NANOMATERIAL BASED ELECTROCHEMICAL SENSORS USED FOR DETECTION OF PHARMACEUTICALS

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ABSTRACT

The rapidly growing human population has presented new biological and environmental issues. These problems, in turn, have contributed to the pharmaceutical industry's rapid expansion. Pharmaceutical manufacturing and drug delivery require portable, sensitive, precise, and cost-effective instruments to monitor patient dosing and assess pharmaceutical dangers. The characteristics and applications of contemporary nanomaterial-based drug detection sensors, emphasizing their potential to increase the detection of bioactive chemicals and thereby promote human health and environmental protection on a broad scale. Electrochemical sensors, in particular, have proven beneficial in bioimaging, electrochemical analysis, and drug administration due to their excellent specificity, selectivity, and durability throughout cycles. This review discusses current advances in electrochemical devices for healthcare applications, including their manufacturing, analytical performance, and clinical applications.

Keywords: Nanoparticles, Electrochemical sensors , Bioimaging, Clinical applications.

1. INTRODUCTION

The use of electrochemical sensors and medication delivery platforms in personalized healthcare and point-of-care diagnostics is gaining interest due to their versatility, safety, and cost-effectiveness. These devices can provide precise real-time assessments of physiological parameters and biomarker concentrations. Flexible sensors are becoming increasingly used in biomedical instruments for targeted drug delivery and diagnostics. Modern transducer materials, such as nanoparticles and graphene, are used for immobilization and detection platforms. Newly synthesized polymers and copolymers are also used for improved sensor signal transduction. Misuse of pharmaceuticals necessitates the development of cost-effective, portable, and precise sensors for practical applications and monitoring pharmaceutical contamination in aquatic environments for human and ecological health protection. Wearable sensors enhance rehabilitation medicine by systematically assessing motor behavior, improving remote monitoring and tele-rehabilitation, and accelerating personalized and precision medicine for neurological or musculoskeletal diseases.

Nanomaterials enhance electrochemical sensor advancements by allowing adjustable morphologies, sizes, and properties. Understanding physicochemical and electrostatic interactions between nanomaterial based electrodes and target analytes is crucial for identifying pharmaceutical compounds like analgesics and antibacterials. Since the 20th century's introduction of the first glucose oxidase biosensor, biosensing technology has made significant advancements. Integrated electrochemical transducers offer portability, disposability, and user accessibility. High-performance electrochemical biosensors improve electronic conductivity, speeding up pharmaceutical applications, environmental monitoring, and diagnostic tests. Literature assesses sensors from various angles, including new materials and specialized fabrication techniques [1]. These sensors play unique roles in human healthcare, including wearable sensor technology, illness diagnostics, and pharmacological screening.

2. ELECTROCHEMICAL METHODS

Drugs can be detected electrochemically using a variety of electroanalytical methods. Given clear electrochemical connections between the nanomaterials used, the target analytes, and the usual application, certain techniques may be more suited to differentiate drug accumulation. Several electrochemical methods. are employed in these sensors, including Voltammetric methods measure current based on applied potential, commonly used in drug detection.Cyclic voltammetry studies drug redox behavior, Differential pulse voltammetry offers high sensitivity, Square wave voltammetry provides rapid detection, and LSV measures current with continuously varying potential. Amperometric methods, such as chronoamperometry (CA) and Multiple Pulse Amperometry (MPA), measure current at a fixed potential over time for continuous drug concentration detection. Photoelectrochemical (PEC) methods enhance drug detection sensitivity by combining light excitation with electrochemical detection [2].

3. ELECTROCHEMICAL SENSOR

Electrochemical sensors are a type of substance sensor that use data from systems to determine chemical characteristics in different species. The sensor element is the focal point, and when interfaced with an identifier, it connects to the species using a substance signal. The cathode is the crucial indication element, and in electro-coagulation sensors, a thin layer of electrolyte isolates the receiving cathode and counter electrode. Electrochemical sensors produce electrical signals from the redox reaction of the cathode surface species, similar to collecting analyte species. For sensors requiring extra voltage, the reference electrode is positioned close to the working electrode, ensuring no current flows between the cathode and reference terminal. A good sensor should have sufficient signal results for the target group, be selective, precise, repeatable, short, and not react to ecological factors [3]. For example, glucose meters equipped with electrochemical sensors can measure diabetics' blood glucose levels. These sensors can be categorized into conductometric, amperometric, impedimetric, voltammetric, and potentiometric classes, and in some cases, colometric and electrochemiluminescence sensors .

4. SIGINIFICANCE OF NANOMATERIALS

The electrochemical sensor serves as the foundation for the detection process, and the integration of nanomaterials significantly enhances its performance by**:**

- Large Surface Area
- Increased Conductivity
- Chemical Functionalization and Selectivity

Nanomaterial-based sensors are highly effective in drug detection due to their modest cost, increased terminal surface area, mass exchange rate, quick electron movement, improved selectivity, greater awareness, and increased reaction to excessive proportions.

5. NANOMATERIAL SELECTION

- **Target drug:** The nanomaterial used depends on the drug being detected, its electrochemical characteristics, and the desired sensitivity and selectivity.
- **Sensor design:** The nanomaterial must be compatible with the sensor design and fabrication method.
- **Biocompatibility:** For in vivo applications, the nanomaterial should be biocompatible and have no detrimental effects.

6. NANOMATERIAL USED FOR ELECTROCHEMICAL SENSOR:-

The incorporation of nanomaterials has resulted in the development of unique and viable detection platforms. This section includes a few significant nanomaterials and nanocomposites that are commonly used to plan the advanced execution of electrochemical sensors and biosensors to discriminate drug molecules.

I. Carbon-Based Nanomaterials

1.Carbon Nanotubes (CNTs)

2. Graphene

II. Metal Nanoparticles

1. Gold Nanoparticles (AuNPs)
2. Silver Nanoparticles (AgNPs)
3. Platinum Nanoparticles (PtNPs)

III. Metal oxide nanoparticles

1. Zinc Oxide (ZnO) Nanoparticles
2. Titanium Dioxide (TiO2) Nanoparticles

IV. Quantum Dots

V. Polymer Nanoparticles

7. DRUG DETECTION USING ELECTROCHEMICAL SENSORS :-

Sensors have been created to recognize a variety of important drugs. However, due to the underlying medical structures, these sensors typically require specific connection points in order to realize their enormous potential for recognition. New electrochemical sensors are always being developed to improve their awareness and power while also addressing identifying limitations. They can be classified into:

7.1. Anti-Inflammatory Drugs

Nonsteroidal anti-inflammatory medications (NSAIDs) reduce inflammation while also relieving discomfort, irritation, and heat. NSAIDs, a type of painkiller, have been developed through chemical discoveries in the 19th and 20th centuries. Recent technological advancements include innovative drug delivery systems and safer corticosteroid uses.

7.1.1 Ibuprofen

Stable Self assembled monolayers functionalized with cysteine and terephthalate, have been developed for an AgNP-modified, acid-functionalized electrochemical sensor for naproxen, offering improved responsiveness and lower detection limit [4]. This study developed an electrochemical sensor for detecting ibuprofen in human fluids using 3D copper tellurate (Cu3TeO6), a potent electrocatalyst, with dynamic detection ranges of 0.02-5 M and 9-246 M [5].

7.1.2 Aspirin

Painkillers, similar to propionic acids, can be oxidized to form free radicals. Poly-4-vinylpyridine (P4VP) can be folded Multi walled carbon nanotubes and drop-projected onto a Glassy carbon electrode surface, influencing its conductivity, electron transport energy, and electrocatalytic action [6] .The rise in inflammatory disorders has sparked a need for pharmacological diagnostic approaches, particularly for Acetylsalicylic acid overdose detection due to potential side effects. This makes it ideal for the creation of sensitive, quick, and portable ASA detection methods [7] .

7.2 Antidepressants

Antidepressants are commonly misused medications that disrupt sleep patterns. Some disrupt sleep early, while others enhance it. However, these effects are brief. Within the first 3-4 weeks, depressed individuals generally improve their sleep quality. Antidepressants are classified into five groups, with the most well-known being selective serotonin reuptake inhibitors (SSRIs). These drugs have larger sizes, making electrochemical oxidation more difficult.

7.2.1 Fluoxetine

MIP NPs containing fluoxetine were integrated into a Carbon paste electrode, with graphene enhancing conductivity. Methacrylic acid and vinyl benzene were used to create a fluoxetine-engraved polymer. The nano - Molecularly imprinted polymer /Goal to critical path technique demonstrated the best results, demonstrating good responsiveness [8]. This study created a carbon nanofiber-epoxy composite cathode for fluoxetine, and antibiotics were detected electrochemically in water concurrently [9] .

7.2.2 Sertraline

By coupling a Ni-levodopa film with AuNPs for electrocatalysis, this work created a graphene nanosheet for sertraline, increasing the surface area for more electrochemical oxidation [10]. According to this study, levodopa greatly increases the oxidation of natural substances such amines, carboxylic groups, and alcohols when Ni(II)-Ni(III) redox couples are used [11] .

7.3 Antibiotics:

Antibiotics are medications used to treat bacterial infections by killing or inhibiting growth. Penicillin, amoxicillin, tetracycline, and ciprofloxacin are examples of common antibiotics. However, improper use, like over prescription or misuse in agriculture, has led to antibiotic resistance. To maintain efficacy, antibiotics should be used judiciously and only when prescribed by a healthcare professional.

7.3.1 Penicillin

Penicillin, a common antibiotic, can be extensively oxidized using a boron-doped precious stone terminal. This electrochemical detection platform, designed for the oxidation of penicillin to penicillin acid, demonstrates high responsiveness to penicillin and antibiotic medications, despite the limited detection approaches [12].

7.3.2. Tetracycline

A circular MoS_2 and TiO_2 sensor for antibiotic detection (TET) was created. An indirect electrochemical identification method is employed by the sensor. When Cyclic voltammetry and Electrochemical impendance spectroscopy were used to test the sensor's potential, the recovery rate was 95.9%. Impedance antimicrobials were employed to investigate the security of the sensors [13] .

7.4 Anticancer Medication

Anticancer medications, including chemotherapy and targeted therapies, target and destroy rapidly dividing cancer cells. It work through DNA replication, blocking cell division, and targeting specific molecular pathways. However, they can cause side effects like hair loss and fatigue. Advances in personalized medicine improve treatment options.

7.4.1 Doxorubicin

Using aptasensor, this study created a drug discovery technique that can identify methotrexate and doxorubicin for use in pharmaceutical, medical, and natural product evaluations. They increased the peak fluxes of methotrexate and doxorubicin using an integrated cyclodextrin graphene nanocomposite on a GCE. Using steady-state voltammetry, another oligonucleotide metal-dependent doxorubicin detector was created; however, as the degree of doxorubicin stacking rose as a result of drug complex binding, responsiveness decreased [14].

7.4.2. Taxol

Taxol, a medicine for breast, ovary, and lung cancer, has been developed using Differential pulse voltammetry and Platinum group electrodes.. However, its interaction with ds-DNA reduced guanine and adenine oxidation signals, allowing for electroanalysis with a detection range of 0.2 to 10.0 μM. The proposed nanocomposite electrode offers a sensitive, reliable, and specific detection platform.

7.5 Antifungal Drugs

Antifungal medications target fungal growth and reproduction, treating various infections like athlete's foot and ringworm. They disrupt fungal cell membranes, interfere with cell wall synthesis, or inhibit essential processes. However, some drugs may cause side effects and resistance is a concern. Proper diagnosis and treatment are crucial.

7.5.1 Natamycin

A reliable integrated graphene oxide/ Multi walled carbon nanotubes senso sensor has been used to detect natamycin, a licensed polyene-type drug for keratitis. A homogenized yogurt beverage containing a particular kind of natamycin was used to evaluate the sensor's electrochemical detection [15]

7.5.2 Tolnaftate

Disposable SPEs were used to electroanalyze the antifungal medication tolnaftate (TNF). The work showed that electrooxidation is a dispersion-controlled process by detecting irreversible oxidation at 1.20 V and a direct range of 0.24 to 3.76 µM [16] .

7.6 Antiviral Medicines

Antiviral medications, like acyclovir, oseltamivir, and Antiretroviral therapy, treat viral infections by inhibiting viral entry, genome replication, and protein synthesis. They reduce infection severity and prevent transmission, but effectiveness depends on early administration. Challenges like viral mutation and drug resistance necessitate ongoing research for more effective therapies.

7.6.1. Acyclovir

Acyclovir (ACV) is a medication used to treat viral infections. A new detection tool uses MWCNTs and DHP for improved direct electrochemical detection [17]. The empty nanostructured film anode's dynamic surface region aids inAcyclovir identification. Chemically manufactured electrodes coated with nanoparticles have shown promising results for small molecule detection [17] .

7.6.2 Valacyclovir (VCV) and Acetaminophen

The proposed approach uses reduced grapheme oxide to detect Valacyclovir and acetaminophen simultaneously, demonstrating potential for simultaneous detection using a Glassy carbon electrode and reduced grapheme oxide and Glassy carbon electrode . The electrooxidation reaction produces 8-oxovalacyclovir, which is not fully diffusion-controlled and irreversible [18] .

8. **LIMITATIONS:-**

Nanomaterial-based electrochemical sensors show considerable promise for drug detection and monitoring applications, but there are numerous possible limitations. Signal interference, durability in clinical settings, and scaling these technologies for general usage are all challenges[19].

- Nanomaterial instability
- Mitigation strategies
- Interference of body fluids
- Durability in long process

9. APPLICATIONS:-

- Pharmaceutical Quality Control
- Therapeutic Drug Monitoring (TDM)
- Detection of Drugs
- Environmental Monitoring
- Research and Development
- Detection of Antibiotics
- On-Site Testing in Healthcare

10. CONCLUSION:-

Nanomaterial-based electrochemical sensors have emerged as a powerful analytical platform. The advancements in nanomaterial synthesis, sensor design, and integration with other technologies will pave the way for even more sophisticated and versatile sensing platforms. Nanomaterial-based electrochemical sensors used for the detection of pharmaceutical drugs, offering significant advancements over traditional methods. These innovations have the potential to revolutionize drug discovery, therapeutic drug monitoring, and personalized medicine, ultimately improving patient care and public health.

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