particles exhibited a distinctive composition, with a dark core composed of CdSe and a surrounding bright shell. The TEM images confirmed the formation of CdSe@Ag_2S core-shell NPs, as evidenced by the observed contrast between the dark core and the bright outer shell (Figure 1 c and d). The presence of these distinct layers in the images further supports the successful synthesis of CdSe@Ag_2S NPs, with CdSe forming the core and Ag forming the shell.

In addition to the TEM analysis, Figure 2b showcases photos of the CdSe NPs with and without silver coating, which were prepared and ready for the experiment. Furthermore, Figure 2c also includes photos of hemoglobin samples with and without NPs, providing a visual representation of the experimental materials used in the study.

3.2. The Effect of Hemoglobin Concentration on NIR Transmission

The TI of NIR light through a vessel with a diameter of 10 mm was measured for different hemoglobin concentrations. Initially, the TI of light for blood with a normal hemoglobin concentration was determined to be 5.24 mW. Subsequently, the TI values were recorded for blood samples with hemoglobin concentrations multiplied by 2 and 4, resulting in transmitted light intensities of 4.56 mW and 3.34 mW,

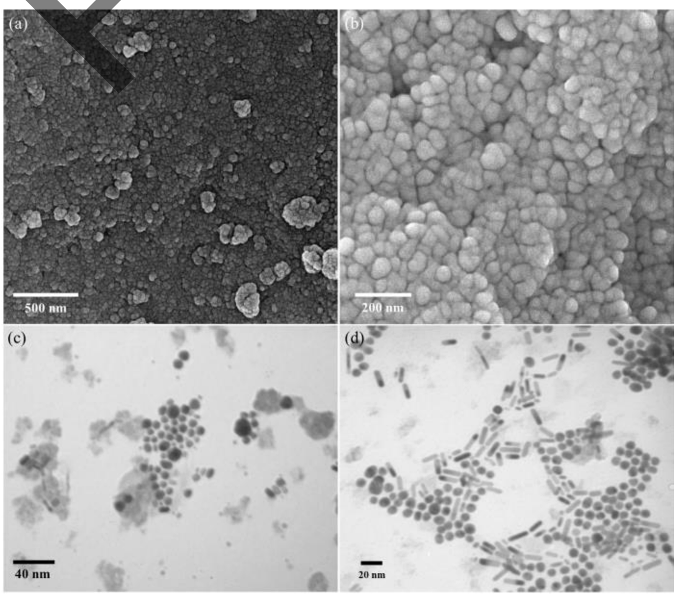

Figure 1. Scanning electron microscope (a, b) and Transmission electron microscopy (c, d) images of CdSe@Ag_2S nanoparticles with different magnification

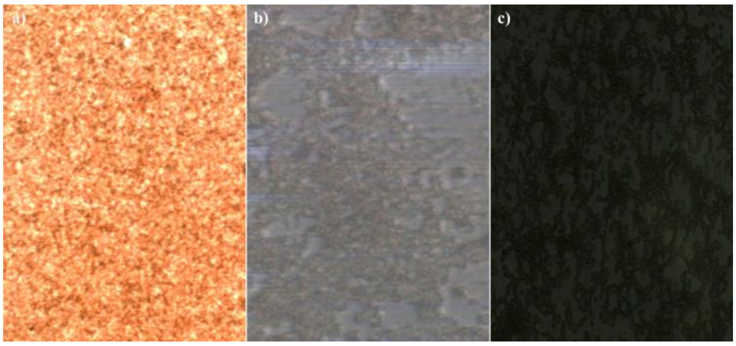

Figure 2. a) Photos of haemoglobin without nanoparticles (NPs), b) haemoglobin with CdSe quantum dots, and c) haemoglobin with CdSe@Ag_2S NPs

respectively. These measurements indicate that an increase in hemoglobin concentration leads to a decrease in the intensity of transmitted light. Consequently, the visual contrast between different concentrations of hemoglobin is enhanced.

Similar behavior was observed when examining the intensity of transmitted light for a non-nanoparticle state inside a vessel with a larger diameter of 5 mm, comparing normal and cancerous blood samples. In the case of normal blood, the TI was measured to be 3.92 µW. However, for cancerous blood samples with hemoglobin concentrations multiplied by 2 and 4, the TI values were reduced to 3.01 µW and 2.49 µW, respectively. These findings further reinforce the inverse relationship between hemoglobin concentration and transmitted light intensity, highlighting the potential for enhanced visual contrast in distinguishing between normal and cancerous blood samples based on their hemoglobin content.

Furthermore, it is worth noting that the TI of NIR light for both minor and major vessels in the absence of QDs exhibited the same behavior, indicating that the presence or absence of QDs did not significantly alter the observed relationship between hemoglobin concentration and NIR transmission. These results emphasize the importance of hemoglobin concentration as a key factor influencing the transmission of NIR light through blood vessels.

3.3. The Effect of CdSe QDs on NIR Transmission

To investigate the impact of CdSe QDs on NIR transmission, blood samples with different hemoglobin concentrations were injected into vessels with a diameter of 10 and 5 mm. The TI values were measured and compared between blood samples with and without CdSe QDs.

For normal blood samples, the TI value dropped to 3.14 µW after the addition of CdSe QDs. In the case of breast cancer, the TI values for blood samples with hemoglobin concentrations multiplied by 2 and 4 were measured at 2.26 mW and 1.22 mW, respectively. These results indicated a decrease in TI values as the concentration of hemoglobin and CdSe QDs increased. A comparison of the data with and without CdSe QDs revealed a reduction in TI values of 41.03%, 52.73%, and 64.14% for normal blood, ×2 and ×4 hemoglobin concentration, respectively, when CdSe QDs were added.

Additionally, when CdSe QDs were combined with different hemoglobin concentrations and injected into a vessel with a smaller diameter of 5 mm, the TI values were measured. For normal blood, the TI value was found to be 2.13 mW. In the case of blood samples with hemoglobin concentrations multiplied by 2 and 4, the TI values were measured at 1.42 mW and 0.81 mW, respectively. These findings demonstrate a further decrease in TI values with the addition of CdSe QDs and higher hemoglobin concentrations. Furthermore, the values of the difference in TI (DTI%) were calculated and presented in Table 1. A significant difference was observed between the measured TI values for 1×, 2× ($p < 0.05$), and ×4 ($p < 0.001$) hemoglobin concentrations when comparing the states with and without CdSe QDs. These results highlight the significant influence of CdSe QDs on NIR transmission in combination with varying hemoglobin concentrations.

Table 1. The measurement of passing light intensity (μW) in the water, normal, twice, and four times of hemoglobin (hb) concentration in the minor vessel (5 mm) with and without $CdSe@Ag_2S$ NPs

-	Water	Normal hb	Twice hb	Four times hb
TI without $CdSe@Ag_2S$	5.20±0.06	3.90±0.12	3.01±0.02	2.49±0.03
TI with $CdSe@Ag_2S$	3.22±0.05	2.13±0.07	1.45±0.06	0.85±0.95
DTI%	37.85	45.66	52.85	67.49
p-value	0.008	0.001	0.001	0.005

3.4. The Effect of CdSe@Ag2S NPs on NIR Transmission

When $CdSe@Ag_2S$ NPs were combined with different concentrations of hemoglobin and injected into the major vessel, the TI values for healthy blood were 1.83 mw for ×2 and 2.52 and 3.31 mw for ×4 hemoglobin concentration, respectively. The percentage of difference in the intensity of transmitted light between the states with and without the NPs is presented in Table 2.

In Table 3, the transmitted light intensities with $CdSe@Ag_2S$ NPs are measured for different hemoglobin concentrations in a vessel with a diameter of 5 mm. The DTI% values represent the percentage difference in transmitted light intensity when compared to the normal concentration of blood without $CdSe@Ag_2S$ NPs. For normal blood samples with $CdSe@Ag_2S$ NPs, the transmitted light intensity is measured at 1.14 mW. When the hemoglobin concentration is doubled (×2), the transmitted light intensity increases to 2.06 mW, representing an 80.70% increase compared to the normal concentration. Similarly, when the hemoglobin concentration is multiplied by four (×4), the transmitted light intensity further increases to 3.74 mW, showing a significant 227.19% increase compared to the normal concentration.

These results indicate that the presence of $CdSe@Ag_2S$ NPs in combination with higher hemoglobin concentrations leads to a substantial enhancement in transmitted light intensity. The DTI% values demonstrate the magnitude of this enhancement, with a significant difference observed between normal blood and blood samples with increased hemoglobin concentrations.

Table 2. The measurement of passing light intensity (μW) in the water, normal, twice, and four times of hemoglobin (hb) concentration in the major vessel (10 mm) with and without $CdSe@Ag_2S$ NPs

-	Water	Normal hb	Twice hb	Four times hb
TI without $CdSe@Ag_2S$	9.22±0.08	5.36±0.16	4.67±0.02	3.59±0.07
TI with $CdSe@Ag_2S$	1.58±0.04	1.83±0.02	2.52±0.15	3.31±0.04
DTI%	82.86	65.85	46.03	7.08
p-value	0.008	0.003	0.001	0.036

Table 3. The measurement of passing light intensity (μW) in the water, normal, twice, and four times of hemoglobin (hb) concentration in the minor vessel (5 mm) with and without CdSe@Ag2S NPs

-	Water	Normal hb	Twice hb	Four times hb
TI without $CdSe@Ag_2S$	5.49±0.05	3.96±0.04	3.17±0.62	2.43±0.25
TI with $CdSe@Ag_2S$	0.75±0.24	1.14±0.02	2.06±0.03	3.74±0.04
DTI%	87.06	70.20	-4.03	-54.3
p-value	0.005	0.002	0.001	0.018

4. Discussion

Various imaging modalities, such as X-ray-based CT scans, Ultrasound, MRI, Nuclear Medical Imaging, and Optical Imaging are employed to breast diagnose and treat diseases by providing anatomical, physiological, and functional representations [20]. The emergence of molecular imaging utilizing NPs has enabled the acquisition of detailed information about disease properties, aiding in the early detection of malignancies [21, 22]. Recent advancements in NP design, the development of hybrid imaging modalities [23], and improved instrument sensitivity have further elevated the capabilities of disease diagnosis [24, 25]. This study demonstrates that the addition of CdSe QDs with and without silver coating to different concentrations of hemoglobin can influence and change the NIR intensity. This suggests that QDs could potentially serve as a method for the early detection and prognosis of cancer.

The study findings indicate a significant difference in the intensity of transmitted NIR through blood samples with different hemoglobin concentrations. Moreover, the values of DTI% for the different hemoglobin concentrations showed a positive correlation with increased hemoglobin concentration. This suggests that QDs can enhance these differences and potentially serve as contrast agents for the early detection of healthy tissues and cancerous ones. The study specifically highlights the changes observed in the intensity of transmitted NIR through vessels when QDs are present, especially in the case of CdSe QDs with silver coating. This suggests that QDs can be utilized as effective contrast agents in the early detection of cancer. Furthermore, the study observed that the differences in NIR intensity were significant between the blood samples with 1×, 2×, and 4× hemoglobin concentrations. This supports the notion that QDs can provide enhanced contrast and facilitate the differentiation between normal and abnormal tissues [26].

The description of different sizes of the vessel and its effect on light transmission when using CdSe QDs and $CdSe@Ag_2S$ NPs showed a significant difference for normal, twice, and four times the concentration of hemoglobin. The detailed comparison between the states with and without nanoparticles and two sizes of vessels are shown in Figure 3.

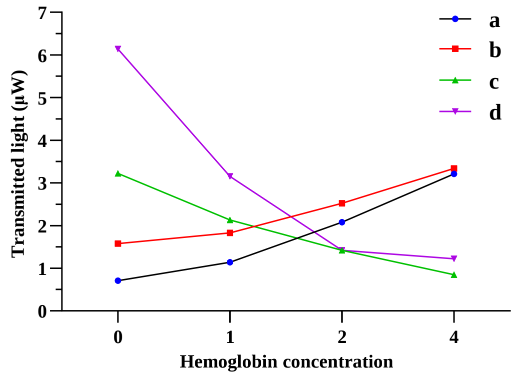

Figure 3. Comparison of transmitted light in both the major and minor vessels, with and without CdSe quantum dots (QDs) and $CdSe@Ag_2S$ nanoparticles (NPs). The Figure is divided into four parts: a) Transmitted light with CdSe QDs in the minor vessel, b) Transmitted light with CdSe QDs in the major vessel, c) Transmitted light with $CdSe@Ag_2S$ NPs in the minor vessel, and d) Transmitted light with $CdSe@Ag_2S$ NPs in the major vessel

In addition to the intensity differences, the study also found a positive correlation between the values of DTI% and increased hemoglobin concentration. This further supports the potential of QDs to serve as effective markers for detecting abnormal tissue. Previous research has established that the mean hemoglobin concentration in normal women is 34±9 µmol/l in pre-menopausal cases and 14±0 µmol/l in post-menopausal women [27]. A systematic review by Leff et al. presented that breast cancer patients have mean hemoglobin concentrations of around 65±34 µmol/l, which are at least twice that of a normal breast (Hb=21±6 µmol/l) [28]. This indicates a difference of 2 and 4 times the hemoglobin concentration between normal and abnormal cases, which justifies the use of 1× Hb as a representation of normal tissue and 2× Hb and 4× Hb as abnormal breast tissues. $CdSe@Ag_2S$ NPs, contrary to previous studies, lead to increases in the transmitted intensity NIR light with increases in hemoglobin concentration. This discrepancy can be attributed to the emitting spectrum of $CdSe@Ag_2S$ NPs which is close to the wavelength (635 nm) of the NIR source used in this study. The choice of this wavelength is based on its non-ionizing nature, non-invasiveness, safety for imaging repeat, and its ability to penetrate deeper into the vessel, making it suitable for all ages and cost-effective compared to other methods. The measurements in this study indicate that QDs can induce changes in the intensity of transmitted light as it crosses hemoglobin through mechanisms such as reflection, absorption, and scattering of NIR light [29].

In both major and minor vessels, the TI of light decreases with increasing hemoglobin concentration, and this change is significant. However, the addition of QDs, particularly in minor vessels, amplifies the difference between states with and without NPs, providing better visual contrast in NIR imaging. Notably, the difference in the transmitted intensity is greater at the ×2 hemoglobin concentration compared to the major vessels. These findings suggest that this method has the potential to aid in the early detection of cancer during its initial stages. The measurements conducted at ×2 and ×4 hemoglobin concentrations, which simulate breast cancer in women before and after menopause, can be particularly useful for large groups of women. QDs exhibit high optical stability and have a high signal ratio, making them easier to detect compared to other NPs [30]. In the previous study, when considering the ×2 and ×4 concentrations of hemoglobin without NPs in the major vessel, the average NIR transmissions were reported to be 5.38 μW and 6.66 μW, respectively. However, in the present study using CdSe QDs, the average NIR transmissions were measured at 2.26 μW and 1.22 μW for the same hemoglobin concentrations. When CdSe@Ag QDs were used, the transmissions were even lower, measuring 1.42 μW and 0.81 μW for the ×2 and ×4 hemoglobin concentrations, respectively. This indicates a significant difference between the experiments conducted with CdSe QDs, with a reduction of approximately 58% for the ×2 hemoglobin concentration and 81% for the ×4 hemoglobin concentration. The difference observed with CdSe@Ag_2S NPs was even more pronounced, with a reduction of 73% for the ×2 hemoglobin concentration and 87% for the ×4 hemoglobin concentration.

Comparing these findings to the present study using CdSe QDs, there was a difference of approximately 73% for the ×2 hemoglobin concentration and 85% for the ×4 hemoglobin concentration. With CdSe@Ag_2S NPs, the difference was even greater, with a reduction of 83% for the ×2 hemoglobin concentration and 90% for the ×4 hemoglobin concentration. Based on these observations, this study suggests that combining different concentrations of hemoglobin with QDs, particularly CdSe QDs and CdSe@Ag_2S NPs, can effectively distinguish healthy blood from cancerous blood and aid in the early detection of breast cancer during its initial stages. The substantial differences in NIR transmissions observed between healthy and cancerous blood samples indicate the potential utility of this method for early detection and monitoring of breast cancer.

5. Conclusion

In conclusion, this study demonstrates that the addition of CdSe quantum dots (QDs) and CdSe@Ag_2S NPs to different concentrations of hemoglobin can significantly influence the intensity of transmitted Near-Infrared (NIR) light, providing a potential method for the early detection and prognosis of cancer, particularly breast cancer. The findings highlight the ability of QDs to enhance the contrast in NIR imaging and distinguish between healthy and cancerous blood samples. The observed reductions in NIR transmissions with increasing hemoglobin concentration, particularly when QDs are present, suggest the potential of this technique for detecting breast cancer at its early stages. The significant differences in transmitted light intensity between healthy and cancerous blood samples, as well as the high optical stability and detectability of QDs, further support the feasibility of this approach for large-scale screenings and improved diagnostic techniques. Further research and development in this field are warranted to fully explore the clinical applications and potential benefits of QDs in cancer detection and monitoring.

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