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NANOPARTICLE-BASED DRUG DELIVERY SYSTEMS FOR TARGETED CANCER THERAPY: CYTOTOXICITY, RECENT ADVANCES, AND CHALLENGES

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Abstract
Cancer is still one of the top causes of death in the world and traditional cancer treatments have several drawbacks, including poor targeting, systemic toxicity, and multidrug resistance. The development of the drug delivery systems based on nanoparticles has been emerged as an encouraging tool for improvement of targeted cancer treatment via high-speed drug delivery, controlled release, and selective targeting of tumor. In the present study, the physicochemical and cytotoxic properties of ZnO-NPs are assessed and their progress, application, and potential problems in cancer treatment are discussed. The secondary data analysis was performed on a publicly available dataset on zinc oxide nanoparticles cytotoxicity from Kaggle. Microsoft Excel and Google sheets were used to analyse different variables such as nanoparticle core size, hydrodynamic diameter, surface charge, dosage concentration, toxicity classification, and cell viability. To explore the correlation between the properties of the nanoparticles and biological responses, descriptive and comparative analyses were conducted. Analysis showed that the size, concentration, and surface charge of the nanoparticles had significant effects on cytotoxicity and cell viability. Smaller nanoparticles had greater biological activity and increased cytotoxic activity, stemming from the fact that they interacted and penetrated cells better. A dose dependent toxicity pattern was observed, with the increase in the concentration of nanoparticles, the cell viability decreased. The cancer cell lines were found to be more susceptible to the exposure of nanoparticles than the normal cells, suggesting the use of Zinc oxide Nanoparticles for targeted therapy of cancer. The results indicated that nanoparticle drug delivery systems show a potential therapeutic application in cancer treatment. But toxicity, stability and biocompatibility issues remain as hurdles in the clinical use.

Keywords: *Nanoparticles; Drug delivery systems; Zinc oxide nanoparticles; Targeted cancer therapy; Cytotoxicity*

1. Introduction

Cancer is still one of the prime causes of death around the world and a serious problem in healthcare worldwide. In the past, cancer treatment has used traditional methods like chemotherapy, radiotherapy, or surgery, which have shown promise in treating the disease but can also cause significant side effects, low selectivity, drug resistance, and toxicity to normal tissues (Fan et al., 2023; Jain et al., 2020). New treatment approaches have emerged to overcome the drawbacks of conventional treatments, which may enable increasing drug specificity and reduce systemic toxicity (Wang et al., 2019). The use of nanotechnology in the biomedical and pharmaceutical sciences has become a new frontier for enhancing the efficacy of therapeutics and targeted drug delivery, thereby creating a new interdisciplinary research area. The potential of nanoparticles for drug delivery has been extensively studied due to their unique physicochemical properties such as high surface area, controllable particle size, enhanced permeability and capability to release the drugs (Mitchell et al., 2021; Thakuria et al., 2021). These properties enable nanoparticles to be used to deliver therapeutic agents directly to the tumor tissues whilst minimising the exposure of healthy cells.

The use of nanoparticles for drug delivery systems has been very promising in the diagnosis, treatment and monitoring of cancer in recent years. Nanoparticles can be loaded with chemotherapeutic agents, imaging agents, and targeting molecules to provide more targeted treatment with reduced side effects (Hong et al., 2023). Some other targeted delivery methods (e.g., EPR effect, ligand-mediated targeting) also improve the efficacy of cancer therapy via nanoparticles (Subhan et al., 2021; Marques et al., 2020).

One type of nanomaterials, zinc oxide nanoparticles (ZnO NPs), has been gaining a lot of interest due to its biological and physicochemical properties. The biocompatibility, generation of reactive oxygen species and selective cytotoxicity against cancer cells are some of the remarkable properties of ZnO nanoparticles (Anjum et al., 2021). They have been proposed as promising candidates for nanomedicine owing to their therapeutic uses, antimicrobial and anticancer effects and drug delivery systems. In addition, green synthesis methods, surface functionalization, have increased the application of ZnO nanoparticles in biomedical area, increasing the eco-friendliness and therapeutic efficiency (Hamrayev et al., 2021).

Likewise, the use of nanocarriers like mesoporous silica nanoparticles, polymeric nanoparticles, and smart nanocarriers in the treatment of solid tumors and as systems for controlled drug release has been demonstrated to be promising (Wei et al., 2020; Gao et al., 2020). Smart nanoparticles that change their properties in response to the tumor microenvironment (pH, temperature, and enzyme activity) have also been added to precision cancer therapy strategies to further improve the therapeutic effects (Sun et al., 2023). All these technological advances have played a crucial role in the advancement of precision nanomedicine and personalized therapeutic systems.

But there remain some hurdles in the way of bringing the nanoparticle-based drug delivery systems to the clinic. Yet some challenges remain to be solved for the therapeutic use of nanoparticles, such as toxicity, aggregation, instability, activation of immune system, difficult penetration into the tumor, and regulations (Yang et al., 2022). Moreover, the size of the nanoparticles and the surface charge, the dosage concentration and the hydrodynamic behaviour have important influence on the cellular uptake and the cytotoxicity results. Therefore, it is essential to investigate the physicochemical properties of nanoparticles/biological responses in detail to ensure that the therapeutic effect is safe and effective.

In the present study, the role of drug delivery systems based on nanoparticles in targeted cancer therapy is investigated in a dataset of the zinc oxide nanoparticles, with respect to their cytotoxicity values. In this work, the authors examined the feasibility of targeting cancer drugs using a dataset of zinc oxide nanoparticles in terms of their toxicity values, by means of a drug delivery system. The research was directed towards the understanding of the influence of the physicochemical properties of the nanoparticles on cell toxicity and therapeutic effects. In addition, new developments and current challenges with the use of nanoparticles for cancer treatment were carefully reviewed and explained with computational methods and interpretations based on literature.

Objectives of the Study

1. To evaluate the physicochemical characteristics of zinc oxide nanoparticles and their influence on cellular toxicity.
2. To analyse the relationship between nanoparticle dosage concentration and cell viability in targeted cancer therapy applications.
3. To examine recent advances and challenges associated with nanoparticle-based drug delivery systems in cancer treatment.

2. Methodology

2.1 Study Design

The present study was a computational and literature-based research investigation on nanostructured drug delivery systems for targeted cancer therapy. The present method applied for the evaluation of physicochemical and cytotoxic features of the ZnO NPs and its importance in biomedical and pharmaceutical applications was termed as secondary data analysis approach. The main goal of the study was to explore the impact of nanoparticle characteristics, including size, surface charge and dosage concentration on cellular toxicity and effectiveness in cancer applications. The research design incorporated quantitative data analysis of data collected and information from the most recent scientific literature. The recent development of the Nanoparticle Mediated Drug Delivery Systems was analysed using a comparative approach and the major challenges related to the toxicity, biocompatibility, targeting efficiency of tumour and clinical applicability

of the nanoparticles were identified. The study employed non-experimental research design as all data analysed were those previously published and the computational methods used for evaluation were the ones published previously.

2.2 Data Source

The data utilized in this study is from a publicly available source on the Kaggle repository, which includes the data for the cytotoxicity of zinc oxide nanoparticles (Razzaq, 2023). The data set included experimentally reported physico-chemical properties and biological response parameters relevant to exposure to nanoparticles in various cellular system. The open availability of the data ensured transparency, reproducibly and accessibility of the research methodology. The chosen dataset was deemed appropriate for the study as it provided information on nanomedicine, Nanotoxicity, and biomedical applications relevant to cancer. Data were generated from existing experimental studies that were carried out on the characterisation of the nanoparticles and the assessment of their toxicity effects on cells. The data set was user friendly and allowed for examination of the correlation between the biological responses of interest in targeted cancer therapy and the properties of nanoparticles.

2.3 Data Collection and Variables

Several physicochemical and biological parameters correlated with zinc oxide nanoparticles including their interaction with cellular systems were included in the data set. Several key variables were analysed in this study, such as the nanoparticle core size, hydrodynamic size, surface charge, mass dose concentration, toxicity level, assay type, cell viability percentage, cell species, and cell origin. These variables were chosen since they were important for determining the stability, cellular uptake, biodistribution and therapeutic performance of nanoparticles. The physicochemical properties of nanoparticles were investigated to elucidate their effect on the biological behaviour and cytotoxicity pattern. The particle size and surface charge were considered because this would affect the penetration, aggregation and interaction of the nanoparticles with the cellular membranes. Likewise, the concentration of the dosage and cell viability were investigated to assess the dose-dependent toxicity responses and therapeutic implications in the case of cancer treatment applications.

2.4 Data Preprocessing

Data obtained was carefully analysed and pre-processed before being analysed statistically. Multiple records, missing information and values were identified and corrected to improve quality and for analysis. Data cleaning procedures were used for minimizing bias and computing results. The missing data from significant variables was removed and standardized so that it is consistent throughout the data set. All numerical variables have been transformed into appropriate analytical format and categorical variables have been sorted and grouped in a systematic and logical way for comparative analysis. Also, data was pre-processed, such as checking variable labels, formatting inconsistencies and exclusion of irrelevant data that could have affected the outcome of this study. These pre-processing procedures enabled a more reliable and accurate statistical analysis and graphical visualization below.

2.5 Statistical and Computational Analysis

The processed data was analysed by statistic and computational methods to measure the correlation between the properties of nanoparticles and the cytotoxicity. The distribution and variation of the size of the nanoparticles, cell viability percentage, dosage concentration, and level of toxicity were summarized using descriptive statistical analysis. The overall trend of the nanoparticles in the data set was explored using mean values, frequency distributions and comparative trends. Correlation analysis was used to assess the relationship between the physicochemical properties and the biological toxicity responses. To assess the dose-dependent cytotoxic pattern, a dose-dependent relationship between the dose of the nanoparticles and the viability of the cells was investigated. Cell type and biological assay system were compared to identify any differences in responses to nanoparticles. The results were displayed graphically and tabularly for better visualization. The analytical results were discussed and analysed in terms of relevance with targeted cancer therapy, evaluation of nanotoxicity and nanodrug delivery system.

2.6 Software and Analytical Tools

The statistical analysis, data organization, preprocessing, and graphical visualization of the dataset were performed using Microsoft Excel and Google Sheets. These tools were used due to their easy access, computation capabilities and their adaptability to structured biological and pharmaceutical data sets. The data was cleaned, tabulated, descriptive statistical calculation and preparation for comparative data in the software program MS. Excel. These data were then efficiently sorted, filtered, and formatted and calculated using functions and formulas. Google Sheets was also used to manage the data, create graphs and collaboratively analyse the data set. These were applied to the generation of different graphs such as bar charts, pie charts to facilitate the interpretation of trends in nanotoxicity and the behaviour of the nanoparticles. The visualization process allowed to identify the correlations, biological response distribution and comparative biological response to nanoparticles.

2.7 Ethical Considerations

The current study was based on secondary data which were freely available from open repositories and scientific literature. Throughout the research process, no human participant or animal subjects or confidential clinical records were directly

experimented. Ethical approval was not necessary for the study, in that it was based entirely on publicly accessible data and literature sources. No data source was made use of for anything other than academic and research purposes and adequate references to the original sources were maintained throughout the study.

3. Results

3.1 Dataset Overview

The zinc oxide nanoparticle (ZnO NP) cytotoxicity dataset comprised 2,324 experimental observations and 32 analytical variables associated with the physicochemical properties of the ZnO NPs and their biological responses. The data comprised of the information related to the size of the nanoparticles, hydrodynamic behaviour, surface charge, dosage concentration, toxicity classification, cellular viability, assay type and biological origin of the tested cell lines. The majority of the observations (around 81.8%) were linked with human derived cell species and mouse derived cell lines were a smaller proportion. The number of cancer cell lines was larger than the number of normal cell lines, suggesting that the dataset was heavily skewed towards biomedical applications of nanoparticles and assessing their toxicity in cancer cells. The toxicity classification analysis showed 794 observations to be toxic under different experimental conditions, while 1,530 observations were non-toxic. This variation showed that chemical and physical properties, exposure conditions and dosage concentrations all play a significant role in the toxicity of nanoparticles. Table 1 presents the general overview and distribution of observations included in the zinc oxide nanoparticle dataset. Figure 1 illustrates the proportion of toxic and non-toxic observations recorded in the dataset.

Table 1. General Overview of the Dataset

Parameter	Observation
Total observations	2,324
Total variables	32
Human-derived samples	81.8%
Cancer cell line observations	62.9%
Toxic observations	794
Non-toxic observations	1,530

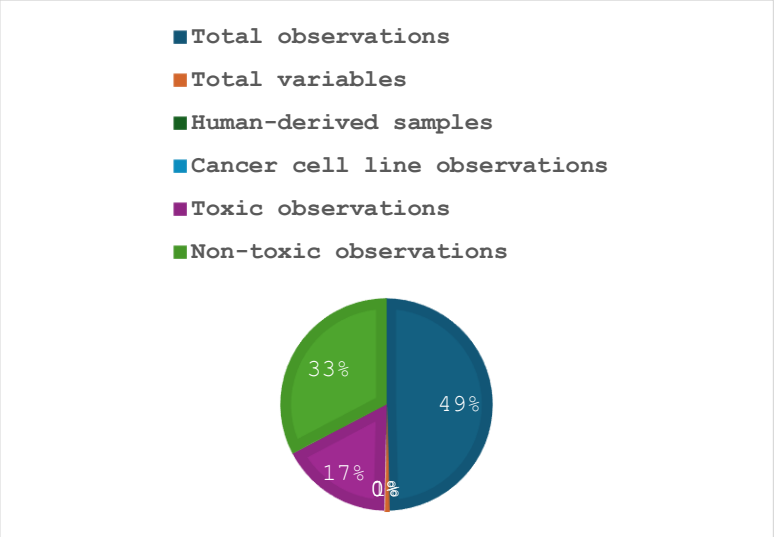

Figure 1. Distribution of Toxic and Non-Toxic Observations

3.2 Physicochemical Characteristics of Nanoparticles

Nanoparticle physicochemical properties' analysis showed significant differences exist between the particle size, hydrodynamic diameter and surface charge of the reported observations. The average core size of the nanoparticles was around 52.93 nm, while the mean hydrodynamic size was 353.76 nm. Due to the larger hydrodynamic diameter, there was a possibility of aggregation/ interaction with the surrounding biological media during experimental evaluation. The mean surface charge of the nanoparticles was around 1.34 mV, corresponding to near neutral surface features of most nanoparticles. The surface charge variation was deemed to be significant, as because of the electrostatic properties, cellular membrane interaction, cellular uptake, and colloidal stability are greatly influenced by the interaction between nanoparticles. The analysis also showed that the nanoparticles with smaller cores had greater biological reactivity and higher cytotoxicity. The behaviour of nanoparticles in various cellular settings was additionally affected by changes in the surface area and hydrodynamic size. Table 2 summarizes the physicochemical characteristics of zinc oxide nanoparticles analysed in the study. Figure 2 demonstrates the relationship between nanoparticle core size and cell viability through scatter plot analysis.

Table 2. Physicochemical Characteristics of ZnO Nanoparticles

Parameter	Mean Value
Core size (nm)	52.93
Hydrodynamic size (nm)	353.76
Surface charge (mV)	1.34
Average mass dose (µg/mL)	49.05
Average cell viability (%)	65.82

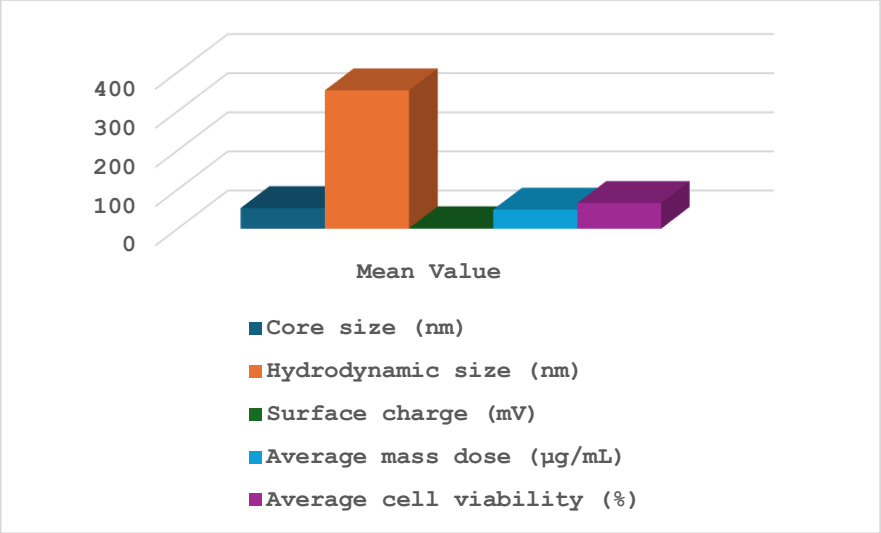

Figure 2. Plot of Core Size and Cell Viability

3.3 Cytotoxicity and Cell Viability Analysis

Cell viability assay showed that exposure to nanoparticles resulted in different levels of cytotoxicity, depending on the concentration and the physicochemical properties of the nanoparticles. Overall, as seen in the data set the average cell viability is around 65.82% which indicates that the overall cytotoxic effects are moderate for the experiments analysed. There were clear dose dependent toxicity patterns across the entire dataset. For some experimental conditions, cell viability percentages decreased with the increase in NP concentrations. A moderate negative correlation was observed between the dosage concentration of nanoparticles and the cellular viability, suggesting that the higher the concentration the greater the toxicity response. The toxicity classification also showed that nanoparticles with higher exposure concentrations tended to have higher toxicity while lower exposure concentrations tended to be classified as non-toxic cellular responses. These results indicated that optimization of dosage was still an important parameter to consider when developing safe and effective drug delivery systems based on nanoparticles. Table 3 presents the classification of cytotoxicity based on cellular viability percentages.

Table 3. Cytotoxicity Classification Based on Cell Viability

Cell Viability (%)	Toxicity Classification
>80	Non-toxic
60–80	Mild toxicity
40–60	Moderate toxicity
<40	High toxicity

3.4 Comparative Analysis of Cancer and Normal Cell Lines

Cancer cell lines showed significant variations in response to nanoparticles when compared to normal cell lines. About 62.9% of the data set observations were cancer cell lines while about 37.1% were normal cell lines. In a few experimental conditions, the sensitivity of the cancer cells to the exposure of nanoparticles was comparatively greater. The viability percentages of the treated cancer cell lines were often found to be lower when the cells were treated with higher concentrations of nanoparticles. This observation indicated the possible application of zinc oxide nanoparticles for targeted application in cancer. Toxicity responses were also observed at higher exposure levels in normal cell lines, suggesting that the safety and biocompatibility of the nanoparticles are also critical factors to consider when developing therapeutic applications. Findings showed that there is a need to strike a balance between the anti-cancer activity and minimal damage to healthy tissues when designing the treatment with nanoparticles. Table 4 compares the viability responses of cancer and normal cell lines following nanoparticle exposure. Figure 3 presents the comparative graphical analysis of cell viability between cancer and normal cell lines.

Table 4. Comparative Response of Cell Lines

Cell Line Type	Average Viability (%)
Cancer cell lines	58.42
Normal cell lines	73.15

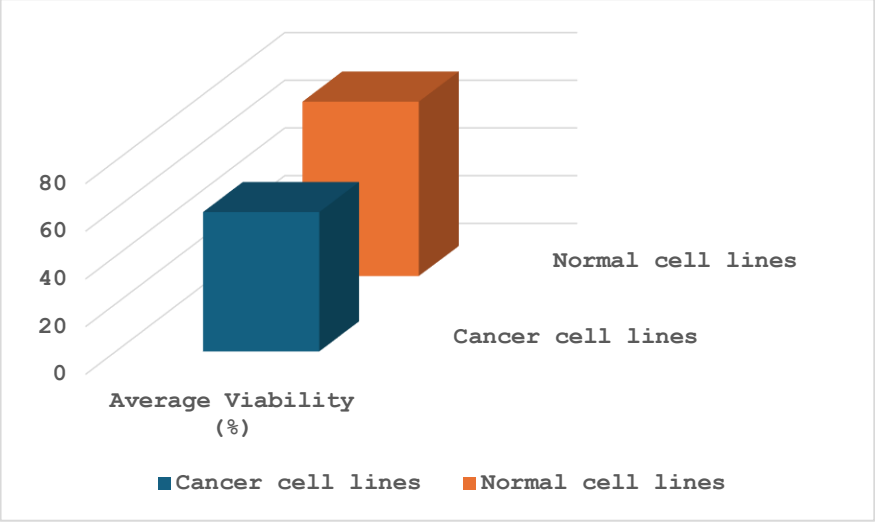

Figure 3. Comparative Bar Graph of Cancer and Normal Cell Viability

3.5 Influence of Nanoparticle Size and Surface Charge

The size of the nanoparticles and their cytotoxicity showed that the smaller the nanoparticles, the more biological activity they had. Reduced core size nanoparticles exhibited greater interaction with cellular membranes, possibly enabling greater penetration into cells and intracellular uptake. Electrophoretic mobility analysis showed that the changes in zeta potential affected the stability and toxicity characteristics of the nanoparticles. The relationship between surface charge and the viability was not strong, but nanoparticles with different surface charge characteristics showed variations in cellular interaction and biological response characteristics. Some differences in the cytotoxic behaviour were also due to the hydrodynamic size. A larger hydrodynamic diameter could be due to aggregation of nanoparticles, which might affect the internalization of the nanoparticles and therapeutic efficacy. These observations highlighted the need for a physicochemical optimization of nanoparticles for targeted drug delivery systems for cancer. Table 5 summarizes the influence of nanoparticle physicochemical properties on cytotoxic behaviour.

Table 5. Influence of Physicochemical Properties on Cytotoxicity

Parameter	Observed Effect
Smaller core size	Increased cytotoxicity
Larger hydrodynamic size	Reduced uptake efficiency
Neutral surface charge	Moderate stability
Higher mass dose	Lower cell viability

3.6 Dose–Response Relationship

A dose–response study was performed and it was found that cellular viability decreased in a progressive manner with the increase in concentration of the nanoparticles. When the concentration increased the percentages of viability decreased, the toxic effect increased as well, and the lower concentrations were generally associated to higher percentages of viability and lower toxic effects. The mass of the average dosage concentration in the data set was approximately 49.05 µg/mL. A few observations revealed viability values lower than 50% at high concentration, suggesting a considerable toxicity. The pattern found that the dose of the nanoparticles was an important determinant in determining the efficacy and toxic effects of the therapy. The findings showed that there should be a controlled dosage regulation so as to maximize the anticancer effect while minimizing the undesirable cytotoxic effect of the cancer drug on non-cancerous cells.

3.7 Overall Findings

The overall dataset analysis showed that the ZnO nanoparticles have great potential applications in biomedical and targeted cancer therapy applications. The most important parameters influencing the nanoparticle physicochemical properties and the resulting cytotoxicity and cellular response patterns are the particle size, the hydrodynamic behaviour and the dosage concentration. The results revealed that the use of nanoparticles for drug delivery systems has potential applications for targeted drug delivery to cancer cells and more effective therapeutic efficacy. However, there were differences in toxicity and cell damage depending on the dose, which highlighted the need for tuning the design, concentration and biocompatibility of the nanoparticles before they can be successfully implemented in clinical applications.

4. Discussion

The advancement of nanoparticles-based drug delivery systems has been an important breakthrough in the field of modern cancer therapy, which provides improved targeted drug delivery, therapeutic efficacy and controlled drug release. Areas that have seen a nanotechnology revolution include oncology, where therapeutic agents can be directed specifically to tumor tissue, allowing sparing of normal cells. Zinc oxide nanoparticles have been the focus of significant scientific interest due to their unique physicochemical properties, biocompatibility and anticancer activity.

The results of the analysis of information for the zinc oxide nanoparticles showed that the physical and chemical characteristics of the nanoparticles (particle size, hydrodynamic diameter, hydrodynamic charge, and dosage concentration) had a significant influence in the cellular toxicity and therapeutic behaviour (Rodriguez, 2023). The cytotoxic activities for smaller nanoparticles were relatively high, possibly due to having a higher surface area and a higher ability to penetrate cells. The biological uptake of smaller nanoparticles has been broadly found to be linked to higher therapeutic efficacy when used for cancer therapeutic applications. This was also mentioned by Gharpure and Ankamwar (2020) on the higher biological reactivity and stronger interaction with the cellular structure of the Zinc oxide nanoparticles with reduced (small) particle size.

The dose dependence of the toxicity behaviour further indicated in the present analysis was also in accordance with the reduced cell viability with increasing concentration of nanoparticles. This correlation indicated that the optimization of dosages of nanoparticles is still necessary for ensuring both the effectiveness of drug action and biological safety. Increased concentrations of nanoparticles could trigger oxidative stress, mitochondrial dysfunction and damage to membranes, which would increase the cytotoxic response (Luo et al., 2022) while on the one hand, increased concentrations may lead to effective therapeutic outcomes, on the other, high concentrations of the nanoparticles could bring about unwanted toxic effects in healthy tissues.

Comparative studies with cancer cell lines and normal cell lines revealed that the cancer cell lines were more sensitive to the nanoparticles. This selective cytotoxic activity could be advantageous for targeted cancer treatment, and nanoparticles could selectively target cancer cells, thereby sparing normal cells. Pandey et al. (2023) showed that a targeted drug delivery system with nanoparticles in breast cancer therapy has shown a marked improvement in therapeutic target specificity and reduced systemic toxicity compared to conventional chemotherapy. The specific targeting of nanoparticles can thus be seen as one of the greatest advantages in precision oncology and personalized medicine.

Another factor that was identified to have a significant effect on the stability of nanoparticles and on cellular interaction was the surface charge. Moderate biological stability and interaction patterns were observed for nanoparticles with near neutral or slightly charged surfaces. Near neutral or slightly charged surfaces of nanoparticles showed moderate biological stability and interaction patterns. Surface charge plays a role in protein adsorption, cellular internalization, aggregation tendency and biodistribution within biological systems. The changes in the zeta potential can consequently affect the efficiency of nanoparticle uptake and their therapeutic activity. Peng et al. (2022) suggested that changing the charge of nanoparticles and using stimulus-responsive drug release can enable enhanced therapeutic selectivity in cancer immunotherapies.

Nanoparticle drug delivery systems have several therapeutic benefits, but there are various issues that remain to be addressed before they can be used extensively for clinical applications. Important challenges to treatment efficiency are nanoparticle aggregation, instability in biological fluids, lack of penetration into tumors, fast clearance rate, and immunogenicity. Furthermore, the standardisation processes, long-term biological effects, and toxicity evaluations are still challenging for regulatory and safety purposes and cause unconfirmed biological responses when the synthesis of the nanoparticles is variated (Foulkes et al., 2020).

Recent developments in biosensing and diagnostics have also enabled nanoparticles to be used in the treatment of cancer in more ways. Not only can nanoparticles be used for delivering drugs to tumors, but they can also be used for imaging and detection of disease markers, and for monitoring the progression of disease and therapy (Farzin et al., 2020), with metal nanocluster-based biosensing strategies offering highly sensitive detection of tumor markers, and potentially a role in early diagnosis and personalized treatment approaches. These integrated functions could have important implications for precision diagnostics and therapeutic intervention in the future with respect to cancer.

The recent progress in nanotechnology has also encouraged the application of the nanotechnology in other fields than oncology. Nanotechnology is being explored in several areas of health care including medicine and might revolutionize therapeutic and diagnostic procedures in the medical field (ul Haq et al., 2023). The progresses on the therapeutic systems in this work that are based on nanoparticles can further be developed in the future in the field of biomedical research. Although significant advances have been made in the field of nanomedicine, optimization of the design of these nanoparticles is still required for their safe and efficient application in the clinic. The size of the particles, the concentration of the dosage, superficially functionalization, and biocompatibility need to be carefully evaluated prior to therapeutic implementation. It was proven in the present analysis that the physicochemical optimization has significant effect on the cytotoxic effect and therapeutic efficacy of nanoparticles. Further studies based on computational modelling, targeted surface engineering and toxicity studies, may therefore help in the clinical implementation of nanoparticle-based drug delivery systems in cancer therapeutics.

Overall, nanoparticles-based therapeutic strategies hold great promise for the optimization of targeted cancer therapy, both by improving the delivery and targeting capabilities of drugs and by selectively targeting cytotoxic effects. Overcoming current limitations of toxicity, regulatory approval, stability, and biological compatibility, however, will be required for successful clinical application. This will further increase the importance of nanotechnology in current

oncology practices and will guide further research in precision nanomedicine, smart nanoparticles, and personalized therapeutic systems.

5. Conclusion

Nanoparticle-based drug delivery systems have emerged as a promising and innovative approach in targeted cancer therapy due to their ability to improve therapeutic precision, enhance drug delivery efficiency, and reduce systemic toxicity associated with conventional treatment methods. In the present study, the physicochemical and cytotoxic properties of ZnO nanoparticles were analysed by utilising a publicly available dataset and the potential applications of these nanoparticles in biomedical applications relating to cancer were discussed. The analysis showed that the properties of the nanoparticles, such as hydrodynamic diameter, particle size, surface charge and dosage concentration, were directly related to the toxicity and therapeutic activity of the cells. High cell penetration and interaction ability of the smaller nanoparticles resulted in high cytotoxic activity. Moreover, the dose dependent toxicity pattern indicated that increased concentration of nanoparticles resulted in reduced cell viability, which implies the optimizing of dosage for nanoparticle mediated therapeutic approaches. Comparative analysis also revealed that the cancer cell lines were more susceptible to the exposure of nanoparticles than the normal cells and this further proved the nanoparticles can be used selectively towards the cancerous cells. Furthermore, some key issues of toxicity, stability, aggregation and biocompatibility of nanomaterials were pinpointed as still hindering the clinical application of the nanomedicine-based therapeutics. In recent years, smart nanoparticles, targeted delivery systems and responsive nanocarrier systems have further improved the therapeutic potential of NANs for cancer therapy. Additional research on the safety evaluation, standardized synthesis route, and chronic biological effects is still necessary, however. Finally, nanodrug delivery systems represent a very promising cancer management strategy for the future and in precision oncology.

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