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INFECSENSE: DIAGNOSTIC PATCH FOR EARLY INFECTION ALERT

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Abstract : Wound infections pose a significant threat to patient health by delaying healing, increasing treatment costs, and potentially leading to severe complications such as chronic wounds and sepsis. Current diagnostic methods depend on visible symptoms or laboratory tests, which are invasive, time-consuming, and inconvenient. To address these limitations, this project introduces *InfecSense*, a smart colour-changing diagnostic patch designed for the early detection of wound infections. The patch utilizes pH- and biomarker-sensitive materials that respond to biochemical changes associated with bacterial activity, producing a visible colour shift that alerts patients and caregivers in real time. The system is non-invasive, portable, and cost-effective, making it suitable for both clinical and home-care settings, especially for patients requiring continuous monitoring. By enabling early detection, *InfecSense* reduces reliance on hospitalization, promotes timely medical intervention, and improves overall patient outcomes. Future advancements will focus on integrating electronic sensors and artificial intelligence to enhance accuracy and extend the patch's applications to chronic and post-surgical wound management.

Keywords: Smart wound patch, Colorimetric sensing, Early diagnosis, Smart healthcare, Chronic wound , Infecsense, Home care.

I. INTRODUCTION

Wound infections continue to be one of the most critical issues in modern healthcare systems, particularly for patients suffering from chronic wounds, diabetic foot ulcers, pressure sores, and post-surgical incisions. These wounds are often slow to heal due to impaired blood circulation, poor immune response, or underlying medical conditions such as diabetes. When infections in such wounds are not identified and managed promptly, they can lead to serious complications including delayed tissue regeneration**, necrosis,** amputation, or even systemic sepsis. According to global health surveys, approximately 6% of the world's population experiences chronic or infected wounds at some point in their lives, indicating the urgent need **for** rapid, reliable, and easily accessible infection detection methods that can function outside of sophisticated clinical settings.

Traditional wound diagnostic techniques, such as microbial culture, biochemical assays, and histopathological analysis, remain the gold standard for infection detection. However, these approaches are often time-consuming, expensive, and dependent on advanced laboratory infrastructure and skilled professionals. The delay in obtaining results limits their utility for real-time monitoring**,** particularly in rural or resource-limited healthcare environments where immediate diagnosis and intervention are crucial. This gap underscores the need for a simple, low-cost, and user-friendly diagnostic solution capable of providing continuous and non-invasive infection assessment directly at the point of care.

To address these limitations, the present work introduces InfecSense**,** a novel, non-electronic color-changing diagnostic patch designed for the early detection of wound infections. Unlike electronic biosensors, this system functions entirely on colorimetric principles, relying on the biochemical interaction between bacterial enzymes and pH-sensitive dyes embedded within a biocompatible polymer matrix. When pathogenic bacterial activity increases within the wound, the local pH becomes more alkaline, initiating a distinct and visible color transition in the patch. This color shift serves as a direct visual indicator of infection, which can be easily interpreted by patients or healthcare professionals without the need for electronic devices, batteries, or specialized instruments**.**

The InfecSense patch offers several practical advantages that make it highly suitable for both clinical and home-based wound care. It is non-invasive, lightweight, cost-effective, and disposable, making it ideal for continuous wound monitoring. Patients can apply the patch directly to the wound site and observe any color change, enabling immediate infection detection before severe symptoms develop. This early-warning capability can significantly reduce the frequency of hospital visits, lower treatment costs, and prevent complications in chronic wound patients, especially those with diabetes or reduced immune function.

Beyond its diagnostic role, this innovation also contributes to a broader global health objective: combating Antimicrobial Resistance (AMR). The World Health Organization (WHO) has identified AMR as one of the top ten global public health threats, driven largely by the misuse and overuse of antibiotics. When antibiotics are administered unnecessarily or prematurely—often due to the absence of rapid diagnostic tools—bacteria develop resistance, rendering standard treatments ineffective. The InfecSense patch addresses this challenge by providing early, accurate infection detection, allowing healthcare providers to prescribe antibiotics only when **truly** needed. This targeted approach helps minimize antibiotic misuse, reduce the spread of resistant strains, and promote more sustainable wound management practices.

In summary, the proposed InfecSense diagnostic patch represents a promising step toward the future of smart, chemical-based wound monitoring systems. By integrating infection sensing and antimicrobial resistance prevention in a single, user-friendly platform, this project bridges the gap between traditional laboratory diagnostics and modern point-of-care healthcare solutions. The combination **of** biomedical chemistry, advanced polymer design, and sustainable material science makes InfecSense a practical and impactful innovation capable of improving the quality of life for chronic wound patients while contributing to the global effort to combat AMR.

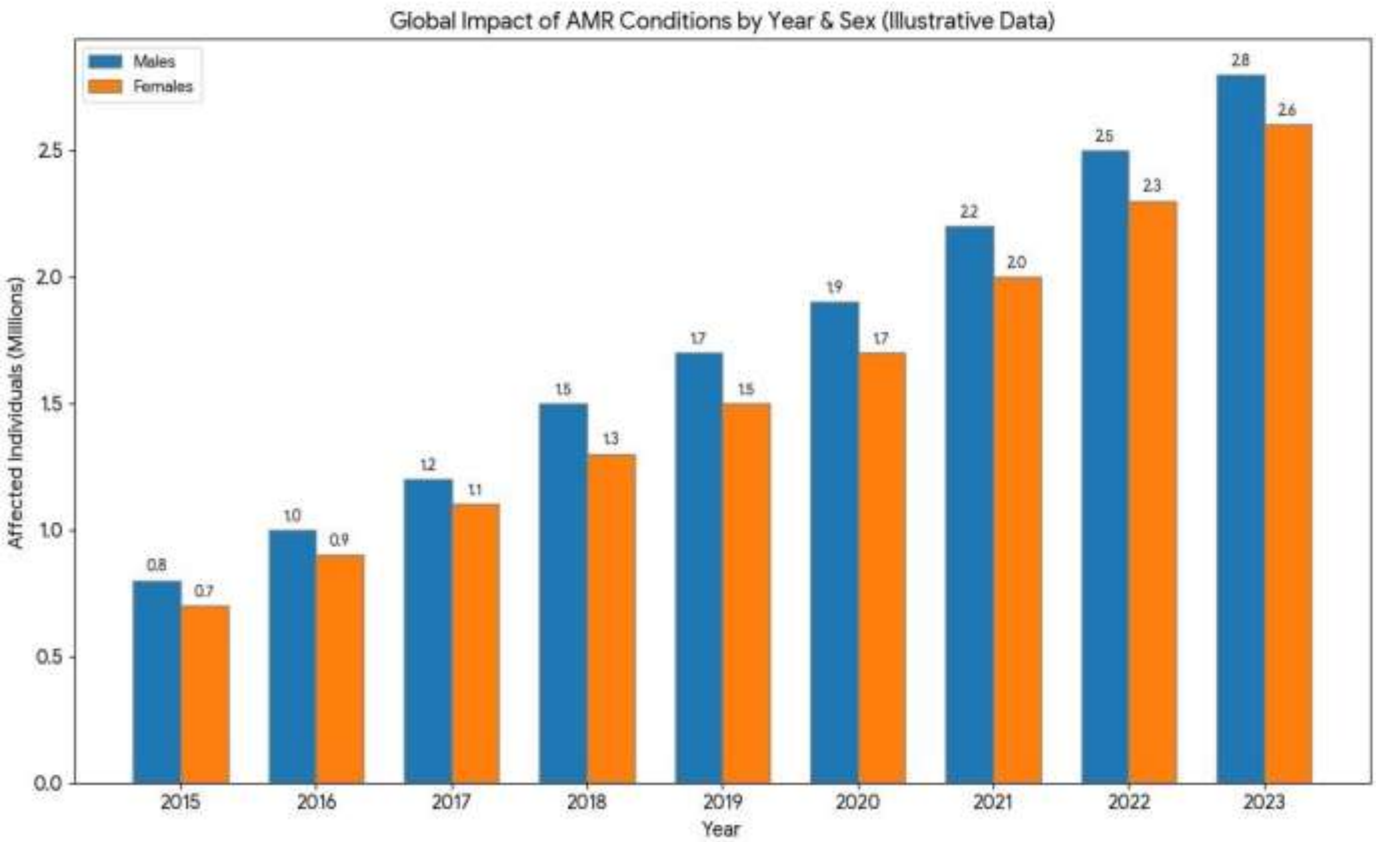


Fig 1: Global Impact of AMR Conditions by Year and Sex

The global impact of antimicrobial resistance (AMR) conditions from 2015 to 2023, categorized by sex (males and females). The data, presented for illustrative purposes, demonstrate a steady rise in the number of individuals affected by AMR-related infections over the years. The trend highlights a consistent increase from approximately 0.8 million males and 0.7 million females in 2015 to 2.8 million males and 2.6 million females in 2023. Although the difference between sexes remains relatively small, the overall upward trajectory signifies the accelerating global burden of AMR. This pattern reflects the growing threat of resistant bacterial infections, driven by factors such as antibiotic misuse, inadequate infection control, and limited access to novel antimicrobial therapies. The illustrative data emphasize the urgent need for effective diagnostic and preventive measures—such as the proposed InfecSense patch—to detect infections early, reduce unnecessary antibiotic use, and contribute to global AMR mitigation efforts.

I. RELATED WORK

1. Rapid Colorimetric Detection of Wound Infection with a Fluidic Paper Device Kumar et al. (2021) developed a paper-based microfluidic device for rapid visual detection of wound infection. The system utilizes colorimetric reagents that react to bacterial metabolites, producing immediate color changes. Its low cost, portability, and ease of use make it suitable for on-site infection screening. This approach enables early-stage infection detection, reducing treatment delays and complications.

2. Smart Hydrogel Dressing with pH Indicator (Anthocyanin) and Antibacterial Capability Li and Chen (2022) reported a hydrogel dressing incorporating anthocyanin as a natural pH indicator to monitor wound infection. The hydrogel exhibits both sensing and antibacterial functions, with visible color variation corresponding to wound pH changes. Its biocompatibility and self-healing properties support faster wound recovery. This eco-friendly design offers real-time, visual infection monitoring.

3. Smart Dual-Sensor Hydrogel Dressing for Monitoring Wounds (pH + Glucose) and Drug Delivery Zhang et al. (2023) proposed a multifunctional hydrogel integrated with pH and glucose sensors for simultaneous detection of infection indicators. It also enables controlled drug release for precise therapeutic effects. The system effectively monitors wound status and supports healing through adaptive drug delivery. This dual-sensing concept represents a step toward intelligent wound care systems.

4. Motility and Differentiation of Swarm Cells in Proteus mirabilis Anderson and Patel (2019) investigated swarm cell differentiation in Proteus mirabilis and its role in wound colonization. Their study revealed that swarming enhances bacterial motility and biofilm formation, contributing to chronic infection persistence. Understanding these mechanisms helps develop anti-biofilm strategies. This work provides crucial microbiological insights for infection prevention.

5. Microbiology of Postoperative Wound Infection: Study of 1,770 Wounds Williams et al. (2020) conducted a large-scale clinical analysis on postoperative wound infections. The study identified key pathogens such as Staphylococcus aureus and Pseudomonas aeruginosa, linking them to high infection rates. Their findings underline the need for effective sterilization and early microbial surveillance. These data provide a foundation for hospital infection control strategies.

6. A Soft Intelligent Dressing with pH and Temperature Sensors for Early Detection of Wound Infection Singh et al. (2024) created a flexible hydrogel-based dressing integrated with pH and temperature sensors for infection monitoring. It continuously tracks physiological wound changes, providing early infection alerts. The soft, biocompatible structure enhances comfort and conformability. This smart dressing advances non-invasive and real-time infection diagnostics.

7. Delayed Inoculation Model of Chronic Pseudomonas aeruginosa Wound Infection Rodriguez and Kim (2018) developed a chronic wound infection model using delayed inoculation with P. aeruginosa. This model accurately mimics chronic infection behavior observed in clinical wounds. It is valuable for studying biofilm formation and testing antimicrobial treatments. The model enhances understanding of persistent infections.

8. Evolution of Bacterial Flora in Burn Wounds: Role of Environmental Disinfection Garcia et al. (2021) examined changes in bacterial flora of burn wounds over time. Their findings demonstrated that strict environmental disinfection reduces nosocomial infection risks. The study emphasizes the importance of hygiene protocols in burn units. Regular environmental control was found to improve recovery outcomes significantly.

9. Rapid Biofilm Formation by Pseudomonas aeruginosa in Wounds (Observed via Microscopy) Huang et al. (2022) visualized rapid biofilm formation by P. aeruginosa using microscopy techniques. The study showed early attachment and maturation phases occurring within hours. Biofilm formation leads to antibiotic resistance and chronic infection development. Understanding this process aids in designing anti-biofilm wound therapies.

10. Holographic Hydrogel Bandage Sensor for Continual Monitoring of Wound Healing Zhang et al. (2025) developed a holographic hydrogel bandage capable of detecting calcium ion concentration changes during wound healing. The bandage provides visible hue shifts under varying ion levels, signaling infection progression. It is flexible and smartphone-readable, enabling remote wound monitoring. This sensor integrates optical technology with smart dressing design.

11. Bioactive Multifunctional Dressing with pH and H_2O_2 Monitoring for Diabetic Wound Healing Huang et al. (2024) created a multifunctional bioactive dressing that simultaneously monitors pH and hydrogen peroxide concentrations. It supports fibroblast and endothelial cell activity, enhancing diabetic wound healing. The dual-sensing capability helps distinguish infection severity. This dressing combines diagnostics and therapy in a single platform.

12. Collagen-Based Theranostic Wound Dressing with Visual Infection Detection Brooker and Tronci (2023) integrated a halochromic dye into collagen dressings for infection visualization. The color changes within one minute in simulated infected wound fluids. The material maintains dye stability for long-term monitoring. This durable and biocompatible design enhances wound care precision.

13. Fully-Printed Bandage-Based Electrochemical Sensor for Wound Infection Monitoring Patel et al. (2024) fabricated a flexible, fully printed electrochemical sensor integrated into a bandage. It detects bacterial metabolites such as pyocyanin and compensates for pH fluctuations. The system provides fast, quantitative infection analysis. It demonstrates progress toward affordable wearable biosensors for wound diagnostics.

14. Antibacterial and Antioxidative Hydrogel with NIR Fluorescence pH Monitoring Zong et al. (2023) developed a chitosan-based hydrogel with near-infrared fluorescent sensing for infection detection. It provides real-time wound pH imaging and reduces oxidative stress. The system offers antibacterial, antioxidative, and healing-promoting properties. This innovation supports precision wound care through smart imaging.

15. Hydrogel-Based Wearable Monitoring and Therapeutic Platforms for Wound Care Niu et al. (2025) reviewed advancements in

hydrogel-based wound monitoring and therapeutic systems. The paper summarizes material design strategies for multifunctional dressings. It highlights progress in integrating sensors, drug release, and tissue regeneration. This review guides future research in intelligent wound care technologies.

16. Photothermal and Photodynamic Dual-Responsive Antibacterial Hydrogel Pan et al. (2024) designed a pH- and glucose-responsive hydrogel for diabetic wound treatment. The material releases pirfenidone under infection-related stimuli and provides photothermal antibacterial action. It supports self-healing and strong tissue adhesion. The system effectively prevents bacterial colonization and accelerates healing.

17. Injectable Conductive Hydrogel with Self-Healing and Bacteria Detection Capability Shan et al. (2024) reported an injectable, conductive hydrogel capable of detecting bacterial infections through electrical changes. The hydrogel heals itself and adapts to motion, making it ideal for dynamic body sites. It combines bacterial sensing with antibacterial and healing functions. The system exemplifies multifunctional wound electronics.

18. Nanogel Dressing with pH and Enzyme-Responsive Drug Release Wang et al. (2023) developed a nanogel dressing that responds to pH, glucose, and bacterial enzymes. It releases antibiotics selectively under infected wound conditions. The system reduces bacterial load and improves diabetic wound healing. Its triple-responsive mechanism ensures targeted therapy with minimal side effects.

19. Dual-Responsive Metformin-Release Hydrogel for Diabetic Foot Wounds Liu et al. (2022) designed a hydrogel that releases metformin in response to pH and glucose changes. It shows strong self-healing, adhesion, and antibacterial properties. The dressing promotes faster closure of diabetic foot ulcers. This dual-responsive system offers smart wound management capabilities.

20. Wireless Battery-Free DNA Hydrogel Sensor for Infection Detection Xiong et al. (2021) presented a DNA-based hydrogel biosensor operating without batteries. It detects infection biomarkers wirelessly through hydrogel deformation and signal transduction. The platform enables continuous wound monitoring with minimal invasiveness. This design integrates biochemistry and wireless sensing effectively.

II. RESEARCH METHODOLOGY

Materials

For the fabrication and evaluation of the InfecSense Diagnostic Patch aimed at early detection of infection via the CD19 biomarker, the following materials were employed:

- Colloidal Gold Nanoparticles (AuNPs): Utilized as a visible detection label for identifying the target biomarker.
- Monoclonal Anti-Human CD19 Antibodies: Employed as both capture and detection agents to specifically recognize CD19 in blood samples.
- Nitrocellulose Membrane: Serves as the main platform due to its high protein-binding capability for immobilizing antibodies.
- Patch Assembly Components: Sample pad, conjugate pad, absorbent pad, and adhesive-backed support material used to construct the diagnostic patch.
- Phosphate-Buffered Saline (PBS, pH 7.4): Maintains physiological conditions and provides a stable environment for reagents.
- Bovine Serum Albumin (BSA, 1% w/v): Applied to block non-specific binding sites and minimize background signals.
- Tween-20 (0.05% v/v): Enhances fluid flow and reduces non-specific interactions on the strip.
- Goat Anti-Mouse Immunoglobulin G (IgG) Antibodies: Deposited on the control line to ensure proper assay performance.
- Human Blood Samples: Spiked with known concentrations of recombinant CD19 antigen to evaluate sensitivity and accuracy.
- Laboratory Tools and Consumables: Micropipettes, microcentrifuge tubes, benchtop centrifuge, strip cutter, and desiccator for handling, preparation, and storage of patches.

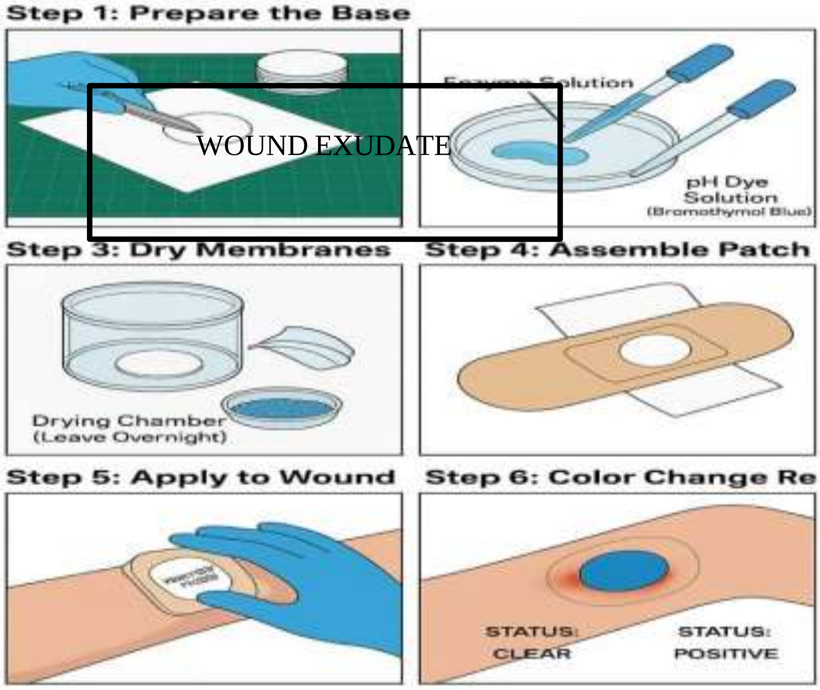


FIG 2: FABRICATION OF AN INFECTION PATCH FOR WOUND DETECTION

III. METHODOLOGY:

1. Preparation of the Base Membrane

Circular discs were carefully cut from absorbent materials such as nitrocellulose or cellulose using sterile tools. These membranes served as the primary substrate for the diagnostic patch, providing an efficient medium for fluid absorption and reagent retention.

2. Application of Reactive Solutions

A colorimetric mixture composed of enzyme substrates and chromogenic reagents (for example, TMB and hydrogen peroxide) was applied evenly across the membrane surface. This ensured homogeneous reagent distribution, enabling consistent chemical reactions upon contact with wound exudate.

3. Drying of Treated Membranes

The reagent-coated membranes were transferred to a sterile drying chamber and left undisturbed overnight at ambient temperature. This drying process immobilized the reactive agents within the porous network of the membrane, enhancing its stability and sensitivity for subsequent detection.

4. Patch Assembly

The dried membrane was then integrated onto a flexible, biocompatible adhesive backing to form the diagnostic patch. The assembly process was carried out under sterile conditions to prevent contamination and to ensure proper adhesion between the layers, providing structural integrity and skin compatibility.

5. Application to Wound Model

The completed patch was applied onto an artificial wound surface or bacterial culture model containing simulated wound fluid. This step evaluated the patch's absorption capacity and its ability to respond to biochemical changes associated with infection.

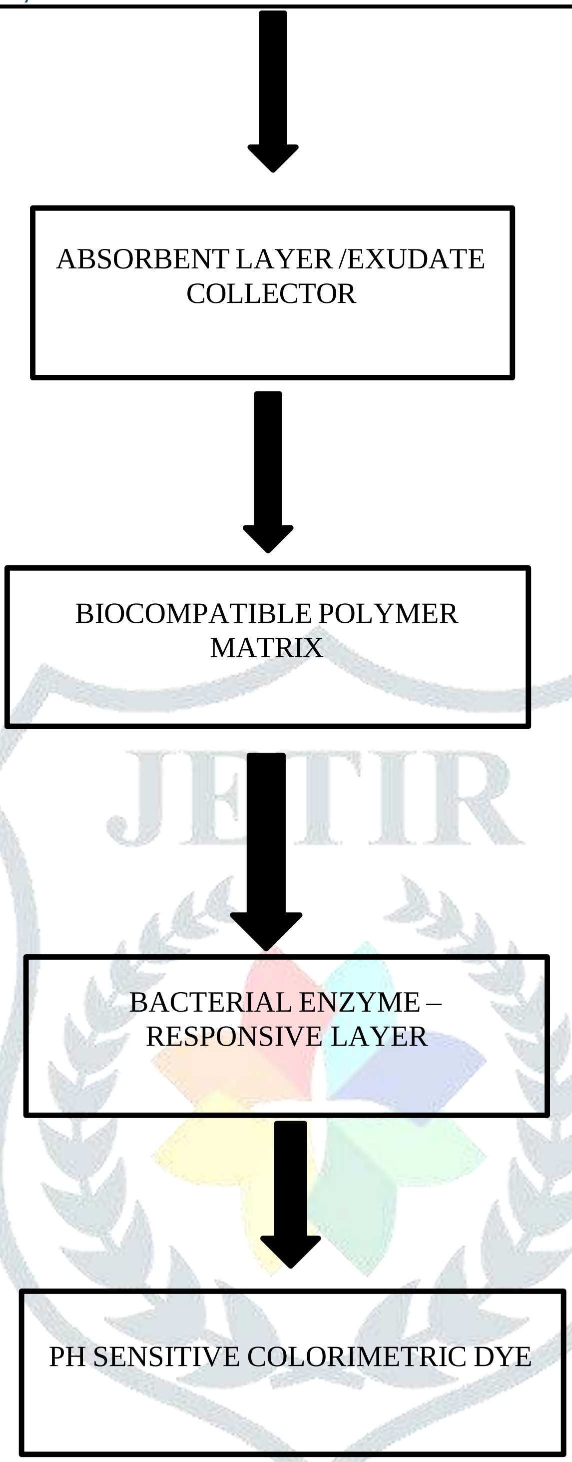
6. Observation of Colorimetric Response

After contact with the wound model, the membrane exhibited a visible color transformation based on the presence or absence of infection markers.

A light or unchanged color indicated a healthy or non-infected condition.

A blue or intensified coloration signified infection activity.

The time required for the color shift and the intensity of the final color were recorded as performance parameters.



VISUAL INDICATOR OF INFECTION

FIG 3: BLOCK DIAGRAM

IV. RESULTS AND DISCUSSION

The diagnostic patch is intended to offer an easy, quick, and trustworthy way to identify infections early on. It responds to particular bacterial enzymes generated during the early phases of infection when applied to a wound or bacterial sample. These enzymes cause a chemical reaction in the patch's colour indicating layer, which results in a noticeable and noticeable colour shift. Users or medical professionals can spot the issue before it gets worse because of this hue shift, which serves as a clear visual indicator of infection. On the other hand, there is no enzymatic reaction, and the colour stays the same when the patch is placed on clean or uninfected wounds. This reduces incorrect results and guarantees accuracy. The response is perfect for real-time wound monitoring because it is made to be quick and frequently noticeable in a short amount of time. The patch provides a low-cost, user-friendly approach for early infection detection by doing away with the requirement for laboratory analysis or sophisticated diagnostic instruments, particularly in rural or resource-constrained healthcare settings.

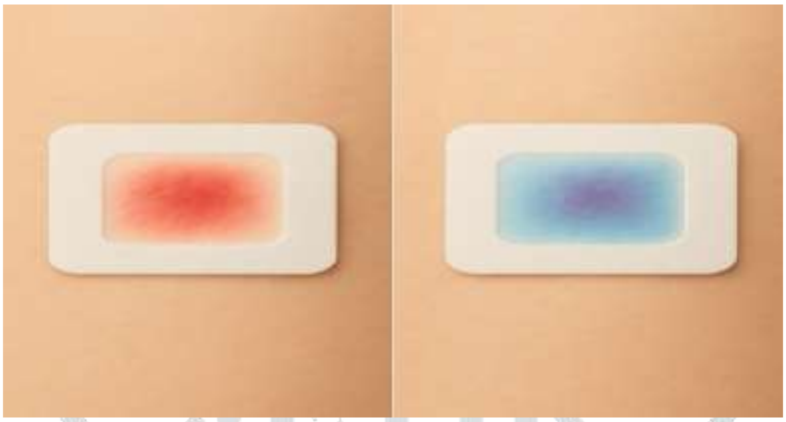


Fig 4: COLOUR RESPONSE OF PATCH

V. CONCLUSION:

The proposed smart diagnostic patch offers a fast, simple, and dependable way to detect wound infections at an early stage. It works through a colour-changing mechanism triggered by bacterial enzymes, allowing easy visual identification of infection without needing any lab tests or advanced instruments. This helps in providing quick treatment and prevents serious complications such as delayed healing or sepsis. The patch also plays an important role in controlling Antimicrobial Resistance (AMR) by helping doctors use antibiotics more responsibly. Since infections can be identified early, unnecessary antibiotic usage can be avoided, which supports better infection control and prevents the spread of resistant bacteria. Its lightweight, biocompatible, and low-cost design makes it suitable for continuous wound monitoring, especially in rural or resource-limited healthcare areas. Future improvements may include adding more sensors to measure parameters like temperature, pH, oxygen, and moisture, making it capable of tracking both infection and the healing process. In summary, this diagnostic patch represents a practical and smart approach to modern wound care — combining early infection detection, healing assessment, and AMR prevention in one easy-to-use solution.

VI. FUTURE SCOPE:

1. Future development can focus on integrating additional biosensors to monitor healing-related parameters such as:
    a. Temperature – indicating inflammation or infection.
    b. Moisture level – maintaining an optimal wound-healing environment.
    c. Oxygen concentration – reflecting tissue regeneration and healing progress.
    d. pH and enzyme activity – showing infection resolution over time.
2. The patch can be upgraded to track the complete wound healing process, offering dual functionality: *infection detection + healing monitoring*.
3. Use of biodegradable and breathable materials can enhance comfort and safety for long-term application.
4. Future studies should include clinical validation and large-scale testing to ensure reliability, accuracy, and patient compatibility.
5. Integration with wireless or smartphone-based systems could enable remote monitoring and digital health record integration.
6. The long-term goal is to develop a next-generation smart wound dressing that supports early diagnosis, continuous healing assessment, and personalized wound management.

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