NANO MATERIALS- BASED SENSORS FOR THROAT VIRAL DETECTION

Ms. Anjali M. Sanap[1], Prof V.M. Waghulkar[2]

1 ***M Pharmacy Quality Assurance , Vidyabhari College Of Pharmacy ,Amravati Maharashtra India***

2Professor , Department of Quality Assurance ,Vidyabharti College Of Pharmacy, Amravati, Maharashtra, India

3M Pharmacy Quality Assurance , Vidyabharti College Of Pharmacy ,Amravati, Maharashtra, India

ABSTRACT

Throat viral infections, including those caused by respiratory viruses like influenza and SARS- CoV-2, pose significant diagnostic challenges due to their rapid transmission and symptom overlap. Traditional diagnostic methods such as PCR and ELISA, though accurate, are limited by time, infrastructure, and cost. Nanomaterials-based sensors offer a promising alternative due to their high sensitivity, specificity, portability, and rapid detection capabilities. Various nanomaterials like graphene, gold nanoparticles, and quantum dots have been integrated into electrochemical, optical, and FET-based sensor platforms for real-time detection of viral RNA, proteins, or antigens from throat swabs or saliva. This review explores the working principles, advantages, and limitations of nanomaterials-based sensors tailored for throat viral detection. Additionally, it highlights current research trends, novel electrode materials, and the future potential of these nano-enabled biosensing platforms in the context of point-of-care diagnostics and global healthcare needs.

Index Terms: - Nanomaterial, Throat Viral Detection, SARS-CoV2, types of sensor.

1. INTRODUCTION :-

The rapid and accurate detection of viral infections in the throat is critical for early diagnosis, treatment, and containment of infectious diseases. Traditional diagnostic methods, such as polymerase chain reaction (PCR) and enzyme-linked immunosorbent assay (ELISA), often require complex laboratory setups, trained personnel, and longer processing times. In contrast, nano-material-based sensors offer a promising alternative due to their high sensitivity, rapid response, and portability.

Nanomaterials, including carbon-based nanostructures (graphene, carbon nanotubes), metal nanoparticles (gold, silver), and quantum dots, have unique physicochemical properties that enable enhanced viral detection. These sensors function via various mechanisms such as optical (fluorescence, plasmonic), electrochemical, and piezoelectric detection, providing real-time, point-of-care diagnostics. Recent advances have demonstrated that nano-biosensors can effectively detect viral RNA, proteins, and whole virions with exceptional specificity and lower detection limits than conventional methods.

The integration of nanotechnology into viral diagnostics is particularly relevant for addressing respiratory infections like influenza, SARS-CoV-2, and other emerging throat- targeting viruses. Future developments aim to improve biosensor stability, multiplexed detection, and smartphone-based readouts, making them more accessible for global health applications.

Nano-based sensors are advanced diagnostic tools that utilize nanomaterials to detect throat viral infections with high sensitivity and accuracy. These sensors work by identifying viral

RNA, proteins, or antigens using nanoscale interactions. Compared to conventional diagnostic methods like PCR and ELISA, nano-based sensors offer faster results, portability, and real-time detection, making them ideal for point-of-care testing.

1.1 How Nano-Based Sensors Work for Throat Viral Detection

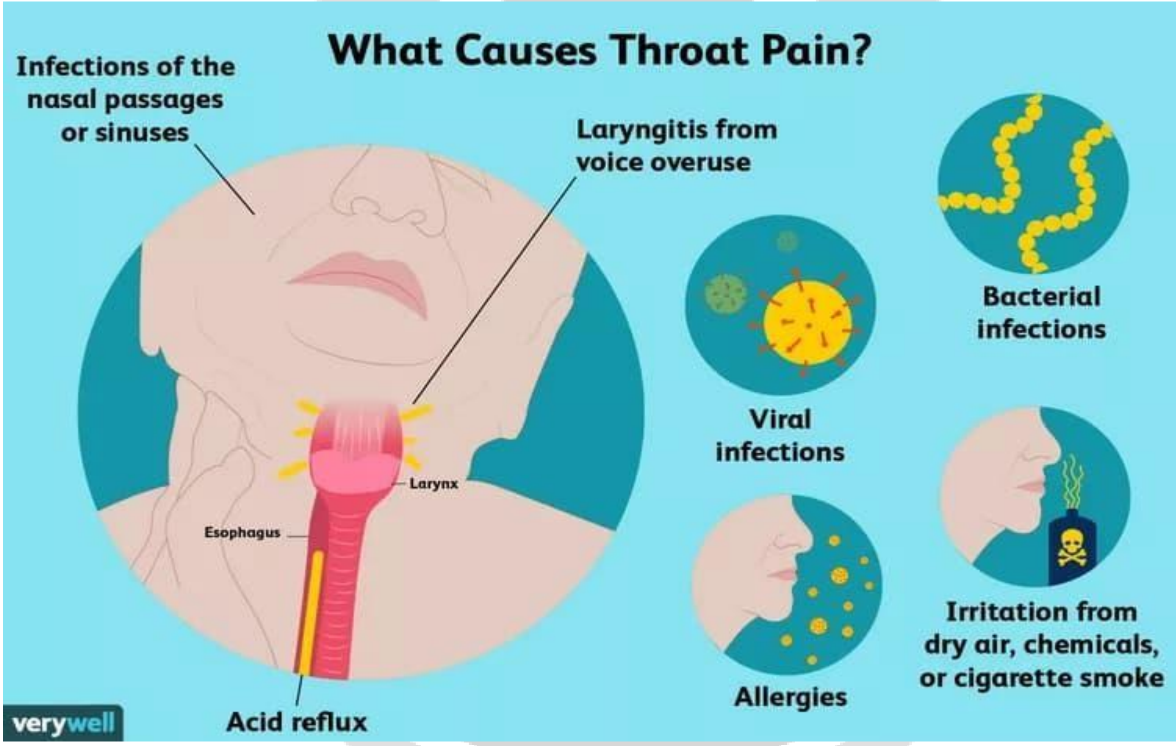
Nano-sensors operate through different mechanisms, including:

1. Electrochemical Sensing: Detects viral biomarkers through electrical signals (e.g., graphene-based sensors).

2. Optical Biosensing: Uses fluorescence, plasmonic, or colorimetric changes to identify viral presence (e.g., gold nanoparticles).

3. Piezoelectric Detection: Measures changes in mass or frequency when viral particles bind to the sensor surface.

4. Field-Effect Transistor (FET) Sensors: Identify viral RNA or proteins by altering the electrical conductivity of nanomaterials.



1.2 Causes of Throat Pain:-

There are many possible causes of throat pain. These causes include viral. infections, bacterial infections, sinus infections, allergies, acid reflux, exposure to irritants, laryngitis, medical procedures, and throat cancer.

1.3 Viral Infections:-

A virus is the most common reason for sore throat. Examples of viral infections that can cause lower throat pain include

a. The flu
b. Cold viruses
c. COVID-19
d. Human immunodeficiency virus (HIV)
e. Mononucleosis (often related to Epstein-Barr virus)

Other causes can include infections typically associated with childhood, such as herpangina, measles, chickenpox, and croup.
Epstein-Barr Virus Symptoms and Treatment Bacterial
Infections
Strep throat is a bacterial infection of the throat. It can cause severe throat pain and painful swallowing. 4 The tonsils may become very swollen. Bacterial causes of throat pain need to be treated with antibiotics. If left untreated, strep throat complications can include heart or kidney damage.

2.Types of Sensor for Throat Viral Detection.

To detect viral infections in the throat, sensor technologies typically focus on identifying biomarkers such as viral RNA, proteins (antigens), or immune response indicators (antibodies). Here are the main types of sensors used for throat viral detection, along with scholarly references for each:

1. **Biosensors**

These are analytical devices that combine a biological component with a physicochemical detector.
Electrochemical biosensors: Detect viral nucleic acids or antigens using a conductive electrode.
Example: A graphene-based electrochemical biosensor for SARS-CoV-2 detection in throat swabs
biosensors: Use changes in light (e.g., fluorescence, surface plasmon resonance) to detect biomolecules.

2. **Immunosensors**

These sensors detect viral antigens or host antibodies using antigen–antibody interactions.
Lateral flow immunoassays (LFIA): Often used in rapid throat swab antigen tests.

3. **Nucleic Acid Sensors**

Used for detecting viral RNA or DNA.
RISPR-based sensors: Use Cas enzymes to detect specific viral genetic sequences. Isothermal amplification sensors (e.g., LAMP): Enable nucleic acid detection at constant temperatures with portable devices.

4. **Wearable or Ingestible Sensors (Emerging)**

Sensors that monitor biomarkers from breath, saliva, or throat continuously.
Integrate sampling, mixing, reaction, and detection in a single micro-scale chip. Enable rapid, low-volume throat swab analysis.

5. **Spectroscopic Techniques**

Infrared (IR)/Near-Infrared (NIR) Sensors: Detect biochemical or structural changes in throat tissue, which may signal infection.
Fluorescence-Based Sensors:
Use tagged antibodies, dyes, or nanomaterials to detect viral proteins, RNA, or immune response indicators.

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8. Electronic Nose (E-Nose)

Detects volatile organic compounds (VOCs) in breath or saliva, which are metabolic byproducts of viral infection.
Useful for non-invasive COVID-19 or flu detection.

9. Acoustic Sensors

Surface Acoustic Wave (SAW) and Quartz Crystal Microbalance (QCM) Sensors: Detect mass changes when viral particles bind to a receptor-coated surface.

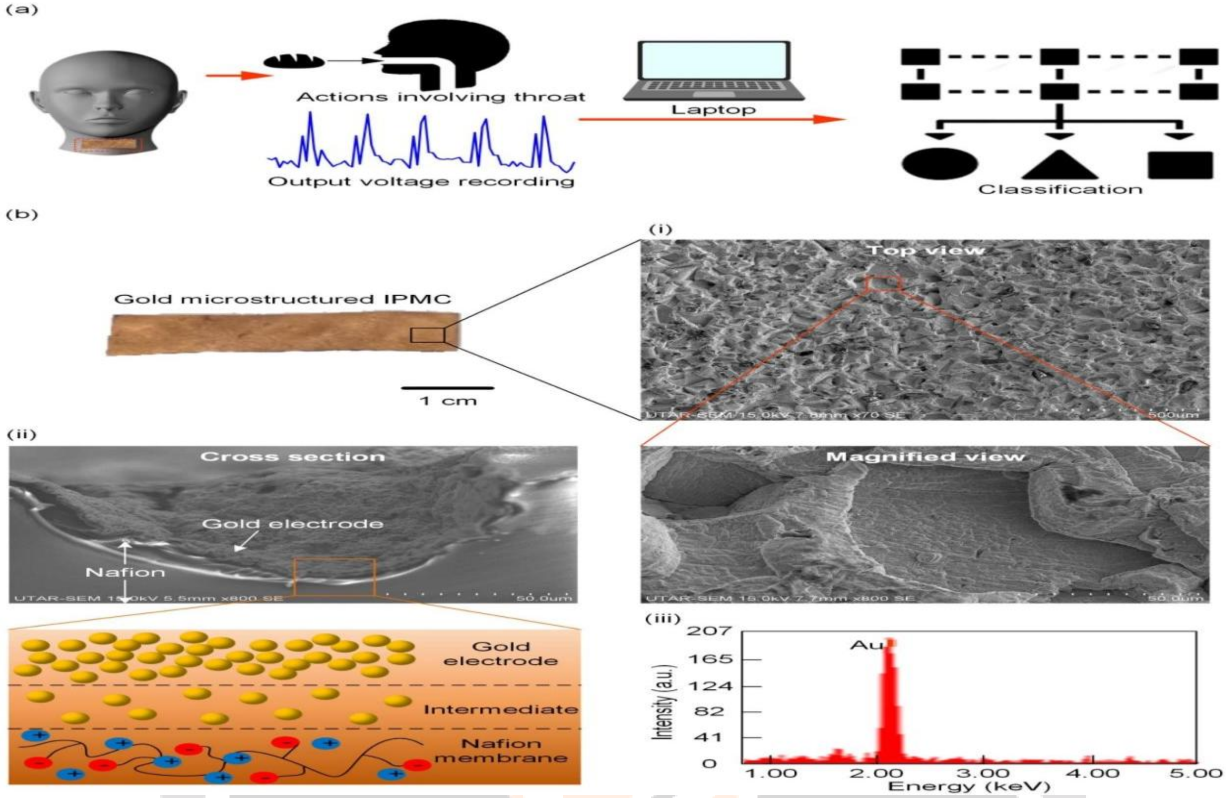
10. Quantum Dot-Based Senso

Quantum Dots (QDs):
Nanocrystals that fluoresce under UV light, used to detect viral RNA or proteins with high sensitivity. Often coupled with microfluidics or immunoassays.

3. Mechanism of Throat Viral Detection:-

Mechanism

The throat sensor utilizes a gold micro structured IPMC to detect mechanical movements such as swallowing, speaking, or coughing. When placed on the throat, these movements generate voltage signals due to ion displacement within the Nafion membrane, which are captured via the gold electrode. The signals are transmitted to a computer and processed for pattern classification. SEM and EDS analysis confirm the microstructure and elemental composition (gold), ensuring sensor performance and sensitivity. This mechanism enables real-time monitoring and classification of throat activity, with potential applications in early detection of infection-related symptoms.



3.1 Explanation of the Mechanism

This image illustrates the mechanism of a gold micro structured IPMC-based throat sensor, which is used for detecting throat-related activities such as speaking, swallowing, or coughing. Here's a breakdown of the mechanism as shown

3.2 Sensing & Classification Mechanism

Sensor Placement: The sensor is attached to the throat area to monitor muscular movements.

I. Throat Activity Detection: Movements such as speech or swallowing produce mechanical signals.

II. Signal Conversion: The sensor converts these mechanical movements into electrical signals (output voltage) due to ion migration within the polymer membrane.

III. Data Transfer & Processing: Signals are transferred to a laptop, where they are analyzed and classified into specific throat activities using pattern recognition algorithms

3.3 Structure and Working Principle of the Sensor

Material Used: Gold micro structured IPMC (Ionic Polymer-Metal Composite).

(i) SEM Images:

Top View & Magnified View: SEM (Scanning Electron Microscopy) images show a rough gold-coated surface, which enhances surface sensitivity.

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(iii) Cross-Section View & Schematic Diagram:

Gold Electrode Layer: Top conductive layer that collects voltage signals. Intermediate Layer: Acts as a transition zone aiding ion/electron transfer.
Nafion Membrane: Ionic polymer that deforms with mechanical pressure (e.g., throat movement), causing ions to shift and generate a signal.

(iv) EDS Analysis:

Energy Dispersive X-ray Spectroscopy (EDS) confirms the presence of gold (Au) with a sharp peak around 2.2 keV, indicating successful deposition of gold on the IPMC surface.

4. Application in Throat Monitoring / Viral Detection:

Although this sensor does not directly detect viruses, it can:

Monitor symptoms like coughing, swallowing difficulty, or changes in voice. Identify abnormal throat activity, which may signal infection or inflammation.
Be integrated with AI/ML models for early detection or classification of disease-related symptoms.

Electrode Materials for the Throat Viral Detection

Electrode Material	Properties	Application on in Viral Detection.
Gold (Au)	High Conductivity , biocompatible, easily Functionalized	Used in biosensors for SARS-Co V-2, influenza antigen detection.
Carbon (Glassy Carbon, CNTs, Graphene)	High surface area stable, modifiable surface	Graphene FET biosensors for swab detection
Indium Tin Oxide (ITO)	Transparent, conductive ,supports optical-electrochemical sensing	ITO modified with antibodies/DNA for viral detection
Screen Printed Electrodes (SPEs)	Disposable cost- effective, portable	Point-of care test strips for antigen/antibody detection

Platinum (pt)	Stable high catalytic activity	Used in enzymatic biosensors, less common for throat swabs
Silver/ Silver Chloride (Ag/AgCl)	Stable reference electrode, used in biosensor systems	Often paired with working electrodes in electrochemical setups

5. Advantages:

a) High Sensitivity:
b) Nanomaterials like graphene and gold nanoparticles provide a large surface area, enabling the detection of very low concentrations of viral biomarkers.
c) High Specificity:
d) Functionalization with antibodies, aptamers, or nucleic acids enables selective detection of throat-specific viruses like SARS-CoV-2 or Influenza.
e) Rapid Detection:
f) Enables real-time or near real-time results, crucial for early diagnosis and isolation.
g) Portability and Miniaturization:
h) Nanomaterials support compact, battery-powered devices suitable for point-of-care (POC) applications..

6. Disadvantages:

a) Stability Issues:
b) Sensor performance may degrade over time due to environmental exposure or nanomaterial instability.
c) Cross-Reactivity:
d) Potential for non-specific binding leading to false positives if not carefully designed.
e) Toxicity Concerns:
f) Some nanomaterials may cause cytotoxicity or biocompatibility issues.
g) High Production Cost:
h) Synthesis and functionalization of nanomaterials can be expensive, limiting large- scale manufacturing.

7. Conclusion:

Nano-material-based sensors represent a transformative approach to the rapid and accurate detection of throat viral infections. Leveraging the unique physicochemical properties of nanomaterials—such as gold nanoparticles, graphene, and quantum dots—these sensors offer significant advantages over conventional diagnostic techniques, including higher sensitivity, faster response times, real-time detection, and portability. The integration of technologies such as electrochemical sensing, optical biosensing, FET systems, and microfluidics has opened new possibilities for point-of-care diagnostics, especially for respiratory viruses like SARS-CoV-2 and influenza.

While there are still challenges to overcome—such as long-term stability, potential toxicity, and fabrication complexity—the progress in sensor design, functionalization, and miniaturization is promising. The future of nano-based throat viral detection lies in developing multiplexed, user-friendly devices with smartphone compatibility and AI integration, aiming for widespread and affordable global health applications. Thus, nanotechnology not only enhances our diagnostic capabilities but also contributes meaningfully to public health preparedness and disease management.

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