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Review Article

A Comprehensive Review on Chemistry Uses in Medicine and Medical Technology

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Abstract

Medicinal chemistry, firmly rooted in chemistry while incorporating elements of biological, medical, and pharmaceutical sciences, spearheads innovation in disease diagnosis, treatment, and prevention at the molecular level. Chemistry serves as a cornerstone for understanding the intricate interactions between medications and biological systems, guiding medicinal chemists in the precise design and synthesis of compounds tailored for specific activities and optimized therapeutic outcomes. Concurrently, nanotechnology, founded on chemical principles, presents promising avenues in advanced imaging, diagnostics, theranostic platforms, and drug delivery systems. The indispensable role of chemistry is further underscored by polymers, integral to medical applications such as orthopedics and cardiovascular devices, driving forward medical advancements. Analytical chemistry techniques play a critical role in drug analysis and biomarker identification, providing essential support for these endeavors. Additionally, radioactive metal ions play pivotal roles in therapy and diagnosis within nuclear medicine, as demonstrated by the innovative DOTA-TATE compound. These interdisciplinary advancements underscore the crucial role of chemistry in fostering innovation and elevating patient care standards within modern healthcare systems.

Keywords: Medicinal chemistry, nanomedicines, polymers, nuclear medicine.

INTRODUCTION

Chemistry is essential to medicine and medical technology, influencing everything from drug development and discovery to diagnosis and treatment strategies. The discovery and development of novel medications are largely dependent on chemistry (Thomford *et al.*, 2018). Medicinal chemists create and assemble compounds with the intended biological activities, adjust their pharmacokinetic characteristics, and maximize the therapeutic benefits of their products while reducing their side effects. This entails comprehending drug metabolism, structure-activity connections, and molecular interactions. Understanding the interactions between medications and biological systems aided by chemistry (Albanese, Tang, & Chan, 2012). Chemical principles play a major role in pharmacokinetics and pharmacodynamics, which deal with how medications are absorbed, distributed, metabolized, and excreted inside the body (Gayathiri *et al.*, 2023). Research on the quantitative structure-activity relationship, or QSAR, helps in dosage optimization and pharmacological behavior prediction. For drug analysis, toxicological testing, and biomarker identification, analytical chemistry techniques like chromatography, mass spectrometry, spectroscopy, and immunoassays employed (Dunn, Broadhurst, Atherton, Goodacre, & Griffin, 2011). Analytical tools known as biosensors are those that identify biological analytes and translate their signals into quantifiable results. The design of biosensors' transducers, such as electrochemical and optical, and recognition elements, such as enzymes, antibodies, and nucleic acids, depends heavily on chemistry (Justino, Freitas, Pereira, Duarte, & Santos, 2015). Point-of-care testing for conditions including diabetes, infectious diseases, and cancer made easier by these devices, which provide quick and sensitive identification of pathogens, biomarkers, and other analytes in clinical samples. Contrast agents are chemicals that used in medical imaging procedures including MRIs, CT scans, ultrasounds, and X-ray imaging to make internal structures or processes more visible. Specific features of contrast agents, like high relativity for MRI contrast agents or high X-ray attenuation for CT contrast agents, synthesized through chemistry (Morales & Halpern, 2018).

By detecting biomarkers, these techniques aid in the accurate assessment of medication concentrations in biological samples and aid in illness diagnosis. In several diagnostic imaging, modalities, including magnetic resonance imaging (MRI), computed tomography (CT), PET (positron emission tomography), and ultrasound, chemistry is essential (Alkilany, Thompson, Boulos, Sisco, & Murphy, 2012). Chemists have produced contrast agents, *price list.

_*. , and imaging probes to increase sensitivity. Nanotechnology is the process of modifying matter at the nanoscale to produce materials with special qualities. Nanotechnology presents prospects in medicine for imaging, diagnostics, and targeted drug delivery. By delivering medications to particular tissues or cells, nanoparticles made with the help of chemical principles can maximize therapeutic effects and reduce negative effects (Wang, Li, Yoon, & Interfaces, 2021).

When creating drug delivery systems that allow therapeutic substances to release into specific body regions in a targeted and regulated manner, chemistry is a key component (Ge & Liu, 2013). Drug carriers that have been created utilizing chemical principles to encapsulate medications, improve their stability, and make it easier for them to penetrate biological barriers include hydrogels, liposomes, nanoparticles, and micelles (Li & Mooney, 2016). These methods increase patient compliance and treatment outcomes by lowering systemic toxicity, promoting prolonged release kinetics, and improving medication efficacy.

The creation of biomedical materials and equipment for tissue engineering, prosthetics, implants, and regenerative medicine depends heavily on chemistry (Kashkooli, Soltani, & Souri, 2020). The mechanical, structural, and biological characteristics of natural tissues intended to be replicated by biomaterials made of polymers, ceramics, metals, and composites. Biomaterial integration made possible by surface modification techniques, including functionalization and coatings (Yi *et al*., 2022). The detection, examination, and modification of nucleic acids, proteins, and other biomolecules at the molecular level made possible by chemistry, which propels developments in molecular diagnostics and genomics (Debnath, Prasad, & Bisen, 2010). To amplify, label, and detect genetic and genomic data, methods like PCR, DNA sequencing, microarrays, and next-generation sequencing (NGS) rely on chemical principles (Yi *et al*., 2022). These technologies help guide individualized treatment plans and track the advancement of diseases by making it easier to diagnose genetic disorders, infectious diseases, cancer, and other problems.

Based on chemistry, nanotechnology presents a bright future for the medical field with its potential for the creation of theranostic platforms and Nano medicines (Buermans & Den Dunnen, 2014). The simultaneous detection and treatment of diseases, known as thermonostics, made possible by nanoparticles functionalized with targeting ligands, imaging agents, and medicinal payloads. Exact control over nanoparticle characteristics, including size, shape, surface chemistry, and drug loading, is made easier by chemistry-driven methods (Sarwat & Yamdagni, 2016). Medical gadgets, tissue engineering, and drug delivery systems all make extensive use of polymers. Designing and creating biocompatible, biodegradable materials with specific qualities for a range of medicinal purposes made possible by polymer chemistry. Progress in molecular biology and genetics depends on our ability to comprehend the structure and function of biomolecules like DNA, RNA, and proteins (Pilecki, Luoma, Bathje, Rhea, & Narloch, 2021). The detection and treatment of genetic illnesses have been transformed by methods like DNA sequencing, PCR (polymerase chain reaction), and CRISPR-Cas9, which are based on chemical principles (Rodríguez-Gascón, Solinís, & Isla, 2021).

Through the identification of biomarkers, the creation of targeted medicines, and the optimization of medication regimens based on specific patient features such as genetics, metabolism, and disease profile, chemistry plays a crucial role in the advancement of personalized medicine methods.

Overall, chemistry is the cornerstone of many advances in medical technology and medicine, spurring innovation and enhancing patient outcomes across a range of healthcare specialties (Rodríguez-Gascón *et al*., 2021).

DISCUSSION

Medicinal chemistry is a “chemistry-based discipline, also involving aspects of biological, medical, and pharmaceutical sciences,” according to the International Union for Pure and Applied Chemistry (IUPAC). It is concerned with the creation, discovery, design, identification, and synthesis of biologically active compounds as well as the metabolism of those compounds, the interpretation of their molecular mechanism of action, and the development of structure-activity connections (Fernandes., 2018). In the field of medicine, nanotechnology is widely used as nanomedicine. Several types of nanoparticles may find use in tissue engineering, biomedical implants, targeted pharmaceuticals, targeted medicinal items, imaging, and new diagnostic tools. The development of large-scale, sophisticated nanotechnology has prompted the use of noble metal-based NPs in bioimaging, targeted drug delivery, biological therapy of malignant cells, and disease diagnostics. Because of the NPs' structural shape, optoelectronic characteristics, and size, researchers are interested in their possible biomedical applications. Nonetheless, recent study has extensively examined the nanostructures of iron, gold, palladium, and silver (Yaqoob *et al*., 2020). Gold nanoparticles (AuNPs) are currently receiving a lot of attention for their potential uses as anticancer, antibacterial, and bio-diagnostic materials, while significant research is promising for the treatment of various diseases, including rheumatoid arthritis, cancer, and HIV (Lee *et al*., 2019). The Phoenicians utilized silver vessels to preserve wine and water during their extensive excursions, demonstrating the usage of silver (Ag) as an anti-microbial and anti-viral substance. Ancient Egyptians believed that silver had therapeutic properties and was useful for curing illness. Consequently, before using antibiotics, AgNP-based compounds are used to eradicate wound infections. Ag-sulfadiazine, a cream based on silver, is now widely used as an antimicrobial therapy for severe wounds (Aziz *et al*., 2019). Palladium (Pd) nanoparticle have been widely applied in areas including electrical equipment composition and exposure to various bio-analytes as sensors (Yaqoob *et al*., 2020).

Chalcone acts as an aromatic ketone that serves as the building block of numerous significant biological molecules referred to as chalcones. Flavonoids as well as isoflavonoids, which are prevalent in plants, have chalcones as their biogenetic antecedents. Due to its open-chain model and ability to modify its skeleton to create new classes of organic compounds like azachalcones, isoxazoles, pyrazoles, and indole grounded chalcones, the chemistry of chalcones has attracted organic chemists from ancient times. Numerous therapeutic actions, including anticancer, antioxidants, anti-inflammatory, antihypertensive, antimalarial, antiulcer, antiviral, antiprotozoal, cardiovascular activity, and mutagenic qualities, are displayed by chalcone derivatives (Rammohan *et al*., 2020).

In nuclear medicine, radioactive metal ions, often known as radiometals, are essential for a number of therapeutic and diagnostic uses. For instance, the somatostatin receptor-targeting peptide octreotate and the macrocyclic chelator 1,4,7,10-tetraazacyclododecane-1,4,7,10-tetraacetate (DOTA) are the components of the somatostatin receptor 2 agonist derivative DOTA-TATE, which was recently approved for use in conjunction with the therapeutic β- emitter 177Lu and the diagnostic positron (β+) emitter 68Ga. The investigation of theranostic platforms in the clinic has been made possible by the combined application of DOTA-TATE with both a diagnostic and a therapeutic radiometal. With DOTA-TATE, a single molecular construct and these interchangeable radiometals can be used for imaging and treating somatostatin receptor-positive neuroendocrine tumors (Aluicio-Sarduy *et al*., 2020). Among medical radioisotopes (RIs), the most commonly utilized one for diagnostic nuclear medicine is 99mTc (T1/2 = 6 h), which is the decay product of 99Mo (T1/2 = 66 h). 99Mo/99mTc generators are typically employed to produce this RI (Nagai & Igashira, 2022).

Biomaterials have a critical role in enhancing human health and well-being. Most biomaterials used in skeletal systems have been composed of metals. Almost all load-bearing implants, including fracture repair wires, screws, plates, and prostheses for the hip and knee, have been made of metal. Biomedical metals are primarily composed of three material groups: titanium and its alloys, cobalt-chromium-molybdenum alloy, and stainless steel. Understanding the various metallic materials' physical and chemical characteristics as well as how they interact with the human body's host tissue is crucial for any surgery (Siraparapu *et al*., 2013).

Many polymers are used in medical applications, including synthetic rubber (SR), polystyrene (PS), polyethylene (PE), polyurethane (PU), polyamide (PA), polytetrafluoroethylene (PTFE), polymethylmethacrylate (PMMA), polyethylene terephthalate (PET), polylactic acid (PLA), and polyglycolide (PGA). Polymers are typically utilized in a variety of medical domains, including orthopedic applications, dental reconstruction, cardiovascular devices, contact lenses and corneas, adhesives, membranes, sutures, and disposable syringes. The degree of crystallinity of a polymer is also important when choosing it for medicinal applications (Festas *et al*., 2020). Thus, it is evident that chemistry is a vital part of our everyday life and has a significant influence on medicine industry.

CONCLUSION

Based on this review, it is concluded that chemists and medical researchers continue to explore new scientific frontiers for diagnosing, treating, curing, and preventing diseases at the molecular/genetic level. The integration of chemistry into medicine and medical technologies has revolutionized healthcare by enabling drug discovery, diagnostics, biomedical materials, drug delivery systems, and understanding disease mechanism. Medicinal chemists utilize their understanding of chemical principles to develop new drugs, optimize existing ones, and create formulations that enhance their efficacy. Polymers with tailored formulations are utilized in a variety of medical domains. In nuclear medicine, radio-metals are essential for a number of therapeutic and diagnostic uses. The emergence of the nanotechnology, the use of nanostructures as recognition elements has also increased the development of efficient nano-sensors, particularly for clinical diagnosis. These advancements continue to drive innovation and improve patient care, underscoring the critical role of chemistry in modern healthcare.

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