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Review Article

A Review on Role of Nanotechnology in Blood Cancer Treatment

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ABSTRACT

Blood cancer, also known as hematologic cancer, is a group of malignancies that originate in the blood-forming tissues, primarily the bone marrow and lymphatic system. It occurs when abnormal blood cells grow uncontrollably, disrupting the normal production and function of red blood cells, white blood cells, and platelets. These abnormal cells interfere with the body's ability to fight infection, transport oxygen, and control bleeding. Multiple myeloma, leukemia, and lymphoma are the three common types of blood cancers. Chemotherapy is the major therapy of blood cancers by systemic administration of anticancer agents into the blood. However, a high incidence of relapse often happens, due to the low efficiency of the anticancer agents that accumulate in the tumor site, and therefore lead to a low survival rate of patients. This indicates an urgent need for a targeted drug delivery system to improve the safety and efficacy of therapeutics for blood cancers.the current targeting strategies for blood cancers and recently investigated and approved drug delivery system formulations for blood cancers. current challenges in the application of drug delivery systems for treating blood cancers like Liposomes, dendrimers, microsphere, Quantum dots, & Nanoshells.

INTRODUCTION

Cancers are one of the leading causes of death in the world. Unlike solid tumors such as those in organs, blood cancers (including multiple myeloma, leukemia, and lymphoma) form in the bone marrow or in the lymphatic system. provides an overview of different types of blood cancers. Current treatments for blood cancers consist of chemotherapy, radiotherapy, immunotherapy, and transplantation. Although, many chemotherapeutic drugs are clinically available for the treatment of blood cancers, there are no curative treatment approaches in clinical practice for these types of cancers due to the inevitable aggravation of blood cancers and bone metastasis . Furthermore, it is difficult to achieve a sufficient therapeutic dose of anticancer agents at tumor sites inside bone marrow or the lymphatic system to suppress tumor growth via systematic administration .To maintain therapeutic levels in bone marrow or the lymphatic system,

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chemotherapeutics require high dosage and/or more frequent administration which can result in increased side effects .In addition, the bone marrow microenvironment contains a huge number of hematopoietic stem/progenitor cells which are resistance to chemotherapy and mediate disease refractory/relapse .targeted drug delivery system for blood cancers is a significant challenge for chemotherapy.

The application of nanotechnology in blood cancer therapy has gained remarkable attention due to its ability to enhance targeted drug delivery, improve pharmacokinetics, and enable controlled release of anticancer agents. Nanocarriers such as liposomes**,** dendrimers**,** polymeric nanoparticles, metallic nanoparticles, and quantum dots have been developed to encapsulate chemotherapy drugs, thereby increasing their stability and bioavailability. These nanocarriers can be functionalized with specific ligands or antibodies that recognize and bind to receptors overexpressed on the surface of cancer cells, allowing for site-specific targeting and reducing unwanted side effects.[1,3]

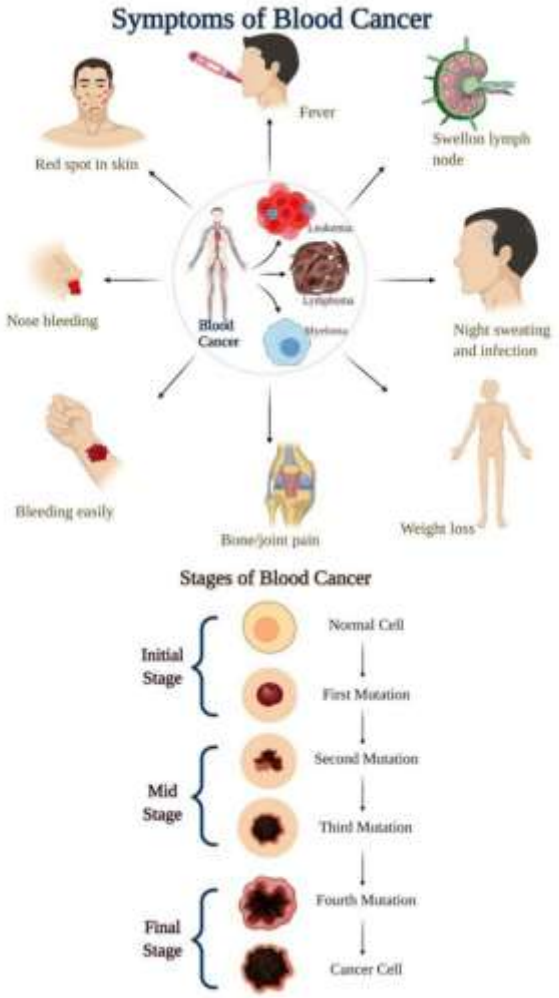

Figure -1. Symptoms of blood cancer & stages of blood cancer

2. LITERATURE REVIEW:

1) Patil, Sharma & Khan (2024) discussed multifunctional nanocarriers capable of delivering drugs while simultaneously enabling imaging through fluorescence or magnetic tracking. These systems allow real-time monitoring of leukemia progression, improving personalized treatment

planning. The file also discusses the structural and functional characteristics of nanoshells, liposomes, microspheres, and dendrimers, all of which contribute to the development of versatile theranostic systems

2) Das & Tripathi (2024) examined siRNA-loaded nanoparticles that selectively inhibited oncogene expression, leading to reduced tumor proliferation and enhanced therapeutic outcomes. These nanoparticles protect siRNA from degradation and ensure efficient delivery to cancer cells, providing a promising next-generation treatment modality. Supporting this, several sections from the file emphasize the role of lipid nanoparticles **(**LNPs**)** and dendrimers in gene therapy, including siRNA, mRNA, and CRISPR-based delivery systems

3) Raza et al. (2023) highlighted the use of liposomes and quantum dots **i**n combination therapy to overcome MDR mechanisms. Their findings emphasized that nanoparticles enhance intracellular drug retention and bypass efflux pump action, thereby restoring the sensitivity of cancer cells to chemotherapy. Quantum dots, beyond drug delivery, also serve as powerful tools in diagnostics and imaging, allowing real-time visualization of cancer progression, as noted in the file's description of QDs' high sensitivity and biomarker-detection abilities

4) Mehta et al. (2023) developed polymeric nanoparticles encapsulating imatinib, a frontline therapeutic for chronic myeloid leukemia (CML). Their in-vitro and in-vivo studies showed enhanced drug accumulation in leukemia cells, improved internalization efficiency, and superior tumor inhibition compared to free imatinib. Such targeted nanoparticle systems are particularly effective in overcoming disease persistence in bone marrow niches where traditional drugs often fail to penetrate effectively.

5) Ali & Ahmed (2022) explored the multifunctional role of magnetic nanoparticles, which allow externally guided targeting using magnetic fields and can be used for hyperthermia-based therapy. These innovations contribute to more effective disease control with lower doses of chemotherapeutics.

6) Kumar et al. (2021) conducted a comparative evaluation of PEGylated liposomal doxorubicin, showing that these formulations improved pharmacokinetics and considerably reduced cardiotoxicity—one of the most severe adverse effects of anthracycline therapy. Improved circulation time and selective tumor uptake further contributed to superior therapeutic responses in blood cancer patients.

7) Patra et al. (2020) comprehensively reviewed the use of lipid nanoparticles, nanomicelles, and polymeric carriers, emphasizing their ability to provide long-term sustained release of anticancer drugs while maintaining optimal plasma concentrations. This sustained delivery is essential for managing hematologic malignancies that require prolonged therapeutic exposure.

8) Zhao and Xu (2019) investigated gold nanoparticles conjugated with monoclonal antibodies, which selectively targeted leukemia cells and induced strong apoptotic activity. Importantly, these conjugated gold nanoparticles showed minimal cytotoxicity toward normal blood cells, demonstrating their potential for precision therapy.

9) Jain et al. (2018), who demonstrated that nanotechnology-based drug delivery markedly improves the therapeutic index of chemotherapeutic agents used in leukemia treatment. Their work showed that liposomes and polymeric nanoparticles significantly enhanced the targeted delivery of conventional drugs such as

doxorubicin and cytarabine, resulting in better bioavailability and reduced systemic toxicity. This research provided foundational evidence for the effectiveness of nanocarriers in improving drug distribution and reducing off-target effects.

3. AIM & OBJECTIVE

Aim:- A review on role of nanotechnology in blood cancer treatment.

Objective:-

To examine the role of nanotechnology in enhancing the diagnosis and management of blood cancers, including leukemia, lymphoma, and multiple myeloma.

To evaluate the benefits of nanotechnology-based drug delivery, such as precise targeting, regulated drug release, lower systemic side effects, and improved treatment effectiveness.

To review the latest developments in nanomedicine and their potential influence on treatment outcomes for patients with blood cancers.[4,6]

4. NEED OF STUDY

Blood cancers, such as leukemia, lymphoma, and multiple myeloma, pose major challenges in the field of oncology due to their complicated biology, often late diagnosis, and limited treatment options. Conventional treatments like chemotherapy and immunotherapy can cause significant side effects and sometimes show limited effectiveness. Nanotechnology provides promising alternatives by enabling precise drug delivery, reducing harmful effects on healthy tissues, and improving overall treatment efficiency. Engineered nanoparticles can specifically target cancer cells, minimizing damage to normal cells and enhancing patient outcomes.

Recent progress in nanotechnology has also led to innovative diagnostic methods, including liquid biopsies that utilize extracellular vesicles to detect cancer biomarkers with high accuracy. These tools allow earlier detection and more effective monitoring of blood cancers, which can improve prognosis and support personalized treatment approaches.

However, challenges remain in bringing nanotechnology-based treatments from research to clinical use. Concerns such as nanoparticle safety, compatibility with the human body, and regulatory approvals must be carefully addressed to ensure these therapies are safe and effective.

Overall, investigating the role of nanotechnology in blood cancer treatment is essential to develop safer, more precise, and effective therapies, ultimately improving patient care and advancing cancer treatment strategies.[7,10]

5. PLAN OF WORK

a) Literature servey
b) selection of Topics
c) Data sources
d) Data Extraction
e) Data Analysis
f) Expected outcome
g) Result & Discussion
h) summary & conclusion

6. MATERIAL AND METHOD:

6.1. Current drug delivery systems for improved blood cancer treatment:

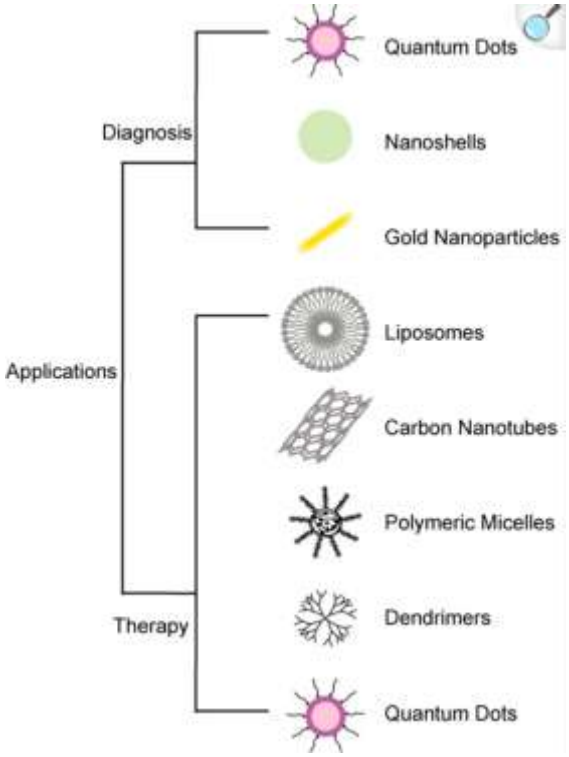

Figure -2. Application of nanomaterials in cancer diagnosis and therapy

6.1.1 Liposomes :-

introduced in 1965 as the first enclosed phospholipid bilayer nanosytem, are spherical vesicles primarily made up of one or more layers of phospholipids. Their size can range from about 20 nanometers to over 1 micrometer. Structurally, liposomes consist of a hydrophilic (water-loving) core surrounded by a hydrophobic (water-repelling) phospholipid bilayer. This unique arrangement enables them to encapsulate both hydrophilic and hydrophobic drugs, depending on the drug's properties. Hydrophilic drugs are trapped within the aqueous core, while hydrophobic drugs are incorporated into the lipid bilayer. The encapsulated drugs remain protected from degradation while circulating in the bloodstream. Additionally, liposomes offer advantages such as efficient drug loading and controlled release of therapeutic agents .[11]

In Nanotechnology:

Liposomes act as nanocarriers(50–1000 nm) that protect drugs from degradation.They improve solubility, bioavailability, and targeted delivery of drugs. Used in cancer therapy, gene delivery, and vaccine formulations (e.g., mRNA vaccines).

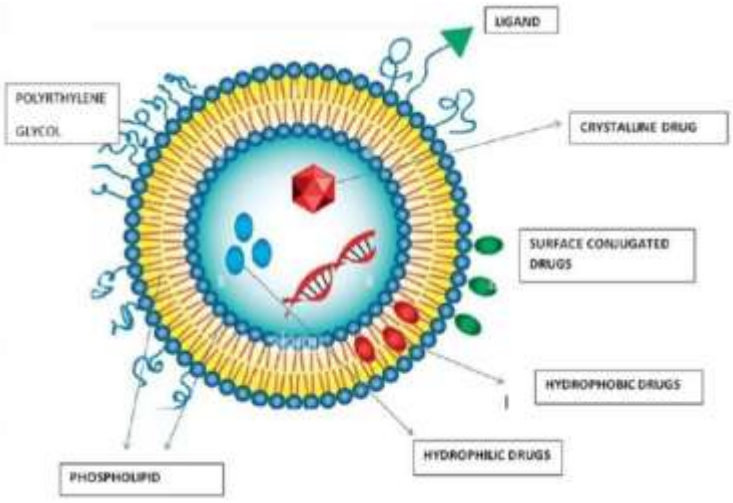

Figure-3. structure of liposomes

6.1.2 Quantum dots.

Quantum dots (QDs) are semiconductor nanocrystals ranging from 2 to 10 nm in size. Their electronic characteristics fall between those of bulk semiconductors and individual atoms due to the high surface-to-volume ratio of these nanoparticles. QD-based immunostaining techniques are more precise than traditional immunochemical methods, especially when

detecting proteins expressed at very low levels. This makes them valuable tools in cancer diagnostics for identifying various tumor biomarkers, including cellular proteins and other molecular components within heterogeneous tumor samples.

Quantum dots also have the ability to accumulate in specific regions of the body, allowing them to deliver drugs directly to targeted sites. This targeted drug delivery can help reduce the adverse side effects commonly associated with chemotherapy. Recent advancements in QD surface modification have enabled their conjugation with biomolecules such as peptides and antibodies, improving their potential use in tumor targeting, imaging, and therapy.

High-sensitivity quantum dot probes have been developed for multicolor fluorescence imaging of cancer cells in living organisms. These probes have been effectively used to detect ovarian cancer marker CA125 in different sample types, including fixed cells, tissue sections, and xenografts.[12]

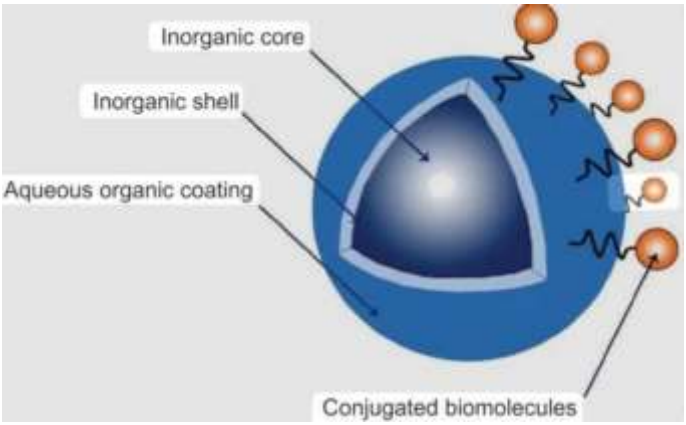

Figure -4. Structure of Quantum dots

6.1.3 Microsphere:

Microspheres are tiny round particles, generally measuring between 10and10micrometers(µm) in diameter. They can be made from natural or artificial substances like polymers, glass, ceramics, or proteins. In the field of nanotechnology, microspheres serve important roles as drug delivery systems, diagnostic tools, and imaging agents because of their consistent spherical shape, compatibility with biological systems, and capacity to release drugs in a controlled manner.[13]

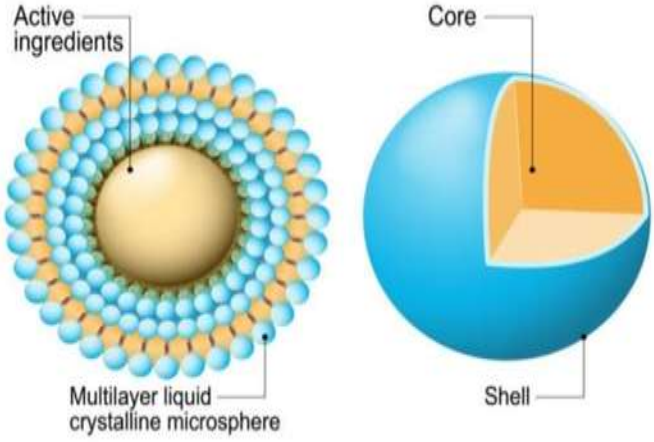

Figure -5. structure of microsphere

6.1.4 Nanoshells :

Nanoshells are another widely used application in nanotechnology. They consist of a dielectric core, typically made of silicon, with a size ranging from 10 to 300 nanometers, which is then coated with a thin metallic layer, often gold. These nanoshells function by transforming plasmagenerated electrical energy into light and can be precisely adjusted for optical responses across the UV to infrared spectrum. They are favored because their imaging does not involve toxic heavy metals, although their relatively large size can limit some of their applications.[14]

6.1.5 Dendrimers:

Dendrimers are nanocarriers with a central spherical polymer core and evenly spaced branching structures. As these macromolecules get larger, they tend to form more spherical shapes. They can be synthesized in two ways: the divergent approach, where branches grow outward from the core, and the convergent approach, where growth starts from the outer branches and moves inward toward the core. Dendrimers are commonly made from materials such as polyacrylamide,polyglycerolsuccinicacid,polylysine,polyglycerin,poly(2,2bis(hydroxymethyl)propionic acid), and melamine. Their chemical properties—like basicity, hydrogen bonding, and surface charge—can be adjusted by modifying the branches or surface groups. Usually, anticancer drugs are attached to the outer groups of dendrimers through covalent bonds to create dendrimer-drug.Conjugate.[15,21]

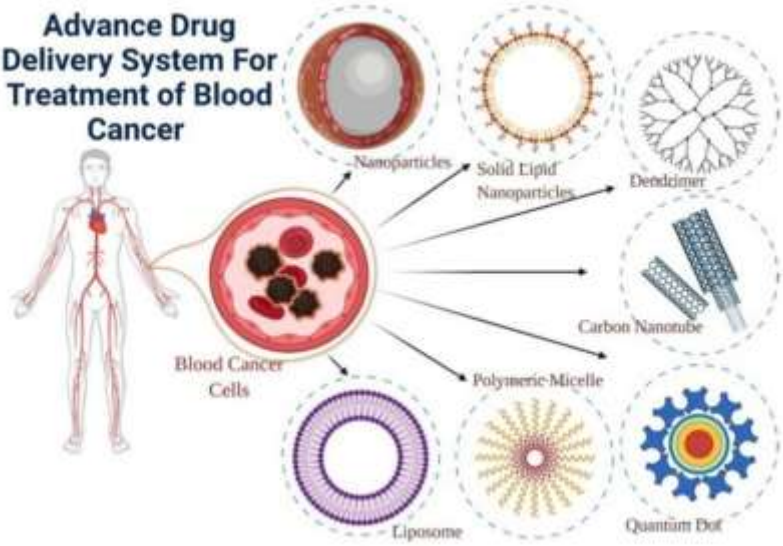

Figure -6. Nano based system for the management of blood cancer.

6.2 Mechanisms of Action of Nanotechnology in Blood Cancers:

6.2.1 Targeted Drug Delivery

Nanoparticles can be modified with ligands, antibodies, or aptamers to target tumor-specific markers (CD19, CD20, CD33), increasing drug uptake by cancer cells.

6.2.2 Controlled and Sustained Release

Nanocarriers maintain drug levels for longer periods, reducing dosing frequency and side effects.

6.2.3 Co-delivery of Multiple Drugs

Nanoparticles can carry combinations in a fixed synergistic ratio.

Example: CPX-351 a 5:1 molar ratio of cytarabine: daunorubicin for AML**.**

6.2.4Gene Therapy and RNA Delivery

LNPs and dendrimers are used to deliver: siRNA (gene silencing), mRNA, CRISPR components Helping overcome drug resistance pathways.

Limitations:-

1. Difficulty reaching deep bone marrow niches, where leukemia cells reside.
2. Potential long-term toxicity, especially with metallic nanoparticles.
3. Off-target effects on healthy blood and bone marrow cells.
4. High manufacturing complexity and need for advanced technology.
5. Batch-to-batch variability during nanoparticle production.
6. Limited clinical trials and slow clinical translation.
7. Difficulty in dose standardization due to size & surface property variations.
8. Possible hypersensitivity or immune reactions (e.g., PEG allergy).
9. High development and treatment cost.
10. Regulatory challenges because approval guidelines for nanomedicine are still evolving.
11. Stability issues such as aggregation or premature drug leakage.Ethical and environmental concerns about nano-waste and long-term exposure.

6.3 Types of blood cancer:

Most blood cancers, also called hematologic malignancies, originate in the bone marrow .the primary site of blood cell production. These cancers occur when abnormal blood cells grow and multiply uncontrollably, disrupting the normal function of healthy blood cells responsible for fighting infections and producing new blood components.

6.3.1 Leukemia:-

Leukemia is a type of cancer that affects white blood cells or their precursors. The abnormal white blood cells in leukemia are unable to effectively combat infections. This disease can involve different immune cells, including lymphocytes, and may present as either acute or chronic, depending on how quickly it progresses. Acute lymphocytic leukemia is particularly common in children under 15. Leukemia is categorized into various subtypes: based on progression, it is classified as acute or chronic, and based on the type of cells affected, it is divided into lymphoid or myeloid leukemia .[22,23]

6.3.2 Lymphoma:-

Lymphoma is a cancer of the lymphatic system, particularly affecting the lymph nodes, and involves abnormal lymphocytes, which are a type of white blood cell. The most common form is Hodgkin lymphoma, while all other forms are classified as non-Hodgkin lymphoma. There are over 70 different types of lymphoma, which can be either slow-growing or aggressive. Hodgkin lymphoma is the most prevalent, followed by non-Hodgkin lymphoma. Both adults and children can develop these cancers. Lymphomas primarily involve B and T lymphocytes, with T-cell lymphocytes being commonly affected. As the disease progresses, cancerous cells can spread through lymphatic vessels to other parts of the body, potentially forming tumors .[24]

6.3.3 myeloma:

Myeloma is a type of cancer that affects plasma cells, a type of lymphocyte responsible for producing antibodies that help fight infections. The disease weakens the immune system, making the body more susceptible to infections. Myeloma develops due to genetic mutations in the plasma cells' DNA, which occurs when new plasma cells are produced in the bone marrow. These abnormal plasma cells multiply uncontrollably and produce defective antibodies. Unlike lymphoma, myeloma does not form solid tumors; instead, the problems arise from the abnormal plasma cells in the bone marrow and the abnormal proteins they release. This condition primarily affects active bone marrow, including the bones of the arms, legs, shoulders, spine, skull, pelvis, and rib cage.[25]

- **Nanoparticle- based drug delivery specific advantages:**

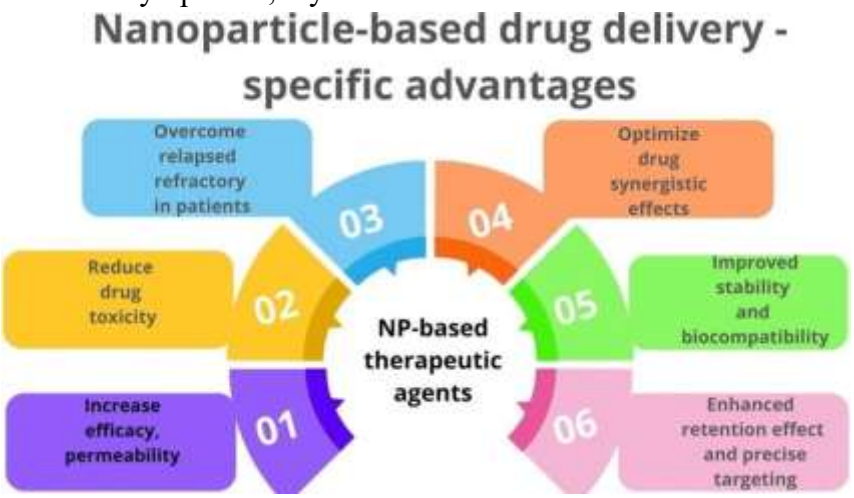

Figure -7. Nanoparticles – based drug delivery specific advantages.

- **Nanomedicine in blood cancer :**

Nanomedicine has significantly advanced cancer treatment, with recent clinical trials exploring the use of nanoparticles for cancer therapy, diagnosis, chemotherapy, radiotherapy, and immunotherapy. A major focus has been on nanoparticle-based drug delivery systems, which improve the pharmacokinetics and distribution of chemotherapeutic drugs. This allows for more precise tumor targeting while reducing toxicity to healthy or peripheral organs. For example, a phase II clinical trial involving 32 patients with malignant tumors metastasized to the pancreas showed that liposomal irinotecan improved overall survival compared to standard supportive care or single-drug treatments. Similarly, a phase III study demonstrated that using nanoparticle-bound paclitaxel in combination with gemcitabine for metastatic pancreatic cancer significantly increased overall survival.[26]

Nanoparticle-based technologies play a crucial role in cancer diagnosis by enabling earlier detection and ongoing monitoring of the disease. The application of nanotechnology in lung cancer detection is not new; for instance, a phase II clinical trial using a blood-based liquid biopsy with gold nanoparticles showed promising results, although accuracy decreased at very early disease stages. In addition, nanoparticles are increasingly being explored as immuno-oncological agents for anti-cancer drug development. A phase I trial of a glioblastoma-specific nanoparticle vaccine produced strong immune responses and improved patient survival compared to chemotherapy alone. The use of nanoparticles to deliver tumor antigens in advanced cancer vaccines holds significant

promise for enhancing the effectiveness of cancer therapies.[27,29]

Table- 1:- application of with or without use of nanotechnology in blood cancer treatment

Application	Without use of nanotechnology	With use of nanotechnology
Diagnosis	FNAC, biopsy, FISH, immune histochemistry used for diagnosis. Early detection is not possible. Only in vitro detection is possible. Real time detection is not possible.	Quantum dots and raman probe can be used for diagnosis. Early detection is possible. In vintro and invivo detection is possible. Real time detection is also possible
Imaging	X- rays, CT scan, MRI, PET scan, isotopes can is used. Ultrasonography is used	Quantum dots can be used UCM ultrasonography can be used Very early detection of neo vascularization is possible Imaging, targeting, delivering and monitoring is possible
Early detection of cancer	Cytology, FNAC, and biopsy is used	Vital optical Imaging is possible Inexpensive mass screening is possible.
Drug delivery	Oral, intramuscular, intravinous, intraarterial drug delivery is possible	Targeting delivery is possible Possible to deliver small dose Low systemic toxicity batter and faster response

Nanotechnology has emerged as a powerful tool in improving the diagnosis and treatment of various hematologic malignancies such as leukemia, lymphoma, and multiple myeloma. Traditional chemotherapeutic drugs often face challenges like poor solubility, nonspecific distribution, and severe systemic toxicity.

6.4 Current therapeutic approaches to treat blood cancers:

Currently, blood cancer can be treated using therapies such as chemotherapy, immunotherapy, radiotherapy, and hematopoietic stem cell transplantation. Although these treatments have seen significant progress over time, they still face certain clinical challenges, including toxic side effects, rapid elimination from the body, and potential disruption of bone marrow function.[30]

6.4.1 Chemotherapy :-

Table-2: List of common FDA-approved chemotherapeutic drugs for blood cancers

Drug	Mechanism of action	Type of blood cancer
Imatinib (Gleevec)	Tyrosine kinase inhibitors	Chronic myeloid leukemia
Dasatinib (sprcel)	Tyrosine kinase inhibitors	Chronic myeloid leukemia
Nilotinib (Tasigna)	Tyrosine kinase inhibitors	Chronic myeloid leukemia
Bosutinib (bosulif)	Tyrosine kinase inhibitors	Chronic myeloid leukemia
Ponatinib (iclusig)	Tyrosine kinase inhibitors	Chronic myeloid leukemia Acute lymphoblas leukemia
Cyclophosphamide (Cytoxan)	Alkylating agent	Leukemia Lymphoma Multiple myeloma

Chemotherapy was among the first treatments developed for blood cancer, with Mustargen being the first drug approved by the U.S. FDA in 1949 for treating leukemia, lymphosarcoma, and Hodgkin's disease. Since then, numerous other chemotherapeutic agents have been introduced and are commonly used as first-line treatments for various blood cancers.[31]

6.4.2 Immunotherapy

In recent years, immunotherapy has become an increasingly important approach in treating blood cancers. Advanced strategies, including checkpoint inhibitors, cell-based therapies, and cancer vaccines, have been successfully incorporated into standard treatment protocols. These therapies work by activating the immune system to eliminate cancer cells and prevent their spread beyond the original site. Among these, checkpoint inhibitors are widely used; they block the pathways that cancer cells exploit to evade destruction by cytotoxic T-cells.[32,33]

6.4.3 Radiotherapy

Radiotherapy is a traditional treatment method for blood cancers, mainly used to control localized disease or as part of an overall conditioning regimen. The specific use of radiotherapy depends on the type and stage of the blood cancer, as well as the overall treatment strategy.[34,37]

6.5 FUTURE PROSPECTS:

Recent progress in Nano medicine has opened up promising avenues for enhancing cancer treatment. Both targeted and non-targeted nanoparticles are being evaluated in preclinical and clinical studies, highlighting the significant role of advanced drug delivery systems. Continued research in this field is expected to widen the therapeutic window of anticancer drugs, minimize side effects, and ultimately improve patient outcomes.

Treating blood cancers like leukemia, lymphoma, and multiple myeloma remains challenging because traditional therapies often lack specificity, have poor bioavailability, and can cause significant systemic toxicity. Conventional treatments including chemotherapy, radiotherapy, immunotherapy, and stem cell transplantation have shown limited success in targeting cancer cells within the protective and complex environment of the bone marrow. To address these limitations, advanced drug delivery systems such as liposomes, pegylated formulations, and polymeric nanoparticles have been developed

These systems enhance drug stability, prolong circulation, and improve retention in tumor tissues while reducing effects on healthy cells. As a result, they optimize drug pharmacokinetics and therapeutic efficacy, enabling more precise, site-specific delivery and better clinical outcomes. Some of these technologies have already received regulatory approval, while others are undergoing advanced clinical trials, highlighting their potential for real-world application.[38,41]

SUMMARY:

role of nanotechnology in the treatment of blood cancers**,** including leukemia, lymphoma, and multiple myeloma. Traditional therapies such as chemotherapy and radiotherapy often suffer from low targeting efficiency, high toxicity, and drug resistance.Nanotechnology helps overcome these limitations by using nanocarrier such as liposomes, dendrimers, polymeric nanoparticles, quantum dots, microspheres, and nanoshells to deliver drugs directly to cancer cells with greater precision. These systems improve drug stability, enhance bioavailability, and allow controlled release, reducing damage to healthy tissues.

applications of nanotechnology in early diagnosis, imaging, and gene therapy. Although challenges like toxicity, manufacturing complexity, and limited clinical trials remain, nanomedicine shows strong potential to revolutionize future blood cancer treatment.

CONCLUSION:

Nanotechnology offers a powerful and innovative platform for improving the diagnosis and treatment of blood cancers such as leukemia, lymphoma, and multiple myeloma. By using nanoscale carriers. including liposomes, dendrimers, polymeric nanoparticles, and metallic nanostructures. therapeutic agents can be delivered selectively to malignant cells with enhanced precision. This targeted delivery helps in reducing systemic toxicity, improving drug stability, and achieving controlled or sustained release, which collectively enhance patient outcomes.

Furthermore, advancements in nanodiagnostics systems are enabling early detection, real-time monitoring of therapy, and personalized treatment strategies. Despite challenges related to biocompatibility, long-term toxicity, regulatory pathways, and large-scale manufacturing, current evidence strongly suggests that nanotechnology has the potential to revolutionize hematological cancer management. Continued research, technological refinement, and clinical evaluation will be essential to translate these promising laboratory findings into reliable and effective clinical interventions for blood cancer patients.

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