



HOPE IN WAR

A report on cabbages in surgical medicine in low-resource and conflict-affected healthcare settings



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1. RESEARCH QUESTION

“How can red cabbage-based, pH-sensitive sutures and dressings be validated and adapted as a low-cost postoperative infection alert for low-resource and conflict-affected healthcare settings?”

2. HYPOTHESIS

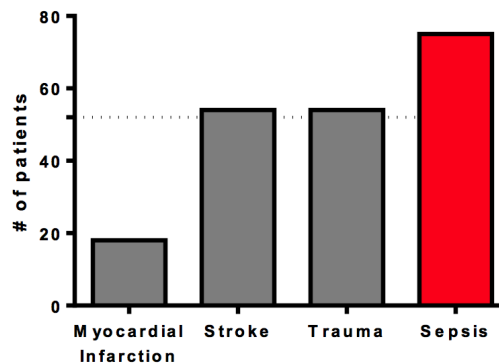
If the use of pH-sensitive sutures and dressings made using plant-based dyes is implemented in resource-scarce environments, such as war-torn regions, it could be a practical and effective early warning aid for postoperative infection, because it is instantaneous, low-tech, and cheaper than most other alternatives.

3. BACKGROUND

3.1. WHAT IS THE PROBLEM?

Postoperative infections are the most common and dangerous complications after surgery. Surgical Site Infections (SSIs) prevail in developing countries where there is a lack of proper healthcare facilities and inadequate monitoring parameters due to high costs and limited equipment. These infections occur when pathogenic bacteria enter the incision site, leading to inflammation or even life-threatening conditions known as Sepsis, which affects an estimated 47 to 50 million people worldwide, representing roughly 20% of all global deaths. The mortality rate of Sepsis varies from 15-50% depending on the severity of organ failure. In some cases the mortality rate of the sepsis and death case is more than the diseases like stroke or trauma.

Mortality Comparison



In high-resource hospitals, early detection relies on laboratory tests, Clinical Monitoring, and Advanced wound care systems, which are costly and highly dependent on electricity. In low-resource and conflict-affected settings, however, these systems are often unavailable. This leads to illnesses going undetected for too long, patients returning with severe conditions, and mortality rates increasing significantly.

A major challenge is that early infections are subtle; In the first few hours or days, there might only be mild redness, slight warmth, small amounts of discharge, or vague pain that may be incorrectly attributed to regular healing by patients. By the time the signs become obvious, more tissue may be infected, or the patient may have developed systemic illness, which makes treatment more difficult,

expensive and dangerous. It also does not help that clinical inspection, as of current, depends on trained staff, repeated follow-ups, and laboratory check-ups, which can be difficult to conduct in conflict zones, requires specialised equipment, and can get expensive.

3.2. WHO IS AFFECTED AND HOW WIDELY?

The people most affected by SSIs and post-procedure complications are patients in settings with limited medical staffing, supplies, and diagnostic capacity. Regions suffering from conflict and poverty are especially prone to SSIs due to the high casualty rate and weaker continuity of care. In low and middle-income countries, 11% of patients who undergo surgery are infected in the process, and in various areas in Africa, up to 20% of women who undergo a caesarean section contract a wound infection. Specifically in Sudan, where there is active civil unrest, the rate of postoperative complications was 57.6% in conflict zones, as opposed to safer areas, which was about 26.4%, with there being a greater proportion of complications attributed to SSIs in conflict areas than in safer areas, according to BJS.

4. KEY FINDINGS

Researchers have found that wound infections alter the chemical environment of wounds, particularly the pH. Normally, the pH of healthy skin is around 4.2 to 5.6, which rises to about 7-9 in the case of an infection due to bacterial metabolism and tissue degradation. A 2015 study showed that in 26 second-degree burn cases (where there is damage to the epidermis and the dermis of the skin), 6 developed local wound infections, and the researchers measured, using probes, a maximum pH of 10 and a minimum of 5 in all cases. In cases of local infection, the pH rose before the onset of clinical signs of local burn infection. Additionally, research authored by Daniel G. Metgalf and team used data from 120 wound samples and concluded that “With increasing wound pH, there was also an increase in the proportion of infected wounds as determined by expert clinical judgement”.

However, the same research also states that monitoring pH alone is not sufficient to promote the use of pH as a diagnostic tool for infection, and that “increases in the activities of myeloperoxidase, elastase and lysozyme were also associated with elevated pH”. Furthermore, research done by Khalad Mariyar, Reneeka Persaud-Jaimangal, and R Gary Sibbald concludes that, in their “100-patient prospective cross-sectional cohort study [which was] conducted with leg and foot wounds... There was no significant difference in the mean wound bed pH in patients with superficial critical colonization and those without”. They instead compared the temperature on their wounded and healthy limb and concluded that it served as a better indicator of infection. This shows that, although pH alone is not perfectly specific to SSIs (as it can be influenced by wound type, discharge, dressing materials, and healing stage) and that it cannot be a conclusive medical diagnosis, it performs best in conjunction with other factors like temperature and neutrophil enzyme activity.

Researchers continue to pursue this area of study, with a focus on building smart dressings that change colour when the pH rises rather than probes. Researchers at Linköping University, with colleagues from Örebro and Luleå Universities, have developed a nanocellulose wound dressing that changes from yellow to blue, due to the presence of bromothymol blue, a pH indicator that changes colour when the pH exceeds 7. However, nanocellulose is currently considered expensive despite how effective it is at keeping pathogens out of the wound. The dye is also loaded onto a silica material, which further increases its cost, and can be toxic if exposed to the wound.

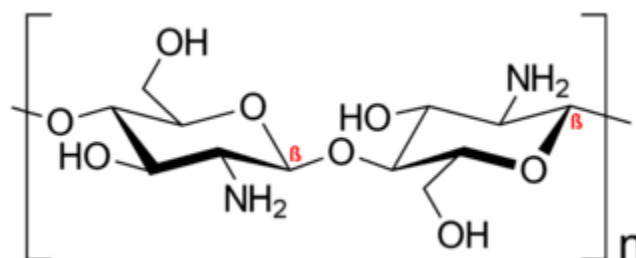
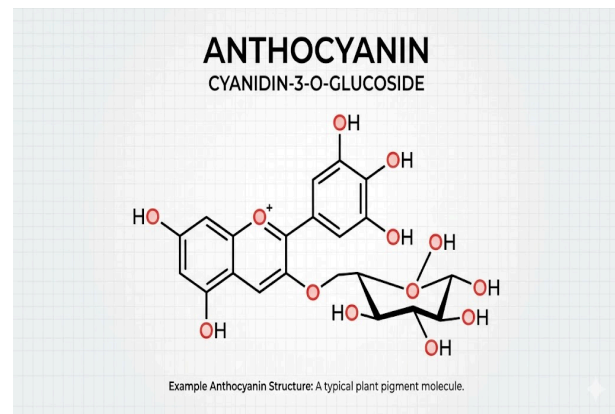
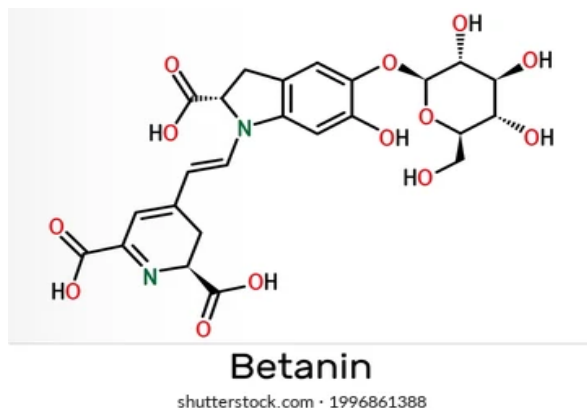
Like this, most smart dressings and sutures use complex and expensive technology, such as Bioelectronic Sutures with Electrochemical pH-Sensing proposed by Hwajoong Kim and team, and the battery-free wireless smart sutures that researchers at NUS invented. A smart dressing made by researchers at RMIT University in Australia, which utilises Magnesium hydroxide in engineered fluorescent nanosheets, is deemed to be 20 times cheaper than its silver-based counterparts, but is still expensive in the context of a high-pressure environment.

Looking at just smart dressings and sutures that utilise cheap dyes, they are separated by fluorescent probes, which glow under UV light, and colourimetric probes, which visually change colour. Out of these two, the colourimetric ones are more cost-effective, while meeting the indication requirements necessary. Additionally, fluorescent probing comes with added design and implementation complexity.

5. PROPOSED IDEA

5.1. WHAT SHOULD BE DONE

This research proposes the development and validation of a low-cost, plant-derived pH-sensitive smart suture system for early detection of post-operative infections. The proposed system was built upon initial beet-based (betanin) concepts but advances toward a more stable and industrially scalable biomaterial design by incorporating Anthocyanin as the primary pH-responsive agent. This pigment will be embedded within a Chitosan coating, which can be applied to the standard surgical sutures.



Chitosan

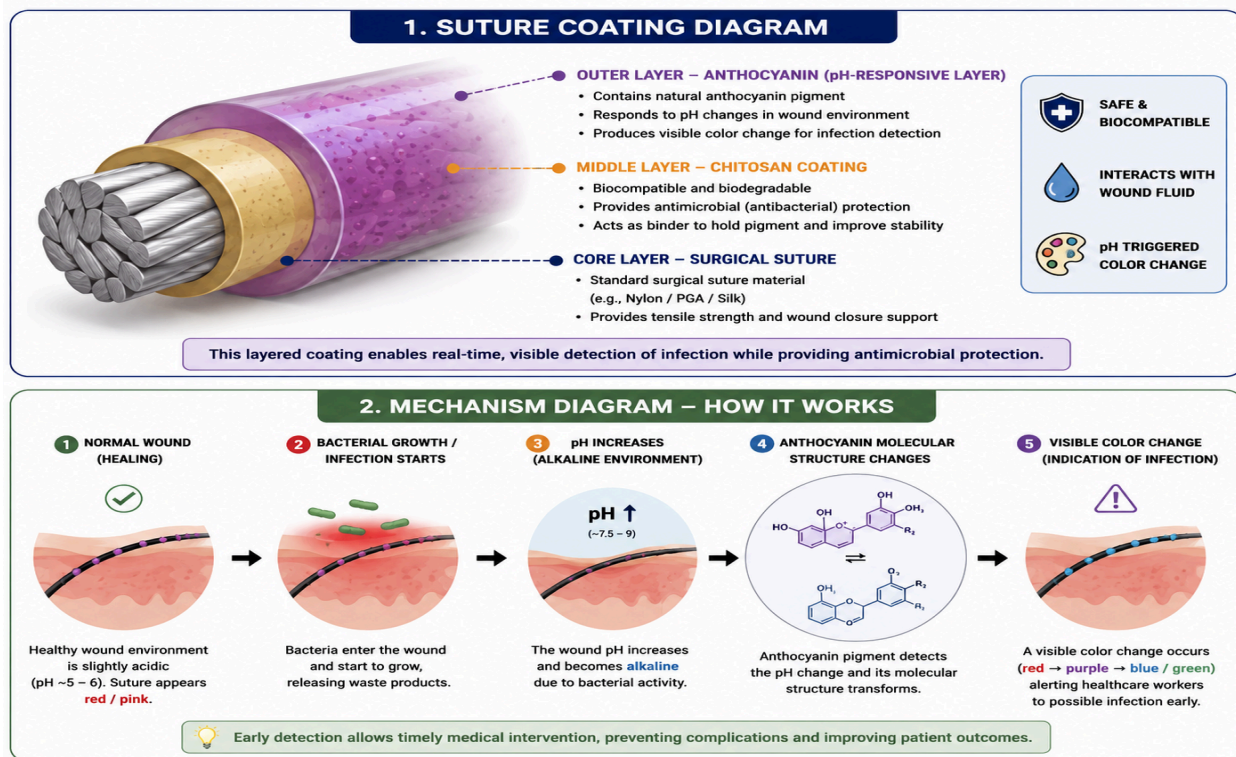
These new sutures will exhibit visible colour changes in response to pH variations associated with infection. They can be engineered to maintain biocompatibility and safety for direct contact with human tissue and to provide real-time, non-invasive monitoring without external devices.

This research will involve:

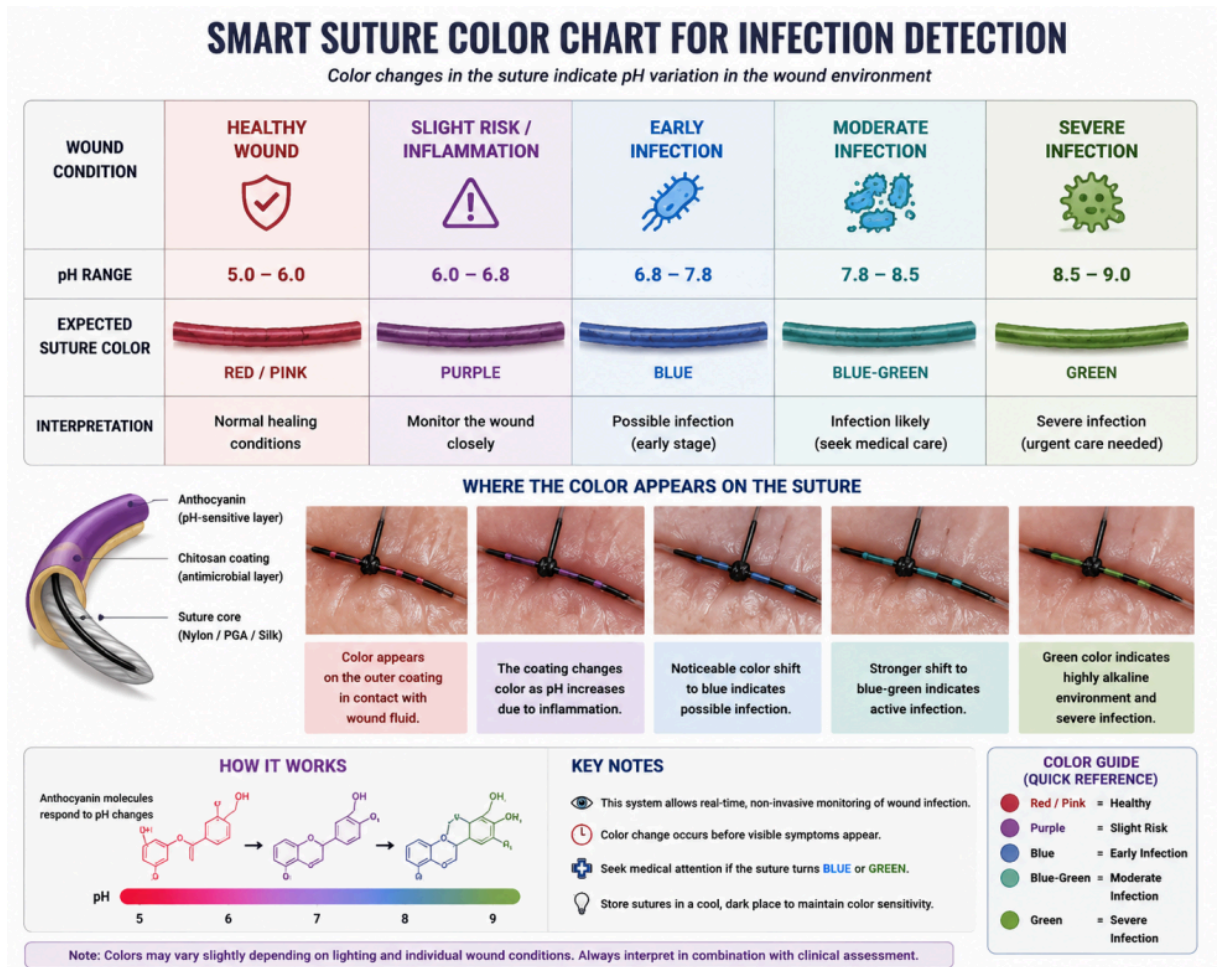
Extraction or sourcing of stable anthocyanin pigments, which can be used for industrial purposes: To ensure that the system designed for a pH-dependent application proves to be stable and scalable, the extraction of Anthocyanins by the acid ethanol method will be carried out. This procedure will allow obtaining maximum extraction efficiency of the pigments and thus developing the most effective system possible. In this case, plant materials, such as red cabbage or purple sweet potatoes, that contain a high amount of Anthocyanins, can be used to develop a solution based on ethanol and acid (for example, citric acid). After that, the resulting substance should be filtered and concentrated at a reduced temperature to avoid its destruction. In order to increase the resistance to heat and light, as well as to ensure its biocompatibility, the solution can be encapsulated by Chitosan.

Development of a chitosan-based coating matrix: A stable coating will be obtained using a formula containing Chitosan due to its good film-forming nature, biocompatibility, and natural antimicrobial properties. Chitosan will first be dissolved in a mild acidic medium, for example, dilute acetic acid, in order to create a homogenous polymer solution that enables good dispersion and interaction between Chitosan and Anthocyanin. In the next step, Anthocyanin will be mixed into this solution under controlled conditions to obtain a good mixture. After mixing, this solution will be coated on the surface of the surgical sutures using techniques like dipping or spraying, followed by a controlled drying process in order to obtain a stable thin coating on the surgical sutures. This will help us to ensure effective adhesion of the film to the suture and protection of the pigment from environmental factors, while keeping its pH-responsive character intact from outer factors.

Application onto surgical sutures: The prepared Chitosan and Anthocyanin coating matrix will be applied onto standard surgical sutures using a controlled dip-coating or spray-coating technique. This would involve submerging the sterilised sutures (nylon and PGA) into the coating mixture so that a thin and even film layer is formed on the suture's surface. The process should be conducted in a controlled environment with regard to temperature and humidity levels to enhance the bonding of the coating with the suture without affecting its physical properties. This technique ensures that there is good adherence between the coating and the surface of the suture.



Calibration of colour response across infection-relevant pH ranges: To ensure that infections can be accurately detected using the Anthocyanin-coated sutures, it is necessary to calibrate them across a range of physiologically relevant pH solutions. In order to accomplish this task, standard buffer solutions corresponding to both normal and infected states of the wound (which are usually in the range of 5.0-9.0 pH) should be used, and then the coated sutures should be exposed to those pH solutions in laboratory conditions. Colour responses resulting from such exposures should be measured and analysed in order to conclude the relationship between the observed colours and the pH level of the medium. Specifically, it is expected that the Anthocyanin-coated sutures would change their color to red or pink when exposed to acidic solutions (with pH of ≈ 5.0 – 6.0), to purple when exposed to near neutral solutions (with pH of ≈ 6.5 – 7.0), to blue when exposed to slightly basic solutions (with pH of ≈ 7.5 – 8.0) and finally to green or blue-green when exposed to highly basic solutions (with pH of ≈ 8.5 – 9.0). Once calibrated, charts that map colour to the corresponding wound condition across a range of skin tones would be created and distributed to patients to monitor their sutures with higher precision, eliminating incorrect diagnoses and skin-tone bias, similar to the chart below.



The outcome aims to produce a low-cost, scalable, and clinically adaptable suture suitable for low-cost healthcare settings.

5.2. WHO SHOULD DO IT?

The successful development and deployment of this solution requires a multi-level collaborative approach:

1. Student researchers and innovation teams for initial prototyping and experimental validation
2. Biomedical scientists and material engineers for optimising polymer–pigment integration and ensuring long-term stability
3. Healthcare professionals (surgeons, nurses) for usability testing and clinical feedback
4. Public health organisations and NGOs for distributing it in low-resource and conflict-affected regions
5. Medical manufacturing companies for large-scale production and regulatory approval

In practice, the technology will be used by surgeons during wound closure, healthcare workers in rural or under-resourced clinics, and emergency responders in disaster and conflict zones

5.3. WHY WOULD IT WORK?

The proposed system is expected to be effective because it integrates established biochemical principles, validated material science, and practical clinical design into a single, optimised solution.

Anthocyanins exhibit distinct and visible colour transitions across different pH ranges, enabling immediate visual detection of infection without requiring electronic sensors or laboratory analysis. Unlike Betanin (which is found in beet), anthocyanin offers:

1. Improved chemical stability
2. Better adaptability for material integration
3. More consistent performance in controlled systems

Chitosan plays a critical role by stabilising the pigments against environmental degradation. It provides inherent antimicrobial properties. It also works as a biocompatible interface with human tissue, which creates a dual function system via Detection (due to the pigment) and Prevention (due to the antimicrobial polymer)

Both anthocyanin and chitosan are widely available, economically feasible, and already used in food and biomedical industries. This allows mass production at low cost and easy adaptation into existing suture manufacturing processes

By combining pH-responsive natural pigments with biocompatible polymer technology, this approach transforms a conventional surgical material into an intelligent diagnostic tool, bridging the gap between advanced medical sensing and real-world accessibility.

6. CONCLUSION

How can sutures, which change colour due to pH as a result of applying red cabbage and other coloured plant dyes to them, be implemented as a cost-effective, post-surgery infection indicator in areas of high pressure and limited resources? As infection takes place, the pH of that wound generally increases from a normal 4.2-5.6 range to a 7-9 range, which provides a useful indicator for the status of a suture or a wound dressing. Taking resource constraints and circumstances into consideration, to provide a relative and early indicator of infection in areas of high pressure, such as in regions where war is taking place, we use anthocyanin in specialised and cost-effective sutures that change colour from red to blue when a change in pH is detected, thereby indicating a high likelihood of infection. We have also detailed a simple method for patients with such sutures to self-identify the status of their wound using a coloured chart, therefore removing the issue of misdiagnosing the presence or severity of the infection. This is crucial to the survival of those living in resource-scarce areas as it proposes an affordable, low-technology solution to SSIs, which is one of the most common healthcare-associated infections in areas where expensive "smart" medical devices are inaccessible.

7. REFERENCES

Ashraf, A., Ibrahim, A., Ibrahim, S., Adam, T., Mohammed, S., Adam, A., Elbager, R., Abdulaziz, L., Gameraldeen, A., Izzeldin, A., Yassir, R., Khalid, S., & Azhari, A. (2025). 291 The Impact of War on Surgical Interventions: A Comparative Analysis on Prevalence and Types of Postoperative

- Complications Across Conflict and Safe Sudanese States, 2024. *British Journal of Surgery*, 112(Supplement_10). <https://doi.org/10.1093/bjs/znaf128.475>
- Eskilson, O., Zattarin, E., Berglund, L., Oksman, K., Hanna, K., Rakar, J., Sivilér, P., Skog, M., Rinklake, I., Shamasha, R., Sotra, Z., Starkenberg, A., Odén, M., Wiman, E., Khalaf, H., Bengtsson, T., Junker, J. P. E., Selegård, R., Björk, E. M., & Aili, D. (2023). Nanocellulose composite wound dressings for real-time pH wound monitoring. *Materials Today Bio*, 19, 100574. <https://doi.org/10.1016/j.mtbio.2023.100574>
- Joy, H. (2021, June 29). *Smart Dressings Developed Help Heal Wounds Faster*. Medindia. <https://www.medindia.net/news/healthwatch/smart-dressings-developed-help-heal-wounds-faster-201988-1.htm>
- Kim, H., Jung Hyun Kim, Jeong, M., Lee, D., Kim, J., Lee, M., Kim, G., Kim, J., Jung Seung Lee, & Lee, J. (2024). Bioelectronic Sutures with Electrochemical pH-Sensing for Long-Term Monitoring of the Wound Healing Progress. *Advanced Functional Materials*. <https://doi.org/10.1002/adfm.202402501>
- Lowe, H., Woodd, S., Lange, I. L., Janjanin, S., Barnett, J., & Graham, W. (2021). Challenges and opportunities for infection prevention and control in hospitals in conflict-affected settings: A qualitative study. *Conflict and Health*, 15(1), 94.
- Maliyar, K., Persaud-Jaimangal, R., & Sibbald, R. G. (2020). Associations Among Skin Surface pH, Temperature, and Bacterial Burden in Wounds. *Advances in Skin & Wound Care*, 33(4), 180–185. <https://doi.org/10.1097/01.asw.0000655488.33274.d0>
- Metcalf, D. G., Haalboom, M., Bowler, P. G., Gamerith, C., Sigl, E., Heinzle, A., & Burnet, M. W. M. (2019). Elevated wound fluid pH correlates with increased risk of wound infection. *Wound Medicine*, 26(1), 100166. <https://doi.org/10.1016/j.wndm.2019.100166>
- National University of Singapore. (2021, December 29). *Smart sutures to monitor deep surgical wounds*. Smart Sutures to Monitor Deep Surgical Wounds ; National University of Singapore. <https://news.nus.edu.sg/smart-sutures-to-monitor-deep-surgical-wounds/>
- Ono, S., Imai, R., Ida, Y., Shibata, D., Komiya, T., & Matsumura, H. (2015). Increased wound pH as an indicator of local wound infection in second degree burns. *Burns*, 41(4), 820–824. <https://doi.org/10.1016/j.burns.2014.10.023>
- Rasheed, S., Ikram, M., Ahmad, D., Naseer Abbas, M., & Shafique, M. (2024). Advancements in colorimetric and fluorescent-based sensing approaches for point-of-care testing in forensic sample analysis. *Microchemical Journal*, 206, 111438. <https://doi.org/10.1016/j.microc.2024.111438>
- Truskewycz, A., Truong, V. K., Ball, A. S., Houshyar, S., Nassar, N., Yin, H., Murdoch, B. J., & Cole, I. (2021). Fluorescent Magnesium Hydroxide Nanosheet Bandages with Tailored Properties for

Biocompatible Antimicrobial Wound Dressings and pH Monitoring. *ACS Applied Materials & Interfaces*, 13(24), 27904–27919. <https://doi.org/10.1021/acsami.1c05908>

Wang, X., Ding, Q., Groleau, R. R., Wu, L., Mao, Y., Che, F., Oxana Kotova, Scanlan, E. M., Lewis, S. E., Li, P., Tang, B., James, T. D., & Thorfinnur Gunnlaugsson. (2024). Fluorescent Probes for Disease Diagnosis. *Chemical Reviews*, 124(11). <https://doi.org/10.1021/acs.chemrev.3c00776>

World Health Organization. (2018). *Surgical site infection*. Wwww.who.int. <https://www.who.int/teams/integrated-health-services/infection-prevention-control/surgical-site-infection>

Chen, T. (2024, January 10). *An Antioxidant Hydrogel dressing with wound pH indication function prepared based on silanized bacterial nanocellulose crosslinked with beet red pigment extract* (Y. Yan & X. Z. Zhou , Eds.). <https://www.sciencedirect.com/science/article/abs/pii/S0141813024026291?>

Gu, H., Sun, X., Bao, H., Feng, X., & Chen, Y. (2025). Optically pH-Sensing in smart wound dressings towards real-time monitoring of wound states: A review. *Analytica Chimica Acta*, 1350, 343808. <https://www.sciencedirect.com/science/article/pii/S0003267025002028>

Luan, Z., Liu, S., Wang, W., Xu, K., & Yang, S. (2022). Aligned nanofibrous collagen membranes from fish swim bladder as a tough and acid-resistant suture for pH-regulated stomach perforation and tendon rupture. *Biomaterials Research*, 26(1). https://www.researchgate.net/publication/365256320_Aligned_nanofibrous_collagen_membranes_from_fish_swim_bladder_as_a_tough_and_acid-resistant_suture_for_pH-regulated_stomach_perforation_and_tendon_rupture

Miao, J., Chai, H., Song, L., Liao, X., Chen, S., Xiao, Y., & Wang, R. (2026). A pH-responsive anthocyanin-based hydrogel with colorimetric infection monitoring and antibacterial properties for wound healing. *Journal of Materials Chemistry B*. <https://pubs.rsc.org/en/content/articlelanding/2026/tb/d5tb01386k/unauth>

Pan, N., Qin, J., Feng, P., Li, Z., & Song, B. (2019). Color-changing smart fibrous materials for naked eye real-time monitoring of wound pH. *Journal of Materials Chemistry B*, 7(16), 2626–2633. <https://pubs.rsc.org/en/content/articlelanding/2019/TB/C9TB00195F>

Phan, P. T., Hoang, T. T., Thai, M. T., Low, H., Davies, J., Lovell, N. H., & Do, T. N. (2021). Smart surgical sutures using soft artificial muscles. *Scientific Reports*, 11, 22420. [Smart surgical sutures using soft artificial muscles - PMC](#)

Syam, A., Cusick, N., Zilles, A., & Schönherr, H. (2026). pH-responsive carborhodol-coupled chitosan-based hydrogels for the detection of wound infection-relevant pH changes. *Materials Advances*.