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Recent Breakthroughs in Diagnosis and Treatment in Internal Medicine

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Abstract

Recent advancements in internal medicine have transformed diagnostic and therapeutic approaches, necessitating a comprehensive review to consolidate these developments and their clinical implications. This review addresses the growing need for updated insights into precision medicine, innovative technologies, and personalized treatment strategies that are reshaping patient care. By synthesizing current research, it aims to bridge gaps between emerging innovations and their practical application in clinical settings. Furthermore, it highlights the urgency of addressing challenges such as accessibility, standardization, and ethical considerations to ensure equitable healthcare progress. The review offers critical insights into breakthroughs such as next-generation sequencing (NGS) for lymphoma classification, artificial intelligence (AI) driven diagnostics in emergency medicine, and targeted drug delivery systems for overcoming chemotherapy resistance. It explores the role of nuclear medicine and molecular imaging in enhancing diagnostic accuracy, as well as microneedle technology for minimally invasive cancer therapy. Advances in acute heart failure management and microRNA-based glioblastoma treatments are examined, emphasizing their potential to improve patient outcomes. Additionally, the review discusses the integration of biomarker-driven therapies and hybrid imaging techniques, underscoring their impact on personalized medicine. The analysis also highlights the limitations of current technologies, including high costs and regulatory hurdles, while proposing strategies for optimization. By evaluating both successes and challenges, this review provides a balanced perspective on the evolving landscape of internal medicine. Future research should focus on refining emerging technologies, such as AI and nanotechnology, to enhance their clinical applicability and affordability. Large-scale, multicenter studies are needed to validate the long-term efficacy and safety of novel therapies like microRNA modulation and theranostics. Finally, fostering interdisciplinary collaboration and global healthcare partnerships will be essential to translate these innovations into widespread clinical practice, ensuring they benefit diverse patient populations.

Keywords: Artificial intelligence, Biomarkers, Drug delivery systems, Internal medicine, Microneedles, Next-generation sequencing, Nuclear medicine, Personalized medicine

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Introduction

Recent advances in diagnosis and treatment within internal medicine have been marked by significant developments across various disease areas, as reflected in recent literature [1-5]. One notable area of progress is the management of acute heart failure, where updated consensus guidelines emphasize comprehensive approaches to diagnosis and treatment [6-10]. Delgado et al. [11] highlights the necessity of integrating recent clinical insights to improve patient outcomes, updating previous guidelines to incorporate novel diagnostic and therapeutic strategies. In the realm of diagnostic innovations, nuclear medicine has emerged as a pivotal field influencing disease detection and personalized treatment planning [12-15]. Yoo et al. [16] discussed how advancements in molecular imaging and the integration of AI are transforming nuclear medicine, enabling more precise diagnosis and tailored interventions across multiple medical disciplines.

Biomolecular diagnostic tools have also seen breakthroughs, particularly with the development of antibody nanoconjugates [17-20]. Kadkhoda et al. [21] review recent trends in antibody nanoconjugates, emphasizing their potential in enhancing diagnostic accuracy and therapeutic efficacy, which could be particularly impactful in internal medicine applications. Furthermore, the understanding and management of sarcopenia, especially in patients with hip fractures, have benefited from recent consensus on diagnostic criteria and treatment approaches [22-24]. Yoo et al. [16] underscore the importance of early diagnosis and targeted management strategies, which are crucial for improving functional recovery in affected patients.

Advances in biomedical materials, such as polymers, are also contributing to internal medicine by enabling the development of innovative therapeutic devices and drug delivery systems [25-28]. Chen et al. [29] summarize progress in biomedical polymers, highlighting their role in creating more effective and biocompatible treatment modalities. Cancer treatment has seen notable breakthroughs,

particularly in overcoming chemotherapy resistance. Davodabadi et al. [30] discussed recent targeted drug delivery systems that address resistance mechanisms, offering hope for more effective therapies in oncology, which are increasingly relevant to internal medicine practitioners managing complex cases. Additionally, Ganeson et al. [31] explore microneedle technology, which facilitates minimally invasive and self-administered drug delivery, representing a significant step forward in patient-centered cancer therapy.

In hematology, the prognosis of multiple myeloma has improved markedly with the introduction of new pharmacological agents [32-35]. Ruff et al. [36] reports that recent drug developments have nearly doubled median survival times, underscoring the rapid progress in therapeutic options for hematologic malignancies within internal medicine. Finally, the diagnosis and management of vasculitis, such as anti-neutrophil cytoplasmic antibodies-associated vasculitis, have been refined through the development of comprehensive guidelines. Holle et al. [37] emphasizes the importance of prompt diagnosis and tailored treatment strategies, which are critical for improving patient outcomes in complex autoimmune conditions. Overall, these recent studies collectively demonstrate a trend toward more precise, personalized, and effective diagnostic and therapeutic approaches in internal medicine, driven by technological innovations, molecular insights, and updated clinical guidelines.

The field of internal medicine has witnessed remarkable advances in recent years, particularly in the areas of diagnosis and treatment. These breakthroughs are largely driven by technological innovations, improved understanding of disease mechanisms, and the integration of personalized medicine approaches [38-40]. This review explores some of the most significant recent developments in internal medicine, highlighting their implications for patient care.

NGS in Lymphomas

NGS has revolutionized the diagnosis and treatment of lymphomas, particularly non-Hodgkin's lymphoma [41]. Recent studies have demonstrated that NGS can identify genomic biomarkers that facilitate better subclassification and more accurate diagnoses of B-cell and T-cell lymphomas [42-45]. This technology not only aids in prognostic assessment but also uncovers recurrent somatic mutations that may serve as novel therapeutic targets or indicate drug resistance. The application of NGS in liquid biopsies allows for minimally invasive diagnosis and real-time monitoring of patients, enabling early detection of relapses and the possibility of response-adapted therapies. As such, NGS is poised to become a standard component of the diagnostic workup for lymphoma patients, paving the way for precision medicine in oncology [46].

A study by Breinholt et al. [47] on NGS in B-cell non-Hodgkin's lymphoma diagnostics reported mutations in a high percentage of the samples analyzed. Specifically, mutations were detected in 94% of the 298 samples included in the study. Most of the lymphomas could be definitively classified using the implemented NGS analysis. However, a subset of 24 cases was initially classified as small B-cell lymphomas without clear defining characteristics. For the 24 cases that lacked defining characteristics, the mutational findings provided significant retrospective diagnostic value. 50% of these cases (12 out of 24) could subsequently be assigned a likely diagnostic subtype based on their mutational profiles. The study demonstrated that integrating a 59-gene exome sequencing panel into routine diagnostics led to a high rate of mutation detection, aided in the definitive classification of most lymphomas, and notably helped in retrospectively subtyping half of the initially unclassified cases.

A study by Albitar et al. [48] demonstrated the effectiveness of combining NGS quantification of RNA from 30 CD markers with machine learning for the diagnosis and classification of various lymphoma types. Machine learning algorithms, specifically Random Forest, showed remarkable sensitivity and specificity in diagnosing most lymphoma subclasses. An area under the curve (AUC) of 1.00 was achieved for several diagnostic distinctions, indicating perfect classification. These included: DLBCL vs T-cell lymphoma, Hodgkin vs T-cell lymphoma, Hodgkin vs diffuses large B-cell lymphoma, Mantle cell lymphoma vs diffuses large B-cell lymphoma, and Follicular lymphoma vs marginal zone lymphoma. For these pairings, the sensitivity and specificity in the testing set were both 100%. Marginal lymphoma vs mantle cell lymphoma: AUC of 0.974 (95% confidence interval (CI): 0.920 to 1.000) with 88% sensitivity and 100% specificity. Follicular lymphoma vs diffuses large B-cell lymphoma: AUC of 0.887 (95% CI: 0.776-0.999) with 81.3% sensitivity and 83.7% specificity. The data confirms that NGS quantification of RNA from 30 CD markers, when combined with machine learning, is sufficient for reliable classification of various lymphoma types. This approach can provide valuable information for distinguishing between challenging diagnoses. Technology has the potential to be automated, making it less susceptible to human errors. RNA quantification using NGS could potentially replace immunohistochemistry and be applied when sample amounts are limited, such as in needle aspiration or core biopsies. In summary, the study successfully demonstrated that a machine learning approach using RNA quantification of CD markers via NGS offers a highly accurate and potentially more efficient alternative to traditional immunohistochemistry for lymphoma diagnosis and classification, especially in cases with limited tissue samples.

A study by Wu et al. [49] found a significant correlation between the genetic variation of ctDNA in the plasma and clinical indices in lymphoma. Clear genetic heterogeneity was observed in the ctDNAs from different lymphoma subtypes, including Hodgkin's lymphoma, germinal center B-cell–like lymphoma, non-germinal center B-cell–like lymphoma, and marginal zone lymphoma. This finding confirms that distinct molecular mechanisms are involved in the pathogenesis of different lymphomas. These findings suggest that NGS-based ctDNA mutation analysis can reveal genetic heterogeneity across lymphoma subtypes. This has potential implications for discovering therapeutic targets, exploring genomic evolution, and developing risk-adaptive therapies. In summary, the research highlights the utility of ctDNA analysis via NGS in understanding the genetic landscape of lymphoma, its correlation with clinical parameters, and its potential to guide future therapeutic strategies.

In conclusion, NGS is a transformative tool in the field of lymphoma diagnostics and treatment. By providing comprehensive genetic insights, NGS facilitates precise diagnosis, prognostication, and the development of personalized therapies. However, the full potential of this technology can only be realized by overcoming existing challenges related to its implementation and accessibility.

Advancements in Acute Heart Failure Management

The management of acute heart failure has also seen significant advancements, as highlighted by a recent consensus document from leading Spanish and European medical societies [50-52]. This document updates the previous guidelines and incorporates new pharmacological treatments, emphasizing early and intermittent treatment strategies. The comprehensive approach outlined in the consensus aims to improve the diagnosis, treatment, and overall management of acute

heart failure, reflecting the evolving understanding of this complex condition [11].

The primary focus [53] of current therapies for acute decompensated heart failure is to rapidly alleviate symptoms such as dyspnea and peripheral edema, and to achieve patient decongestion. Intravenous diuretics are recommended for volume removal and decongestion in patients with significant volume overload. Concomitant use of intravenous vasodilators (e.g., nitroprusside, nitroglycerin, and nesiritide) can aid decongestion and improve symptoms in patients who do not exhibit hypotension. For patients with reduced ejection fraction and signs of decreased perfusion or hemodynamic compromise, intravenous inotropes may be used to enhance and sustain cardiac output and end-organ perfusion. Despite significant advancements in understanding the complex pathophysiology of heart failure and the development of medical therapies that have improved outcomes for chronic stable heart failure, the management strategies and therapies for acute decompensated heart failure have shown little change over time. A critical finding is that none of the current mainstay therapies for acute decompensated heart failure have been demonstrated to improve morbidity and mortality; in fact, they may potentially increase them. The overall mortality rate for heart failure remains high, with 50% mortality at 5 years. Hospitalizations for acute decompensated heart failure are a substantial burden on the healthcare system, and even with medical therapy advancements, the 30-day readmission rate for acute decompensated heart failure is 25%. In summary, while current acute decompensated heart failure therapies effectively manage acute symptoms like dyspnea and edema, they have not been shown to improve long-term morbidity or mortality, and readmission rates remain high, highlighting a significant unmet need for novel therapeutic approaches.

Review by Gouda and Ezekowitz [54] highlights advances in the diagnosis and management of acute heart failure based on recent clinical trials and observational studies. Despite these advancements, the paper concludes that there is currently insufficient evidence to recommend changes to the existing standards of care. The paper examines the use of novel biomarkers for acute heart failure diagnosis. These biomarkers include micro RNAs, osteopontin, and insulin-like growth-factor binding protein-7. Evidence for several novel pharmacological therapies is summarized. These therapies include: serelaxin, ularitide, clevidipine, urocortins, BMS-986231, TRB027, vericiguat, omecamtiv, and torsemide. The review also explores evidence supporting the use of novel management algorithms. In summary, while there have been advances in understanding the pathophysiology of acute heart failure and new diagnostic tools and therapies have been investigated, the current evidence does not yet support a shift from established standards of care.

A study by Velez [55] reported dapagliflozin and empagliflozin have been shown to reduce the risk of heart failure hospitalization and cardiovascular death. This benefit applies to heart failure patients regardless of their left ventricular ejection fraction or diabetes status. SGLT2i are now considered the fourth pillar of heart failure medical therapy, alongside sacubitril-valsartan, evidence-based beta-blockers, and mineralocorticoid receptor antagonists. They are recommended for all symptomatic patients across the full spectrum of heart failure phenotypes, including those hospitalized with heart failure. The precise mechanism of action for SGLT2i in heart failure is not yet fully defined. Vericiguat, which stimulates guanylate cyclase, and omecamtiv mecarbil, a cardiac myotrope, have demonstrated benefits in patients with heart failure with reduced ejection fraction. Vericiguat is particularly beneficial for high-risk patients who have a worsening heart failure clinical profile. Rapid up-titration of guideline-directed medical therapy in patients hospitalized with heart failure has been found to be safe and leads to improved clinical outcomes. Most patients hospitalized with heart failure can achieve high doses of guideline-directed medical therapy within weeks, and this approach reduces the likelihood of adverse heart failure outcomes. In summary, recent advances in heart failure management highlight the significant role of SGLT2i as a foundational therapy, the specific benefits of vericiguat and omecamtiv mecarbil for heart failure with reduced ejection fraction, and the positive impact of rapidly escalating guideline-directed medical therapy in hospitalized patients.

Despite these advancements, several challenges remain in the management of acute heart failure. The high in-hospital mortality and post-discharge readmission rates underscore the need for continued research and innovation. The lack of adequately conducted trials to establish evidence-based strategies for targeted decongestive therapy and the optimal timing for guideline-directed medical therapy initiation are areas requiring further investigation [53, 56]. Additionally, the integration of novel therapies into clinical practice and the development of personalized treatment plans based on patient-specific characteristics are critical for improving acute heart failure outcomes [57, 58].

Nuclear Medicine and Molecular Imaging

Nuclear medicine has emerged as a pivotal field in the diagnosis and treatment of various diseases, including malignancies and neurological disorders [59-61]. The development of hybrid imaging technologies, such as positron emission tomography–computed tomography (PET-CT) and single photon emission computed tomography–computed tomography (SPECT-CT), has significantly enhanced diagnostic accuracy [62-64]. Furthermore, the advent of theranostics-a treatment approach that combines therapy and diagnostics-marks a significant breakthrough in personalized medicine. These innovations not only improve patient outcomes but also reduce radiation exposure, making nuclear medicine a cornerstone of modern diagnostic and therapeutic strategies [65].

A case report by Stephens et al. [66] details the successful treatment of a 57-year-old African American man diagnosed with pancreatic neuroendocrine tumors. The patient's condition significantly improved following a specific treatment regimen. PET imaging, utilizing gallium Ga 68 dotatate, was employed to precisely locate the tumors. Selected tumors were treated with lutetium Lu 177 dotatate. The patient received four doses, each of 200 mCi. This treatment was administered over an 8-month period. The patient transitioned from being bedbound to ambulatory. His mental state improved from confusion to coherence. The patient reported experiencing no adverse effects from the treatment. The case study highlights the effectiveness of combining Ga 68-labeled PET imaging with lutetium Lu 177 dotatate treatment for pancreatic neuroendocrine tumors. While this treatment is not considered a cure, it has demonstrated the ability to enhance a patient's quality of life. In summary, the paper presents a positive outcome for a patient with pancreatic neuroendocrine tumors, showcasing significant improvements in mobility and cognitive function with no reported side effects, underscoring the efficacy of the described nuclear medicine approach.

A study by Paquette et al. [67] reported phase II clinical trial (NCT04824014) investigating the novel estrogen receptor PET radiotracer 18F-4FMFES in estrogen receptor-positive breast cancer patients yielded several significant results when compared to 16α-18F-

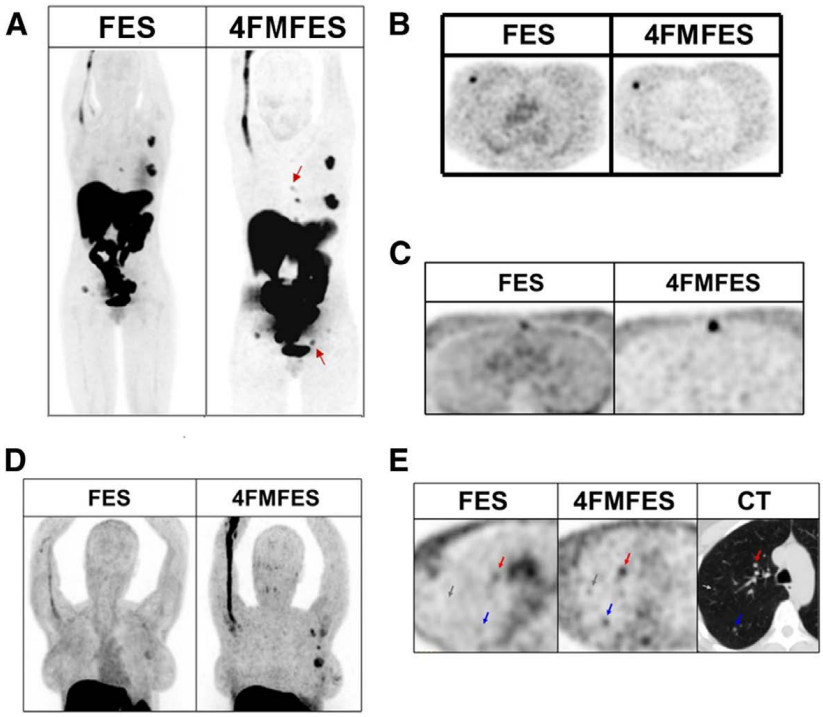

Figure 1: Comparative PET Imaging with ^{18}F-FES and ^{18}F-4FMFES. **(A)** Whole-body maximum-intensity-projection PET scans from a patient initially classified as T1cN2M0, where ^{18}F-FES PET identified previously undetected metastases in the sternum and iliac bone. **(B)** A representative transaxial view of the primary tumor. **(C)** A transaxial section highlighting sternal metastasis. **(D)** Thoracic maximum-intensity-projection images from a patient with suspected post-resection recurrence. **(E)** Side-by-side transaxial PET slices comparing ^{18}F-FES and ^{18}F-4FMFES in assessing pulmonary metastatic disease. Corresponding CT imaging confirmed the presence of three small tumors, measuring 5 mm (red arrow), 4 mm (blue arrow), and 2 mm (gray arrow) [67].

fluoroestradiol (^{18}F-FES) (Figure 1). Analysis of blood metabolites 60 min after tracer injection demonstrated that ^{18}F-4FMFES exhibited a 2.5-fold increase in metabolic stability compared to ^{18}F-FES. While the maximum standardized uptake value for most tumor foci was similar between ^{18}F-4FMFES PET and ^{18}F-FES PET, ^{18}F-4FMFES consistently showed substantially improved tumor contrast in all cases. Lower uptake was observed in nonspecific tissues with ^{18}F-4FMFES, notably a four-fold decrease in blood-pool activity compared to ^{18}F-FES. Consequently, image quality was considerably enhanced when using ^{18}F-4FMFES due to lower overall background activity. As a direct result of the improved image quality and reduced background, ^{18}F-4FMFES successfully identified nine more lesions than ^{18}F-FES. In summary, the study concluded that ^{18}F-4FMFES PET offers a lower nonspecific signal and better tumor contrast than ^{18}F-FES PET, leading to improved diagnostic confidence and a reduction in false-negative diagnoses in estrogen receptor-positive breast cancer patients.

A study on [^{18}F]AlF-RESCA-MIRC213 (NCT05622240), an ^{18}F-labeled nanobody for imaging human epidermal growth factor receptor 2 (HER2)-positive cancers, yielded several significant results regarding its preparation, *in-vitro* and *in-vivo* characteristics, and first-in-human evaluation. [^{18}F]AlF-RESCA-MIRC213 was successfully prepared at room temperature within 20 min. The radiochemical yield was 50.48 ± 7.6%, and its radiochemical purity exceeded 98% (n > 10). In NCI-N87 cells, the 2-hour cellular uptake of [^{18}F]AlF-RESCA-MIRC213 was measured at 11.22 ± 0.60 %IA/10^5 cells. The binding affinity (Kd value) was determined to be 1.23 ± 0.58 nM using SK-OV-3 cells. Xenografted SK-OV-3 tumors were readily detected by [^{18}F] AlF-RESCA-MIRC213 PET 2 h post-injection, showing a maximum standardized uptake value of 4.73 ± 1.18 ID%/g. This was significantly higher than the blocking group's maximum standardized uptake value of 1.70 ± 0.13 ID%/g ($p < 0.05$). No significant radioactivity accumulation was observed in the bone of tumor-bearing animals. No adverse reactions were reported in any of the six breast cancer patients included in the study. The uptake of [^{18}F]AlF-RESCA-MIRC213 was primarily observed in the lacrimal gland, parotid gland, submandibular gland, thyroid gland, gallbladder, kidneys, liver, and intestine. Consistent with preclinical findings, no significant radioactivity accumulation was noted in the bone of cancer patients. At 2 h post-injection, [^{18}F]AlF-RESCA-MIRC213 showed significantly higher tumor uptake in HER2-positive lesions (maximum standardized uptake value of 3.62 ± 1.56) compared to HER2-negative lesions (maximum standardized uptake value of 1.41 ± 0.41), with a p-value of 0.0012. The kidneys received the highest radiation dose at 2.17 x 10^{-2} mGy/MBq, and the effective dose was calculated to be 1.76 x 10^{-2} mSv/MBq. In summary, the study demonstrated that [^{18}F]AlF-RESCA-MIRC213 can be efficiently prepared under mild conditions and exhibits high stability both *in vitro* and *in vivo*. The clinical results suggest it is a safe radiotracer with favorable pharmacokinetics and dosimetry, showing promise for non-invasive diagnosis of HER2-positive cancers due to its selective and high tumor uptake.

While the advancements in nuclear medicine and molecular imaging have significantly enhanced the design and execution of randomized controlled trials, challenges remain. The need for standardization across imaging techniques and trial sites is critical to ensure consistency and reliability of results. Additionally, the high cost and complexity of these advanced imaging modalities may limit their widespread adoption in clinical trials. Nonetheless, ongoing research and development efforts continue to push the boundaries of what is possible in nuclear medicine, promising even greater contributions to personalized medicine and improved patient outcomes in the future

[68].

MicroRNAs in Glioblastoma Treatment

In the realm of oncology, microRNAs (miRNAs) have gained attention for their role in glioblastoma multiforme [69-71]. Research indicates that miRNAs are crucial in regulating cellular processes and may serve as biomarkers for diagnosis and prognosis. Understanding the expression patterns of specific miRNAs could lead to the development of targeted therapies, offering new hope for patients with this aggressive form of brain cancer [69]. The miRNA profile in glioblastoma can indicate the disease stage and facilitate prognosis and therapy selection. Specific miRNAs with the highest prognostic value for glioblastoma have been identified, and their analysis in blood and cerebrospinal fluid can aid in diagnosis. Glioblastoma-specific miRNAs have diverse functions, acting as oncogenes or tumor suppressors [72-74]. They are involved in developing resistance to chemotherapy and radiotherapy, stimulating neo-angiogenesis and cell proliferation, and regulating the cell cycle and apoptosis. Several miRNAs are up-regulated in glioblastoma and function as oncogenic miRNAs. Examples include miR-21, miR-93, miR-10b, miR-196a, miR-221/222, and miR-182. Overexpression of these miRNAs is often associated with aggressive tumor characteristics and poor patient survival. Conversely, other miRNAs are downregulated in glioblastoma and act as tumor suppressors. These include miR-7, miR-128, miR-124/137, miR-101, miR-181, miR-146a, and miR-34a. Reduced expression of these miRNAs contributes to tumor progression by failing to inhibit cell proliferation, promote apoptosis, or regulate other cancer-related pathways [72-74].

A study by McDonald et al. [75] focused on identifying effective microRNAs for glioblastoma treatment and developing an improved delivery system. A stepwise screen successfully identified miR-124-2, miR-135a-2, and let-7i as the most effective miRs across all glioblastoma subtypes. These miRs also demonstrated clinical relevance. Delivery of engineered exosomes containing a polycistronic plasmid (eExos + pPolymiR) resulted in high expression of all three identified miRs in glioma stem cells. *In vitro*, eExos + pPolymiR significantly decreased the proliferation of glioma stem cells. When tested in glioma stem cells-bearing mice, eExos + pPolymiR prolonged survival more effectively than eExos carrying individual miRs or a cocktail of miRs. In summary, the research successfully identified a potent combination of anti-glioblastoma miRs and developed an innovative exosome-based delivery platform that significantly improved therapeutic outcomes both *in vitro* and *in vivo*.

Another study by Grafals-Ruiz et al. [76] investigated the role of miR-92b in glioblastoma and identified its direct target gene, F-box and WD repeat domain containing 7 (FBXW7), highlighting miR-92b's potential as a therapeutic target. miR-92b was found to be significantly upregulated in glioblastoma tumors when compared to normal brain tissue samples. Suppressed glioblastoma cell growth and migration, and induced apoptosis. This was achieved using oligonucleotide microRNA inhibitors. Produced effects opposite to its inhibition, suggesting its role in promoting glioblastoma progression. Systemic administration of liposomal-miR92b-OMIs in a glioblastoma xenograft mouse model led to reductions in tumor volume and weight. FBXW7 was identified as a direct target gene of miR-92b in glioblastoma cells. FBXW7 is recognized as a tumor suppressor gene in various cancer types. Analysis of patient data revealed that glioblastoma patients with higher FBXW7 mRNA levels exhibited significantly better overall survival compared to those with lower levels. In summary, the dysregulated expression of miR-92b in glioblastoma contributes to tumor progression by directly targeting the tumor suppressor gene FBXW7. These findings underscore the potential of miR-92b as a promising therapeutic target for improving treatment outcomes in glioblastoma patients.

While miRNAs offer promising avenues for improving glioblastoma treatment, their clinical application is still in the early stages. The development of effective delivery systems and a deeper understanding of miRNA interactions are crucial for translating these findings into clinical practice. As research progresses, miRNAs may become integral components of personalized glioblastoma therapies, potentially improving patient outcomes and survival rates.

Microneedles for Cancer Therapy

Microneedles represent an innovative approach to drug delivery in cancer therapy (Table 1). These tiny, painless needles allow for transdermal administration of therapeutics, enhancing patient compliance and reducing side effects associated with conventional delivery methods. The potential of microneedles to improve the efficacy of cancer treatments while minimizing discomfort underscores their promise as a breakthrough technology in oncology [31].

A study by Lim et al. [80] investigated the efficacy of microneedle-guided lymphatic delivery of SKKU-06, a natural immune modulator toxin, for enhanced cancer immunotherapy. The key results highlight their potential in modulating the tumor microenvironment and improving anti-tumor immunity. The dissolving microneedle guided delivery of SKKU-06 to skin tumors and tumor-draining lymph nodes effectively induced immunogenic cell death. This delivery method stimulated the activation and maturation of antigen-presenting cells. The combined effects of immunogenic cell death and antigen-presenting cells stimulation promoted the development of both humoral and cellular anti-tumor immunity. The immunomodulatory effects of SKKU-06@dissolving microneedles were significantly enhanced when combined with anti-programmed cell death protein-1 (PD-1) treatment. This combination therapy led to an increased infiltration of CD8+ T cells within the tumor. Concurrently, the treatment resulted in a reduction of reduced regulatory T cell populations in the tumor microenvironment. These changes in the tumor microenvironment contributed to efficient growth inhibition of established skin cancer and metastatic cancer. The treatment also led to prolonged survival of the subjects. In summary, the study demonstrates that microneedle-guided lymphatic delivery of SKKU-06 is a promising strategy for

Table 1: Details of few clinical trials for application of microneedles in cancer therapy.

NCT identifier	Study title	Samples studied	Conditions
NCT04928222 [77]	Placebo microneedles in healthy volunteers (part I) and efficacy/safety of doxorubicin microneedles in basal cell cancer subjects (part II)	Microneedles with placebo and doxorubicin loaded microneedle	Basal cell carcinoma
NCT02192021 [78]	Microneedles array-doxorubicin in patients with cutaneous T-cell lymphoma	Doxorubicin loaded microneedle	Cutaneous T cell lymphoma
NCT03646188 [79]	Open-label dose escalation trial to evaluate dose-limiting toxicity and maximum tolerated dose of microneedles arrays containing doxorubicin in basal cell carcinoma	Microneedles with placebo and 25 µg, 50 µg, 100 µg, 200 µg of doxorubicin containing microneedle	Basal cell carcinoma

cancer immunotherapy. It effectively induces immune responses, modulates the tumor microenvironment, and shows enhanced efficacy when combined with checkpoint blockade, leading to significant tumor regression and improved survival.

A study by Lan et al. [81] successfully developed a microneedle patch loaded with pH-responsive tumor-targeted lipid nanoparticles containing anti-PD-1 and cisplatin (CDDP) for synergistic cancer immuno-chemotherapy. The results demonstrate the efficacy and safety of this novel transdermal delivery approach for cancer treatment, particularly for immunotherapy-unresponsive cancers. The anti-PD-1/CDDP@nanoparticles were synthesized using a reverse-phase microemulsion method, exhibiting a spherical morphology with an average diameter of approximately 57.6 nm. The encapsulation efficiency of anti-PD-1 was 50%, and the nanoparticles showed sustained release of platinum (from CDDP) for 72 h, with higher anti-PD-1dissociation in acidic environment. These nanoparticles facilitated the synergistic delivery of both chemotherapeutic and immunotherapeutic agents. The anti-PD-1/CDDP@nanoparticles demonstrated significantly lower half-maximal inhibitory concentration values and higher cellular uptake in cancer cell lines (FaDu, CAL 27, and SCC VII) compared to free CDDP. This indicates that lipid coating and nano-encapsulation improved drug efficiency. The nanoparticles significantly triggered apoptosis in cancer cell lines, with anti-PD-1/CDDP@nanoparticles inducing 24.5% cell apoptosis compared to only 2.79% by free CDDP. Cell cycle analysis also showed a remarkable decrease in the G2 phase, indicating lower cell growth. In an immunocompetent murine tumor homograft model, the anti-PD-1/CDDP@nanoparticles microneedle group showed the most notable tumor regression effect compared to all other groups, including systemic anti-PD-1 and anti-PD-1 + CDDP combinations. The tumor volume and weight were significantly decreased in the microneedle treated groups. Microneedle mediated delivery of anti-PD-1 significantly reduced tumor volume compared to systemic anti-PD-1 injection, even in animal models unresponsive to systemic anti-PD-1 therapy. This was attributed to the microneedles' ability to induce immune responses by activating T-cells. CDDP inhibited cell proliferation, and anti-PD-1 enhanced T-cell infiltration. The anti-PD-1 microneedle and anti-PD-1/CDDP@nanoparticles microneedle groups showed significantly higher cell apoptotic indexes (61.4% and 73.2%, respectively) compared to the anti-PD-1 group (5.4%). Microneedle mediated anti-PD-1/CDDP@nanoparticles led to the highest T-cell infiltration (75.95% of CD8+ T-cells) among all groups. The anti-PD-1/CDDP@nanoparticles microneedle group also showed the highest IFN-γ expression, and a remarkable decrease in regulatory T-cells was observed in microneedle treated groups. Unlike CDDP, which caused severe body weight loss and elevated blood urea nitrogen levels, mice treated with microneedles showed no body weight loss, and their blood urea nitrogen values remained within the normal range, indicating a safe delivery system without nephrotoxicity. Histological analysis showed that CDDP caused liver and kidney damage, but nano-encapsulation and microneedle mediated delivery significantly reduced this toxicity. The anti-PD-1/CDDP@nanoparticles microneedle groups exhibited generally normal organ structures, comparable to the control group, demonstrating that transdermal delivery via microneedles is a safe solution for cancer therapy. In summary, the study successfully demonstrated that microneedle-mediated local delivery of nano-encapsulated chemotherapeutic and immunotherapeutic agents at tumor skin sites is a promising novel treatment strategy. This approach effectively boosts immune responses, enhances tumor regression, and significantly reduces systemic toxicity compared to conventional methods, offering a potential solution for immunotherapy-unresponsive cancers.

While microneedles present a promising advancement in cancer therapy, it is important to consider the broader context of cancer treatment. Traditional methods, despite their limitations, have been the cornerstone of cancer management for decades. The integration of microneedles into existing treatment protocols requires careful consideration of their compatibility and potential interactions with other therapies [82-84]. Additionally, the regulatory landscape for new medical technologies can pose challenges for the widespread adoption of microneedles. Nonetheless, the ongoing research and development in this field hold the potential to significantly enhance the effectiveness and accessibility of cancer treatments.

Targeted Drug Delivery in Cancer Treatment

Targeted drug delivery systems, particularly those utilizing nanoparticles, have emerged as a critical advancement in overcoming chemotherapy resistance [85, 86]. These systems enhance the concentration of therapeutic agents at tumor sites while minimizing systemic exposure and side effects. The ongoing research in this area aims to refine these technologies, making them more effective and safer for patients undergoing cancer treatment [8]. A study by Rittberg et al. [87] analyzed the feasibility of conducting randomized controlled trials for cancer drugs approved by the Food and Drug Administration (FDA) based on single-arm studies between 2010 and 2019 (Table 2). Out of 172 approvals during the study period, 31 (18.0%) were based on single-arm studies. The majority of these single-arm studies-based approvals, 77.4%, were granted through the accelerated approval pathway. The median sample size for these single-arm studies was 104, with a range from 23 to 411. All studies (100%) reported overall response rate. 55% reported duration of response. 19.4% reported progression-free survival. 22.5% reported overall survival. It was theoretically possible to conduct randomized controlled trials within a duration comparable to that required by single-arm studies for a significant proportion of approvals: (i) 84.6% for overall response rate endpoints, (ii) 94.1% for progression-free survival endpoints, and 80.0% for overall survival endpoints. In conclusion, the study found that an overwhelming majority of FDA approvals based on single-arm studies could have been feasible as randomized controlled trials within a reasonable timeframe, suggesting that drug approval based on single-arm studies should be reserved for exceptional circumstances due to potential harms to patients and scientific rigor.

While targeted drug delivery systems offer significant advantages over traditional chemotherapy, they are not without challenges. The complexity of cancer biology, including tumor heterogeneity and the tumor microenvironment, poses significant hurdles to the effective implementation of these therapies [88, 89]. Moreover, the transition from laboratory research to clinical application is fraught with difficulties, including regulatory hurdles and the need for extensive clinical testing. Despite these challenges, the potential of targeted drug delivery to revolutionize cancer treatment remains substantial, warranting continued research and development in this promising field.

AI in Emergency Medicine

The integration of AI into emergency medicine has shown promising results, particularly in diagnostic accuracy. Recent studies demonstrated that AI models, such as ChatGPT, outperformed resident physicians in diagnosing internal medicine emergencies [90, 91]. This highlights the potential of AI as a supportive tool in clinical

Table 2: Single-arm studies approved by FDA.

Drug	Indication	Line of therapy	Single arm study sample size	Overall response rate (%)	Accelerated approval
Trastuzumab deruxtecan	Metastatic breast cancer, HER2 positive	3rd or later	184	60.3	Yes
Enfortumab vedotin-ejfv	Metastatic urothelial cancer	2nd or later	125	44	Yes
Niraparib	Ovarian, fallopian tube or primary peritoneal cancer, with homologous recombination deficiency	3rd or later	98	24	No
Pembrolizumab plus lenvatinib	Advanced endometrial cancer, not microsatellite instability-high or deficient mismatch repair	2nd or later	108	38.3	Yes
Entrectinib	Metastatic neutropenic tyrosine receptor kinase solid tumors	2nd or later	54	57	Yes
Entrectinib	Metastatic non-small cell lung cancer, ROS proto-oncogene 1 positive	2nd or later	51	78	Yes
Pembrolizumab	Metastatic small cell lung cancer	3rd or later	83	19	Yes
Erdafitinib	Metastatic urothelial cancer, susceptible fibroblast growth factor receptor 3 or fibroblast growth factor receptor 2 genetic alterations	2nd or later	87	32.2	Yes
Pembrolizumab	Advanced Merkel cell carcinoma	1st	50	56	Yes
Larotrectinib	Metastatic neutropenic tyrosine receptor kinase solid tumors	2nd or later	55	75	Yes
Pembrolizumab	Hepatocellular carcinoma	2nd or later	104	17	Yes
Iobenguane I 131	Advanced pheochromocytoma or paraganglioma	1st or later	68	22	No
Pembrolizumab	Advanced cervical cancer, high PD-L1	2nd or later	98	14.3	No
Dabrafenib plus trametinib	Metastatic anaplastic thyroid cancer with BRAF V600E mutation	1st or later	23	61	No
Nivolumab	Metastatic colorectal cancer with microsatellite instability-high or deficient mismatch repair	2nd or later	74	32	Yes
Pembrolizumab	Metastatic colorectal cancer with microsatellite instability-high or deficient mismatch repair	2nd or later	149	39.6	Yes
Avelumab	Metastatic urothelial carcinoma	2nd or later	242	13.3	Yes
Durvalumab	Metastatic urothelial carcinoma	2nd or later	191	17	Yes
Avelumab	Metastatic Merkel cell carcinoma	2nd or later	88	32	Yes
Nivolumab	Metastatic urothelial carcinoma	2nd or later	270	19.6	Yes

decision-making, potentially transforming the landscape of emergency care [90].

A study by Lin et al. [92] evaluated the effectiveness of an AI-enabled electrocardiogram system in identifying high-risk patients and reducing mortality. Data from 15,965 patients were included in the analysis, with 8,001 patients in the intervention group and 7,964 in the control group. The mean age of the patients was 61 ± 18 years. The intervention group demonstrated a significantly reduced cumulative proportion of death compared to the control group. The mortality rate was 3.6% in the intervention group versus 4.3% in the control group, corresponding to a hazard ratio (HR) of 0.83 (95% CI: 0.70 to 0.99). The AI-electrocardiogram system identified 709 high-risk cases in the intervention group and 688 in the control group. For these high-risk patients, the intervention led to a 31% reduction in mortality. The mortality rate was 16.0% in the intervention arm compared to 23.0% in the control arm (HR: 0.69, 95% CI: 0.53 to 0.90; p for interaction = 0.026). The intervention group with high-risk electrocardiograms received more intensive care. These patients also received more arrhythmia interventions, echocardiographic examinations, and electrolyte examinations. These changes contributed to a significant reduction in cardiac death, with a rate of 0.2% in the intervention arm versus 2.4% in the control arm (HR: 0.07, 95% CI: 0.01 to 0.56). In summary, the AI-electrocardiogram system proved effective in identifying high-risk patients, leading to targeted intensive care and interventions, which ultimately resulted in a significant reduction in both all-cause mortality and cardiac-specific mortality.

Another study by Hwang et al. [93] aimed to compare the accuracy of chest radiograph interpretation assisted by AI-based computer-aided detection against conventional interpretation in emergency department patients presenting with acute respiratory symptoms (Figure 2). The primary and secondary outcomes were sensitivity and false-positive rates of chest radiograph interpretation by trainee radiologists for identifying acute thoracic diseases. The sensitivity of chest radiograph interpretation was not significantly associated with

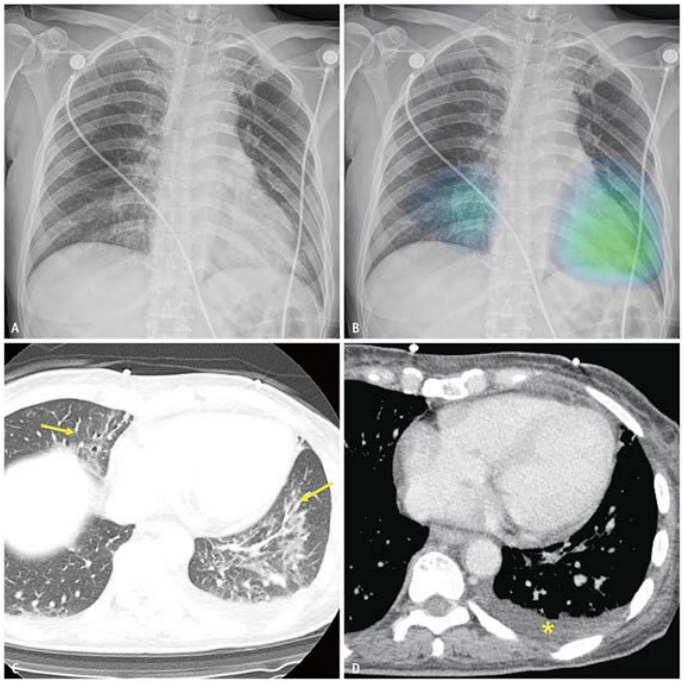

Figure 2: Case presentation: A 62-year-old woman presented to the emergency department with fever. **(A)** Initial chest radiograph demonstrated subtle, ill-defined opacities in both lower lung zones. **(B)** AI-based computer-aided detection flagged these findings with a 52% probability score, though the interpreting radiologist dismissed the AI results and reported no acute thoracic pathology. **(C-D)** Same-day emergency department computer tomography revealed patchy ground-glass opacities in the right middle lobe and left lower lobe (arrows, C), and minimal left pleural effusion (asterisk, D) [90].

the use of AI-computer-aided detection. In the intervention group (with AI assistance), sensitivity was 67.2% (317/472). In the control group (without AI assistance), sensitivity was 66.0% (324/491). The odds ratio was 1.02 (95% CI: 0.70 to 1.49), with a p-value of 0.917, indicating no statistically significant difference. The false-positive rate of chest radiograph interpretation also showed no association with the use of AI-computer-aided detection. The false-positive rate was 19.3% (249/1289) in the intervention group. It was 18.5% (245/1324) in the control group. The odds ratio was 1.00 (95% CI: 0.79 to 1.26), with a p-value of 0.985, again indicating no statistically significant difference. Based on these results, the study concluded that AI-computer-aided detection did not improve either the sensitivity or the false-positive rate of chest radiograph interpretation for diagnosing acute thoracic disease in patients with acute respiratory symptoms in the emergency department.

While AI holds revolutionary potential for emergency medicine, its successful integration requires a careful balance between technological innovation and ethical practice. The future of emergency medicine likely lies in a synergistic relationship between AI and human expertise, where AI augments rather than replaces human decision-making. Ongoing research and the development of appropriate regulatory frameworks are essential to navigate the challenges and fully realize the benefits of AI in emergency medicine [94, 95].

Conclusion

The recent advancements in internal medicine underscore a transformative shift toward precision and personalized healthcare. Innovations such as NGS for lymphoma subtyping, targeted drug delivery systems for cancer therapy, and the integration of AI in emergency medicine exemplify how technology is revolutionizing diagnosis and treatment. These breakthroughs not only enhance diagnostic accuracy and therapeutic efficacy but also pave the way for minimally invasive and patient-centered approaches. However, challenges such as standardization, accessibility, and the need for robust clinical validation remain critical hurdles that must be addressed to fully realize the potential of these technologies in routine clinical practice.

The field has also seen remarkable progress in managing complex conditions like acute heart failure and glioblastoma, where novel biomarkers, microneedle-based drug delivery, and miRNA therapies offer new hope for improved patient outcomes. The development of hybrid imaging technologies in nuclear medicine and the advent of theragnostic further highlight the convergence of diagnostics and therapy, enabling tailored interventions. Despite these advancements, the high costs, regulatory complexities, and ethical considerations associated with emerging technologies necessitate ongoing collaboration among researchers, clinicians, and policymakers to ensure equitable adoption and sustainable integration into healthcare systems.

Looking ahead, the future of internal medicine lies in the seamless integration of cutting-edge science with compassionate patient care. The collective insights from recent studies emphasize the importance of multidisciplinary approaches, continuous innovation, and evidence-based practice. As the field evolves, fostering global partnerships, investing in education, and addressing disparities in healthcare access will be paramount. By harnessing the power of technological advancements while maintaining a patient-centric focus, internal medicine can continue to drive meaningful improvements in health outcomes and quality of life for patients worldwide.

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Conflict of Interest

None.

References

1. Safiri S, Jolfayi AG, Fazlollahi A, Morsali S, Sarkesh A, et al. (2024) Alzheimer's disease: a comprehensive review of epidemiology, risk factors, symptoms diagnosis, management, caregiving, advanced treatments and associated challenges. Front Med 11: 1-39. https://doi.org/10.3389/fmed.2024.1474043

2. McGlone F, Moberg KU, Norholt H, Eggart M, Müller-Oerlinghausen B, et al. (2024) Touch medicine: bridging the gap between recent insights from touch research and clinical medicine and its special significance for the treatment of affective disorders. Front Psychiatry 15: 1-10. https://doi.org/10.3389/fpsyt.2024.1390673

3. Maqsood Q, Sumrin A, Saleem Y, Wajid A, Mahnoor M, et al. (2024) Exosomes in cancer: diagnostic and therapeutic applications. Clin Med Insights Oncol 18: 1-15. https://doi.org/10.1177/11795549231215966

4. Addissouky TA, Ali MM, Sayed IETE, Wang Y (2024) Emerging advanced approaches for diagnosis and inhibition of liver fibrogenesis. Egypt J Intern Med 36: 1-12. https://doi.org/10.1186/s43162-024-00283-y

5. Angjelova A, Jovanova E, Polizzi A, Laganà L, Santonocito S, et al. (2024) Impact of periodontitis on endothelial risk dysfunction and oxidative stress improvement in patients with cardiovascular disease. J Clin Med 13: 3781. https://doi.org/10.3390/jcm13133781

6. Maddox TM, Januzzi JL Jr, Allen LA, Breathett K, Butler J, et al. (2021) 2021 update to the 2017 ACC expert consensus decision pathway for optimization of heart failure treatment: answers to 10 pivotal issues about heart failure with reduced ejection fraction: a report of the American College of Cardiology Solution Set Oversight Committee. J Am Coll Cardiol 77: 772–810. https://doi.org/10.1016/j.jacc.2020.11.022

7. Sapna FNU, Raveena FNU, Chandio M, Bai K, Sayyar M, et al. (2023) Advancements in heart failure management: a comprehensive narrative review of emerging therapies. Cureus 15: e46486. https://doi.org/10.7759/cureus.46486

8. Mullens W, Martens P, Testani JM, Tang WW, Skouri H, et al. (2022) Renal effects of guideline-directed medical therapies in heart failure: a consensus document from the Heart Failure Association of the European Society of Cardiology. Eur J Heart Fail 24: 603–619. https://doi.org/10.1002/ejhf.2471

9. Docherty KF, Lam CS, Rakisheva A, Coats AJ, Greenhalgh T, et al. (2023) Heart failure diagnosis in the general community – who, how and when? a clinical consensus statement of the Heart Failure Association (HFA) of the European Society of Cardiology (ESC). Eur J Heart Fail 25: 1185–1198. https://doi.org/10.1002/ejhf.2946

10. Chioncel O, Adamo M, Nikolaou M, Parissis J, Mebazaa A, et al. (2023) Acute heart failure and valvular heart disease: a scientific statement of the Heart Failure Association, the Association for Acute CardioVascular Care and the European Association of Percutaneous Cardiovascular Interventions of the European Society of Cardiology. Eur J Heart Fail 25: 1025–1048. https://doi.org/10.1002/ejhf.2918

11. Delgado J, Cepeda JM, Llorens P, Jacob J, Comín J, et al. (2021) Consensus on improving the comprehensive care of patients with acute heart failure. Rev Clin Esp (Engl Ed) 221: 163–168. https://doi.org/10.1016/j.rceng.2020.12.001

12. Dhoundiyal S, Srivastava S, Kumar S, Singh G, Ashique S, et al. (2024) Radiopharmaceuticals: navigating the frontier of precision medicine and therapeutic innovation. Eur J Med Res 29: 1-19. https://doi.org/10.1186/s40001-023-01627-0

13. Rajakumar MP, Balamurugan R, Kavitha R, Menaka NA, Jacson J, et al. (2025) Personalized precision integrating AI for tailored treatment planning in nuclear medicine. In AI Insights on Nuclear Medicine. IGI Global Scientific Publishing, pp 181–202.

14. Renugadevi R (2025) The AI evolution in nuclear medicine by enhancing precision and personalization. In AI Insights on Nuclear Medicine. IGI Global Scientific Publishing, pp 355–376.

15. Huang QQ, Huang G (2024) Advances in radiopharmaceuticals for precision medicine: a global and Chinese perspective. LabMed Discov 1: 100031. https://doi.org/10.1016/j.lmd.2024.100031

16. Yoo JI, Kim JT, Park CH, Cha Y (2022) Diagnosis and management of sarcopenia after hip fracture surgery: current concept review. Hip Pelvis 34: 1-9. https://doi.org/10.5371/hp.2022.34.1.1

17. Combes GF, Vučković AM, Perić Bakulić M, Antoine R, Bonačić-Koutecky V, et al. (2021) Nanotechnology in tumor biomarker detection: the potential of liganded nanoclusters as nonlinear optical contrast agents for molecular diagnostics of cancer. Cancers 13: 4206**.** https://doi.org/10.3390/cancers13164206

18. Oliveira BB, Ferreira D, Fernandes AR, Baptista PV (2023) Engineering gold nanoparticles for molecular diagnostics and biosensing. Wiley Interdiscip Rev Nanomed Nanobiotechnol 15: e1836**.** https://doi.org/10.1002/wnan.1836

19. Kumbhar PR, Kumar P, Lasure A, Velayutham R, Mandal D (2023) An updated landscape on nanotechnology-based drug delivery, immunotherapy, vaccinations, imaging, and biomarker detections for cancers: recent trends and future directions with clinical success. Discov Nano 18: 1-49. https://doi.org/10.1186/s11671-023-03913-6

20. Chakraborty D, Ghosh D, Kumar S, Jenkins D, Chandrasekaran N, et al. (2023) Nano-diagnostics as an emerging platform for oral cancer detection: current and emerging trends. Wiley Interdiscip Rev Nanomed Nanobiotechnol 15: e1830. https://doi.org/10.1002/wnan.1830

21. Kadkhoda J, Akrami-Hasan-Kohal M, Tohidkia MR, Khaledi S, Davaran S, et al. (2021) Advances in antibody nanoconjugates for diagnosis and therapy: a review of recent studies and trends. Int J Biol Macromol 185: 664–678. https://doi.org/10.1016/j.ijbiomac.2021.06.191

22. Sayer AA, Cruz-Jentoft A (2022) Sarcopenia definition, diagnosis and treatment: consensus is growing. Age Ageing 51: 1-5. https://doi.org/10.1093/ageing/afac220

23. Pizzonia M, Casabella A, Natali M, Petrocchi L, Carmisciano L, et al. (2021) Osteosarcopenia in very old age adults after hip fracture: a real-world therapeutic standpoint. Front Med 8: 1-8. https://doi.org/10.3389/fmed.2021.612506

24. Voulgaridou G, Tyrovolas S, Detopoulou P, Tsoumana D, Drakaki M, et al. (2024) Diagnostic criteria and measurement techniques of sarcopenia: a critical evaluation of the up-to-date evidence. Nutrients 16: 436. https://doi.org/10.3390/nu16030436

25. Trucillo P (2024) Biomaterials for drug delivery and human applications. Mater 17: 456. https://doi.org/10.3390/ma17020456

26. Ezike TC, Okpala US, Onoja UL, Nwike CP, Ezeako EC, et al. (2023) Advances in drug delivery systems, challenges and future directions. Heliyon 9: 1-17. https://doi.org/10.1016/j.heliyon.2023.e17488

27. Tan M, Xu Y, Gao Z, Yuan T, Liu Q, et al. (2022) Recent advances in intelligent wearable medical devices integrating biosensing and drug delivery. Adv Mater 34: 2108491. https://doi.org/10.1002/adma.202108491

28. Paramshetti S, Angolkar M, Al Fatease A, Alshahrani SM, Hani U, et al. (2023) Revolutionizing drug delivery and therapeutics: the biomedical applications of conductive polymers and composites-based systems. Pharmaceutics 15: 1204. https://doi.org/10.3390/pharmaceutics15041204

29. Chen WH, Chen QW, Chen Q, Cui C, Duan S, et al. (2022) Biomedical polymers: synthesis, properties, and applications. Sci China Chem 65: 1010–1075. https://doi.org/10.1007/s11426-022-1243-5

30. Davodabadi F, Sajjadi SF, Sarhadi M, Mirghasemi S, Hezaveh MN, et al. (2023) Cancer chemotherapy resistance: mechanisms and recent breakthrough in targeted drug delivery. Eur J Pharmacol 958: 176013. https://doi.org/10.1016/j.ejphar.2023.176013

31. Ganeson K, Alias AH, Murugaiyah V, Amirul AAA, Ramakrishna S, et al. (2023) Microneedles for efficient and precise drug delivery in cancer therapy. Pharmaceutics 15: 744. https://doi.org/10.3390/pharmaceutics15030744

32. Naymagon L, Abdul-Hay M (2016) Novel agents in the treatment of multiple myeloma: a review about the future. J Hematol Oncol 9: 1-20. https://doi.org/10.1186/s13045-016-0282-1

33. Mahindra A, Laubach J, Raje N, Munshi N, Richardson PG, et al. (2012) Latest advances and current challenges in the treatment of multiple myeloma. Nat Rev Clin Oncol 9: 135–143. https://doi.org/10.1038/nrclinonc.2012.15

34. Cowan AJ, Green DJ, Kwok M, Lee S, Coffey DG, et al. (2022) Diagnosis and management of multiple myeloma: a review. JAMA 327: 464–477. https://doi.org/10.1001/jama.2022.0003

35. Moreau P (2017) How I treat myeloma with new agents. Blood 130: 1507–1513. https://doi.org/10.1182/blood-2017-05-743203

36. Ruff E, Gaal L, Szita VR, Wiedemann Á, Svorenj S, et al. (2024) Survival of patients affected with multiple myeloma at the Department of Internal Medicine and Haematology of Semmelweis University. Orv Hetil 165: 1539–1547. https://doi.org/10.1556/650.2024.33120

37. Holle JU, Kubacki T, Aries P, Hellmich B, Kernder A, et al. (2025) Diagnosis and treatment of ANCA-associated vasculitis. Z Rheumatol 84: 225–251. https://doi.org/10.1007/s00393-024-01597-6

38. Marques L, Costa B, Pereira M, Silva A, Santos J, et al. (2024) Advancing precision medicine: a review of innovative in silico approaches for drug development, clinical pharmacology and personalized healthcare. Pharmaceutics 16: 332. https://doi.org/10.3390/pharmaceutics16030332

39. Serrano DR, Luciano FC, Anaya BJ, Ongoren B, Kara A, et al. (2024) Artificial intelligence (AI) applications in drug discovery and drug delivery: revolutionizing personalized medicine. Pharmaceutics 16: 1328. https://doi.org/10.3390/pharmaceutics16101328

40. Tanaka M (2025) From serendipity to precision: integrating AI, multi-omics, and human-specific models for personalized neuropsychiatric care. Biomedicines 13: 167. https://doi.org/10.3390/biomedicines13010167

41. Tomacinschii V, Orgueira AM, Santos CA, Robu M, Buruiana S, et al. (2023) The implication of next-generation sequencing in the diagnosis and clinical management of non-Hodgkin lymphomas. Front Oncol 13: 1-10. https://doi.org/10.3389/fonc.2023.1275327

42. Huang Z, Fu Y, Yang H, Zhou Y, Shi M, et al. (2024) Liquid biopsy in T-cell lymphoma: biomarker detection techniques and clinical application. Mol Cancer 23: 1-32. https://doi.org/10.1186/s12943-024-01947-7

43. Esmeray E, Küçük CAN (2020) Genetic alterations in B cell lymphoma subtypes as potential biomarkers for noninvasive diagnosis, prognosis, therapy, and disease monitoring. Turk J Biol 44: 1–14. https://doi.org/10.3906/biy-1908-23

44. Lauer EM, Mutter J, Scherer F (2022) Circulating tumor DNA in B-cell lymphoma: technical advances, clinical applications, and perspectives for translational research. Leukemia 36: 2151–2164. https://doi.org/10.1038/s41375-022-01618-w

45. Walter W, Iacobucci I, Meggendorfer M (2025) Diagnosis of acute lymphoblastic leukaemia: an overview of the current genomic classification, diagnostic approaches, and future directions. Histopathology 86: 134–145. https://doi.org/10.1111/his.15338

46. Heimann P, Dewispelaere L (2020) Indications of next-generation sequencing in non-Hodgkin's lymphoma. Curr Opin Oncol 32: 391–397. https://doi.org/10.1097/cco.0000000000000666

47. Breinholt MF, Schejbel L, Gang AO, Nielsen TH, Pedersen LM, et al. (2023) Next generation sequencing in routine diagnostics of mature non-Hodgkin's B-cell lymphomas. Eur J Haematol 111: 583–591. https://doi.org/10.1111/ejh.14048

48. Albitar M, Zhang H, Ip A, Ma W, Estella JJ, et al. (2023) Lymphoma diagnosis and classification using next generation sequencing of 30 CD markers and machine learning as an alternative to immunohistochemistry. Blood 142: 3665-3667. https://doi.org/10.1182/blood-2023-187534

49. Wu XB, Hou SL, Zhang QH, Jia N, Hou M, et al. (2022) Circulating tumor DNA characteristics based on next generation sequencing and its correlation with clinical parameters in patients with lymphoma. Front Oncol 12: 1-11. https://doi.org/10.3389/fonc.2022.901547

50. Pinilla JMG, Díez-Villanueva P, Freire RB, Formiga F, Marcos MC, et al. (2020) Consensus document and recommendations on palliative care in heart failure of the Heart Failure and Geriatric Cardiology Working Groups of the Spanish Society of Cardiology. Rev Esp Cardiol (Engl Ed) 73: 69–77. https://doi.org/10.1016/j.rec.2019.06.019

51. Crespo-Leiro MG, Metra M, Lund LH, Milicic D, Costanzo MR, et al. (2018) Advanced heart failure: a position statement of the Heart Failure Association of the European Society of Cardiology. Eur J Heart Fail 20: 1505–1535. https://doi.org/10.1002/ejhf.1236

52. Harjola VP, Parissis J, Brunner-La Rocca HP, Čelutkienė J, Chioncel O, et al. (2018) Comprehensive in-hospital monitoring in acute heart failure: applications for clinical practice and future directions for research. A statement from the Acute Heart Failure Committee of the Heart Failure Association (HFA) of the European Society of Cardiology (ESC). Eur J Heart Fail 20: 1081–1099. https://doi.org/10.1002/ejhf.1204

53. Degoma EM, Vagelos RH, Fowler MB, Ashley EA (2006) Emerging therapies for the management of decompensated heart failure: from bench to bedside. J Am Coll Cardiol 48: 2397–2409. https://doi.org/10.1016/j.jacc.2006.08.039

54. Gouda P, Ezekowitz JA (2019) Update on the diagnosis and management of acute heart failure. Curr Opin Cardiol 34: 202–206. https://doi.org/10.1097/hco.0000000000000594

55. Velez M (2023) Advances in contemporary medical management to treat patients with heart failure. Curr Opin Cardiol 38: 136–142. https://doi.org/10.1097/hco.0000000000001021

56. Antohi EL, Ambrosy AP, Collins SP, Ahmed A, Iliescu VA, et al. (2019) Therapeutic advances in the management of acute decompensated heart failure. Am J Ther 26: e222–e233. https://doi.org/10.1097/mjt.0000000000000919

57. Heidenreich P, Sandhu A (2024) Advances in management of heart failure. BMJ 385: 1-17. https://doi.org/10.1136/bmj-2023-077025

58. Devadoss R, Dhillon G, Sharma P, Verma RK, Munjal R, et al. (2024) Heartfelt breakthroughs: elevating quality of life with cutting-edge advances in heart failure treatment. J Cardiovasc Dev Dis 11: 15. https://doi.org/10.3390/jcdd11010015

59. Weber WA, Czernin J, Anderson CJ, Badawi RD, Barthel H, et al. (2020) The future of nuclear medicine, molecular imaging, and theranostics. J Nucl Med 61: 263S–272S. https://doi.org/10.2967/jnumed.120.254532

60. Vaz SC, Oliveira F, Herrmann K, Veit-Haibach P (2020) Nuclear medicine and molecular imaging advances in the 21st century. Br J Radiol 93: 20200095. https://doi.org/10.1259/bjr.20200095

61. Czernin J, Sonni I, Razmaria A, Calais J (2019) The future of nuclear medicine as an independent specialty. J Nucl Med 60: 3S–12S. https://doi.org/10.2967/jnumed.118.220558

62. Bouchareb Y, AlSaadi A, Zabah J, Jain A, Al-Jabri A, et al. (2024) Technological advances in SPECT and SPECT/CT imaging. Diagnostics 14: 1431. https://doi.org/10.3390/diagnostics14131431

63. Peştean C, Pavel A, Piciu D (2024) The role of SPECT/CT and PET/CT hybrid imaging in the management of ectopic thyroid carcinoma—a systematic review. Diagnostics 14: 1369. https://doi.org/10.3390/diagnostics14131369

64. Alqahtani FF (2023) SPECT/CT and PET/CT, related radiopharmaceuticals, and areas of application and comparison. Saudi Pharm J 31: 312–328. https://doi.org/10.1016/j.jsps.2022.12.013

65. Visvikis D, Lambin P, Beuschau Mauridsen K, Hustinx R, Lassmann M, et al. (2022) Application of artificial intelligence in nuclear medicine and molecular imaging: a review of current status and future perspectives for clinical translation. Eur J Nucl Med Mol Imaging 49: 4452–4463. https://doi.org/10.1007/s00259-022-05891-w

66. Palmer Stephens C, Street Beam A, Gray Z, Mansfield J, Reves L, et al. (2022) Imaging advancements in nuclear medicine: pancreatic neuroendocrine tumor localization and treatment. Radiol Technol 93: 431-436.

67. Paquette M, Espinosa-Bentancourt E, Lavallee E, Phoenix S, Lapointe-Milot K, et al. (2022) 18F-4FMFES and 18F-FDG PET/CT in estrogen receptor-positive endometrial carcinomas: preliminary report. J Nucl Med 63: 702–707. https://doi.org/10.2967/jnumed.121.262617

68. Qin X, Guo X, Liu T, Li L, Zhou N, et al. (2023) High in-vivo stability in preclinical and first-in-human experiments with [^{18}F]AlF-RESCA-MIRC213: a ^{18}F-labeled nanobody as PET radiotracer for diagnosis of HER2-positive cancers. Eur J Nucl Med Mol Imaging 50: 302–313. https://doi.org/10.1007/s00259-022-05967-7

69. Makowska M, Smolarz B, Romanowicz H (2023) microRNAs (miRNAs) in glioblastoma multiforme (GBM)-recent literature review. Int J Mol Sci 24: 3521. https://doi.org/10.3390/ijms24043521

70. Pottoo FH, Javed MN, Rahman JU, Abu-Izneid T, Khan FA (2021) Targeted delivery of miRNA based therapeuticals in the clinical management of glioblastoma multiforme. Semin Cancer Biol 69: 391–398. https://doi.org/10.1016/j.semcancer.2020.04.001

71. Bravo-Vázquez LA, Méndez-García A, Rodríguez AL, Sahare P, Pathak S, et al. (2023) Applications of nanotechnologies for miRNA-based cancer therapeutics: current advances and future perspectives. Front Bioeng Biotechnol 11: 1-21. https://doi.org/10.3389/fbioe.2023.1208547

72. Bhowmick R, Sarkar RR (2023) Identification of potential microRNAs regulating metabolic plasticity and cellular phenotypes in glioblastoma. Mol Genet Genomics 298: 161–181. https://doi.org/10.1007/s00438-022-01966-3

73. Xingli D, Gareev I, Roumiantsev S, Beylerli O, Pavlov V, et al. (2023) Identify key genes and construct the lncRNA–miRNA–mRNA regulatory networks associated with glioblastoma by bioinformatics analysis. Curr Med Chem 2023. https://doi.org/10.2174/0109298673372488250530173615

74. Liu R, Gao Z, Li Q, Fu Q, Han D, et al. (2022) Integrated analysis of ceRNA network to reveal potential prognostic biomarkers for glioblastoma. Front Genet 12: 1-7. https://doi.org/10.3389/fgene.2021.803257

75. McDonald MF, Hossain A, Momin EN, Hasan I, Singh S, et al. (2024) Tumor-specific polycistronic miRNA delivered by engineered exosomes for the treatment of glioblastoma. Neuro Oncol 26: 236–250. https://doi.org/10.1093/neuonc/noad199

76. Grafals-Ruiz N, Sanchez-Alvarez AO, Santana-Rivera Y, Lozada-Delgado EL, Rabelo-Fernandez RJ, et al. (2023) MicroRNA-92b targets tumor suppressor gene FBXW7 in glioblastoma. Front Oncol 13: 1-15. https://doi.org/10.3389/fonc.2023.1249649

77. Gittard SD, Miller PR, Boehm RD, Ovsianikov A, Chichkov BN, et al. (2011) Multiphoton microscopy of transdermal quantum dot delivery using two photon polymerization-fabricated polymer microneedles. Faraday Discuss 149: 171–185. https://doi.org/10.1039/c005374k

78. Micro Needle Array-Doxorubicin (MNA-D) in Patients with Cutaneous T-cell Lymphoma (CTCL) (MNA-D). [https://www.clinicaltrials.gov/study/NCT02192021] [Accessed February 20, 2026]

79. Dose Escalation Trial to Evaluate Dose Limiting Toxicity/Maximum Tolerated Dose of Microneedle Arrays Containing Doxorubicin (D-MNA) in Basal Cell Carcinoma (BCC). [https://www.clinicaltrials.gov/study/NCT03646188] [Accessed February 20, 2026]

80. Lim SY, Kim BD, Liu P, Shin JH, Jeong JH (2024) Microneedle-guided lymphatic delivery of a natural immune modulator toxin for enhanced cancer immunotherapy. Cancer Res 84: 5572. https://doi.org/10.1158/1538-7445.am2024-5572

81. Lan X, Zhu W, Huang X, Yu Y, Xiao H, et al. (2020) Microneedles loaded with anti-PD-1–cisplatin nanoparticles for synergistic cancer immuno-chemotherapy. Nanoscale 12: 18885–18898. https://doi.org/10.1039/d0nr04213g

82. Kumar D, Pandey S, Shiekmydeen J, Kumar M, Chopra S, et al. (2025) Therapeutic potential of microneedle assisted drug delivery for wound healing: current state of the art, challenges, and future perspective. AAPS PharmSciTech 26: 25. https://doi.org/10.1208/s12249-024-03017-z

83. Zhou Q, Li H, Liao Z, Gao B, He B (2023) Bridging the gap between invasive and noninvasive medical care: emerging microneedle approaches. Anal Chem 95: 515–534. https://doi.org/10.1021/acs.analchem.2c01895

84. Liu Y, Mao R, Han S, Yu Z, Xu B, et al. (2024) Polymeric microneedle drug delivery systems: mechanisms of treatment, material properties, and clinical applications—a comprehensive review. Polymers 16: 2568. https://doi.org/10.3390/polym16182568

85. Yao Y, Zhou Y, Liu L, Xu Y, Chen Q, et al. (2020) Nanoparticle-based drug delivery in cancer therapy and its role in overcoming drug resistance. Front Mol Biosci 7: 1-14. https://doi.org/10.3389/fmolb.2020.00193

86. Sun X, Zhao P, Lin J, Chen K, Shen J (2023) Recent advances in access to overcome cancer drug resistance by nanocarrier drug delivery system. Cancer Drug Resist 6: 390-415. https://doi.org/10.20517/cdr.2023.16

87. Rittberg R, Czaykowski P, Niraula S (2021) Feasibility of randomized controlled trials for cancer drugs approved by the food and drug administration based on single-arm studies. JNCI Cancer Spectr 5: 1-7. https://doi.org/10.1093/jncics/pkab061

88. Zhu L, Jiang M, Wang H, Sun H, Zhu J, et al. (2021) A narrative review of tumor heterogeneity and challenges to tumor drug therapy. Ann Transl Med 9: 1-9. https://doi.org/10.21037/atm-21-1948

89. Imodoye SO, Adedokun KA, Bello IO (2024) From complexity to clarity: unravelling tumor heterogeneity through the lens of tumor microenvironment for innovative cancer therapy. Histochem Cell Biol 161: 299–323. https://doi.org/10.1007/s00418-023-02258-6

90. Hoppe JM, Auer MK, Strüven A, Massberg S, Stremmel C (2024) ChatGPT with GPT-4 outperforms emergency department physicians in diagnostic accuracy: retrospective analysis. J Med Internet Res 26: 1-7. https://doi.org/10.2196/56110

91. Masanneck L, Schmidt L, Seifert A, Kölsche T, Huntemann N, et al. (2024) Triage performance across large language models, ChatGPT, and untrained doctors in emergency medicine: comparative study. J Med Internet Res 26: 1-10. https://doi.org/10.2196/53297

92. Lin CS, Liu WT, Tsai DJ, Lou YS, Chang CH, et al. (2023) Applying an artificial intelligence-enabled electrocardiographic system for reducing mortality: a pragmatic randomized clinical trial. SSRN.

93. Hwang EJ, Goo JM, Nam JG, Park CM, Hong KJ, et al. (2023) Conventional versus artificial intelligence-assisted interpretation of chest radiographs in patients with acute respiratory symptoms in emergency department: a pragmatic randomized clinical trial. Korean J Radiol 24: 259-270. https://doi.org/10.3348/kjr.2022.0651

94. Soares F, Padeiro D, Sampaio MC, Brás GR, Marcão R, et al. (2025) Artificial intelligence in emergency services: a bioethical perspective. Strateg Manag Regul Challenges Glob Gov MedTech 2025: 1–20. https://doi.org/10.4018/979-8-3373-1205-7.ch001

95. Boussina A, Krishnamoorthy R, Quintero K, Joshi S, Wardi G, et al. (2024) Large language models for more efficient reporting of hospital quality measures. NEJM AI 1: AIcs2400420. https://doi.org/10.1056/aics2400420