BIOSENSORS & NANOTHERANOSTICS REVIEW

Smart Textiles with Integrated Biosensors for Real-time Health Monitoring

Hilal Ahmad Rather [1], Mohd Arif Dar [2]

Abstract

Background: The advent of wearable technology has paved the way for smart textiles, which integrate biosensors into the fabric itself. This integration enhances comfort, continuous monitoring, and data accuracy, transforming the fabric into a second skin. These smart textiles can monitor vital signs, metabolic markers, and environmental pollutants in real-time, providing valuable health insights and environmental data. Methods: This review explores the materials, types of biosensors, and methods used to integrate them into textiles. It examines various bioreceptors, such as enzymes, antibodies, and nucleic acids, and their specific applications in biosensing. The study also discusses physicochemical detectors, including electrochemical, optical, and piezoelectric sensors, and their signal transduction mechanisms. Results: Smart textiles equipped with biosensors demonstrate significant potential in real-time health monitoring and environmental sensing. Vital signs, glucose, lactate, pathogens, and pollutants can be effectively monitored using these textiles. The integration techniques, such as weaving, knitting, and printing technologies, ensure seamless blending of biosensors with the fabric. The incorporation of advanced materials like graphene and carbon nanotubes enhances the conductivity and sensing capabilities of these textiles. Conclusion: Smart textiles with integrated biosensors represent a significant advancement in healthcare and environmental monitoring. They offer real-time, continuous, and non-invasive monitoring capabilities, transforming how individuals manage their health and how environmental data is collected. Despite challenges such as biocompatibility, durability, and cost, ongoing research and development promise to address these issues, paving the way for widespread adoption and innovation in this field.

Keywords: Smart textiles, Biosensors, Health monitoring, Environmental sensing, Wearable technology

Significance | Integrating biosensors into smart textiles revolutionizes health monitoring, offering real-time, unobtrusive data collection for proactive healthcare management.

*Correspondence. Hilal Ahmad Rather, Research and Development Division, A TO Z HERBALS, Industrial estate, Tulbal, Sopore, J&K-193201 India.
Email ID: dararifphy@gmail.com

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1. Introduction

As wearable technology becomes more popular, smart textiles emerge as a step forward. They provide better comfort, are less noticeable, and offer continuous monitoring compared to regular wristbands and chest straps (Park, J., et al., 2024). Instead of just sticking sensors onto clothes, the real innovation is integrating biosensors directly into the fabric itself. This creates a closer connection and more accurate data collection, making the boundary between clothing and a second skin almost indistinguishable (Schügerl, K., et al., 1996).

These biosensors, working in real-time, open up numerous possibilities. They can monitor vital signs like heart rate and respiration, as well as important substances like glucose and lactate. Essentially, these fabrics act as a live window into our body, enabling individuals to actively manage their health (Cherenack, K.,

Author Affiliation.
[1] Research and Development Division, A TO Z HERBALS, Industrial estate, Tulbal, Sopore, J&K-193201 India.
[2] Faculty of Allied Health Sciences, Chettinad Hospital, and Research Institute, Chettinad Academy of Research and Education, Kelambakkam-603103, Tamil Nadu, India

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& Van Pieterson, L. 2012).

Smart textiles mark a significant change in healthcare, shifting from reacting to health issues to actively managing well-being. Imagine clothes that effortlessly gather essential data, warn about potential health risks, and give personalized advice, promoting a proactive approach to staying healthy (Tröster, G. 2005).

This review presents comprehensive information about smart textiles and their integrated biosensors. We explore the various kinds of biosensors used, the different substances they can identify, and the wide array of applications they open up in different areas of healthcare. Furthermore, we illuminate the challenges and future pathways, tackling issues related to how well these devices work with our bodies, keeping our data secure, and staying current with ongoing developments in materials and integration.

2. Smart Textiles: Weaving Technology into the Fabric.

Smart textiles are defined as "textile materials which can sense and react to environmental stimuli or which can actively control environmental conditions". They go beyond mere textiles by incorporating a range of functionalities, including, 1. Sensing is the ability to detect various stimuli like temperature, pressure, light, and even biometrics, 2. Actuation which includes responding to those stimuli by changing color, shape, or emitting light or heat and 3. Communication that's transmitting data wirelessly to other devices or systems (Končar, V. 2016).

2.1. Materials for Smart Textiles:

Smart textiles incorporate a wide variety of materials, each contributing distinct properties and functionalities to enhance their performance. Among the commonly employed materials are natural fibers such as cotton, wool, and silk (Ali, N., El-Khatib, E., & Bassyouni, F. 2022), which undergo treatment with conductive polymers or nanoparticles to acquire functional attributes. Synthetic fibers like polyester, nylon, and Spandex provide inherent flexibility and are easily modifiable through chemical treatments (Ding, Y., et al., 2023). Additionally, high-tech fibers, exemplified by advanced materials like graphene and carbon nanotubes, bring about exceptional conductivity and sensing capabilities to further augment the functionalities of smart textiles(Alamer, F. A., & Almalki, G. A. 2022).

3. Biosensors Translating biomolecular interactions into measurable signals.

Biosensors are analytical devices that combine a biological component with a physicochemical detector to convert a biological response into a measurable signal (Victorious, A., et al., 2019). In the context of health monitoring, biosensors play a pivotal role by enabling the real-time detection and quantification of specific biological markers.

3.1. Components in Biosensing for Smart Textiles.

3.1.1. Bioreceptors:

At the core of a biosensor lies the bioreceptor or biological component, a molecule selectively interacting with a specific target analyte (e.g., glucose, lactate). Enzymes, antibodies, and DNA are popular bioreceptor choices, each exhibiting exquisite specificity for their designated targets (Table 2). Upon analyte binding, the bioreceptor undergoes a physical or chemical change, influencing a transducer element.

3.1.1.1. Enzymes:

Enzymes are proteins that catalyze specific biochemical reactions. In biosensors, they play a crucial role in recognizing and reacting with target substances, leading to a measurable response. For example, glucose biosensors often use glucose oxidase to detect glucose levels (Sonawane, A., et al., 2017).

3.1.1.2 Antibodies:

Antibodies are immune system proteins that bind to specific antigens. In biosensors, antibodies are employed to recognize and bind with target molecules, forming the basis for selective detection. This specificity is beneficial for identifying particular pathogens or biomarkers (Ponmozhi, J., et al., 2012).

3.1.1.3. Nucleic Acids:

DNA and RNA can also serve as biological components in biosensors. DNA probes or aptamers can be designed to bind selectively to target molecules, providing a molecular recognition element for biosensor applications. This approach is particularly valuable in nucleic acid sensing (Malucelli, G., et al., 2014).

3.1.2. Physicochemical Detectors:

The detectors in biosensors convert the biological response triggered by the interaction of biological components with target analytes into measurable signals. Various physicochemical detectors are employed to capture these responses:

3.1.2.1. Electrochemical Sensors:

These sensors measure changes in electrical current or voltage resulting from a biochemical reaction. Common in glucose monitoring, electrochemical biosensors are known for their sensitivity and real-time detection capabilities.

Electrochemical sensors are used in smart textiles to detect signals from their surrounding environment and convert them into useful data for analysis. The working mechanism of electrochemical sensors for smart textiles involves the use of a conductive polymer that is coated onto the textile surface (Figure 1). This polymer is then used to detect changes in the environment, such as changes in temperature, humidity, or the presence of certain gasses. When the polymer comes into contact with the target analyte, it undergoes a chemical reaction that generates an electrical signal (Stoppa M, and Chiolerio A. 2014).

The electrical signal generated by the sensor is then transmitted to a microcontroller, which processes the data and sends it to a computer or other device for analysis. This data can be used to

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monitor environmental conditions, detect the presence of harmful gasses, or track the movement of people or objects (Stoppa M, and Chiolerio A. 2014).

3.1.2.2. Optical Sensors:

Optical detectors use light absorption, fluorescence, or refractive index changes to signal biochemical interactions. This includes fluorescence-based sensors for DNA detection or colorimetric assays. These sensors use light sources and detectors to measure various parameters. Light absorption, reflection, or fluorescence changes can indicate temperature, pressure, gas presence, or even chemical composition. Bahin, L., et al., (2023) investigated the feasibility of integrating polymeric optical fibers (POFs) into textiles to accurately measure compression and bending near the skin's surface. The study systematically examines the impact of various mechanical loads on the optical signal transmitted by the POF. Employing an optical device comprising a light source, optical sensor, and photodiode, the researchers utilized a PDMS POF for deformation sensitivity and PMMA multifilaments for non-deformation sensitivity. By subjecting the sensor POF to tension, torsion, transverse compression, and pure bending, the researchers characterized its response to each loading condition. They observed high sensitivity to bending, moderate sensitivity to compression, and insensitivity to tension and torsion. Consequently, they developed a method to integrate the POF sensor into textile structures, enabling effective measurement of compression and bending. This approach offers promising prospects for the development of smart textiles capable of accurately monitoring these mechanical parameters.

Additionally, the study conducted by Guignier, et al., in 2019, aimed to determine the properties of POFs suitable for insertion into knitted fabrics. The chosen POF was the Geniomer® 100, which was inserted into three knitted fabrics. The POFs were found to be sensitive to both compression and friction, with the single jersey fabric showing the highest sensitivity. Additionally, a feasibility study demonstrated that the POFs inserted into a sock were able to measure stresses during walking, indicating potential for monitoring friction and compression during walking.

3.1.2.3. Piezoelectric Sensors:

These sensors detect changes in mass on a quartz crystal surface, resulting in alterations in frequency. Piezoelectric biosensors are sensitive and can be used in label-free detection methods, making them suitable for applications like protein-protein interactions.

When piezoelectric materials experience mechanical stress, such as pressure or stretching, they respond by generating an electric charge. Conversely, applying an electric field can also cause them to physically deform. This two-way interaction forms the basis of piezoelectric sensors. A recent study was conducted by Lee, et al., (2023) for the development of a force-sensing smart textile by integrating Fiber Bragg Grating (FBG) sensors into a knitted undergarment using a novel inlay and embedding technique. The smart textile aims to monitor and adjust the force exerted by braces, particularly for conditions like adolescent idiopathic scoliosis (AIS). The study demonstrates the enhanced stability, linearity, and reliability of the silicone-embedded FBG sensors compared to conventional methods. The sensors are designed to provide real-time data acquisition for monitoring and adjusting force during the fitting process, particularly in bracing treatment for conditions such as AIS. The study also highlights the potential of smart textiles to improve the fitting process, prevent excessive pressure, and enhance the effectiveness of bracing treatment.

3.1.3. Transducers:

The transducer serves as the conductor of the biosensing orchestra, converting the bioreceptor's response into a quantifiable signal. Signal transduction is the process by which the biological response generated by the interaction between biological components and target analytes is translated into a measurable signal (Stock, A., et al., 2000). This is a critical step in biosensing for health monitoring:

3.1.3.1. Electrochemical Signal Transduction:

In electrochemical biosensors, the biochemical reaction leads to changes in electrical properties, such as current or voltage. These changes are then translated into a measurable signal indicating the presence and concentration of the target analyte. According to Sinha, A., et al., (2022), electrochemical signal transduction in smart textiles represents a burgeoning field where textiles and their composite materials serve as preferred platforms for functional sensors. These sensors are fabricated through integration of conductive fibers and yarns into textiles using weaving, knitting, and embroidery techniques, or by functionalizing textile materials with conductive nanomaterials/inks through printing or coating methods. They enable rapid and accurate electrical measurements for real-time point-of-care diagnostics and environmental monitoring applications. Recent progress has been made in developing textile-based electrochemical sensors and biosensors, with electrode configurations based on both natural and synthetic fabrics.

3.1.3.2. Optical Signal Transduction:

Optical biosensors convert biochemical interactions into detectable optical signals, such as changes in light intensity or wavelength. The resulting optical signals provide information about the concentration of the target analyte. Embedded fibers act as sensors, whispering changes in light based on pressure, temperature, or even chemicals. Specialized materials translate these whispers into electrical signals, allowing your shirt to monitor your heart rate or your bandage to track healing, all thanks to the silent symphony of light within the fabric. Challenges remain, but imagine clothes that seamlessly gather data, respond to your needs, and weave the future into a personalized experience, one thread at a time.(Narayanaswamy, R., 1993)

3.1.3.3. Piezoelectric Signal Transduction: In piezoelectric biosensors, the interaction between biological components and target analytes causes a mass change on the crystal surface, altering its resonance frequency. This change in frequency is translated into a measurable signal indicative of the analyte concentration (Zang, Y., et al., 2015).

3.2 Advancing the Biosensing properties:

Nanomaterials like graphene and carbon nanotubes are being woven into fabrics, enhancing their conductivity and sensing capabilities. Microfluidics is being incorporated to manage biofluids within textile sensors, enabling analysis of sweat, tears, and even interstitial fluid. Furthermore, the burgeoning field of biocompatible electronics paves the way for flexible, skin-like sensors seamlessly integrating with the human body (Libertino, S., et al., 2018).

4. Integration of Biosensors into Smart Textiles

4.1 Navigating Challenges and Embracing Opportunities

4.1.1. Challenges:

Biocompatibility Balancing Act: Striking a delicate balance between effective biosensing and biocompatibility to prevent skin irritation or allergic reactions (Karamchand, L., et al., 2023).

Durability Dilemmas: Addressing the challenge of creating robust biosensors capable of withstanding daily wear, including washing and stretching (Zhou, J., et al., 2023).

Cost Considerations: Acknowledging the economic challenges associated with scaling up the production of biosensor-integrated textiles for broader accessibility (Zhou, J., et al., 2023).

4.1.2. Opportunities:

Precision in Health Monitoring: Harnessing biosensors offers unparalleled precision in real-time health monitoring, providing invaluable insights into vital metrics (Velasco-Garcia, M. N., & Mottram, T. 2003).

Customization Potential: Tailoring biosensors to specific health parameters opens avenues for personalized healthcare solutions, catering to individual needs (Mehrotra, P. 2016).

Market Growth Prospects: The surging demand for wearable health technology creates a promising landscape for innovators in the realm of biosensor-integrated textiles (Cherenack, K., & Van Pieterson, L. 2012).

4.2 Techniques for Harmonious Integration

4.2.1. Textile Fabrication Methods:

Weaving and Knitting: Incorporating biosensors during the weaving or knitting process ensures even distribution, seamlessly blending with the fabric's intrinsic properties (De Kok, M., et al., 2015).

Printing Technologies: Leveraging techniques like screen or inkjet printing empowers precise application of biosensors onto textiles, affording control over their placement (Li, S. 2023).

4.2.2. Flexible Substrates:

Flexible Electronics: The development of biosensors with flexible electronic components facilitates conformity to textile movement, ensuring optimal comfort during wear (Stoppa, M., & Chiolerio, A. 2014b).

Conductive Threads: Integration of conductive threads into the fabric establishes pathways for electrical signals without compromising flexibility (Stoppa, M., & Chiolerio, A. 2014b).

4.2.3. Encapsulation and Protection:

Coating Techniques: Applying protective coatings shields biosensors from environmental factors, enhancing their durability and lifespan (Agarwal, S., Wendorff, J. H., & Greiner, A. 2008).

Nanoencapsulation: The use of nanotechnology for encapsulation protects biosensors, contributing to wear resistance while preserving flexibility (Crivelli, B., et al., 2018).

5 Types of Integrated Biosensors

5.1 Enzymatic Biosensors

Enzymatic biosensors utilize specific enzymes to catalyze reactions with target substances, generating a measurable signal. Often employed in glucose monitoring, these biosensors offer high specificity and sensitivity. Integration into smart textiles enhances real-time tracking of biochemical markers (Sonawane, A., et al., 2017).

5.2 Immunosensors

Immunosensors leverage antibodies as recognition elements to detect and bind with specific antigens. This type of biosensor is instrumental in identifying pathogens, allergens, and various biomarkers. Integration into textiles broadens the scope of applications, from environmental monitoring to personalized healthcare (Ponmozhi, J., et al., 2012).

5.3 Nucleic Acid-Based Biosensors

DNA and RNA serve as the biological components in nucleic acid-based biosensors. Customizable DNA probes or aptamers can selectively bind to target molecules, facilitating applications in genetic testing and pathogen detection. Integrating these biosensors into textiles enhances their utility in real-time molecular diagnostics (Malucelli, G., et al., 2014).

5.4 Optical Biosensors

Optical biosensors rely on light interactions for signal generation. Fluorescence, absorption, or refractive index changes are common mechanisms. In textiles, optical biosensors find applications in monitoring biomolecules and environmental factors. Their non-invasive nature and high sensitivity make them valuable for continuous health monitoring (Pasche, S., etal., 2012).

5.5 Electrochemical Biosensors

Electrochemical biosensors detect changes in electrical properties resulting from biochemical reactions. Ideal for tracking analytes like glucose or lactate, these biosensors offer real-time data.

Table 1. Material Properties of Different Fibers for Smart Textile Applications.

Fiber type	**Materials**	**Functionalization methods**	**Cost effectiveness**	**Efficiency**	**Merits**	**Demerits**	**References**
Natural fibers	Cotton, wool, silk	Conductive polymers, nanoparticles	High	Moderate	Comfortable, biodegradable, renewable	Limited conductivity, processing complexity	Ali, N., El-Khatib, E., & Bassyouni, F. (2022)
Synthetic fibers	Polyester, nylon, Spandex	Chemical treatments	Moderate	High	Durable, wrinkle-resistant, affordable	Lower breathability, potential environmental concerns	Ding, Y., et al., (2023)
High-tech fibers	Graphene, carbon nanotubes	Exceptional conductivity, sensing capabilities	Low	Very high	Exceptional conductivity, sensing capabilities, lightweight	High cost, limited scalability, potential health risks	Alamer, F. A., & Almalki, G. A. (2022)

Table 2. Comparing Bioreceptors for Biosensing and Diagnostics (Windmiller, J. R., & Wang, J. 2012, Denmark, D. J., et al., 2020, Takita, S., et al., 2023, Emrizal, N., et al., 2023)

Parameter	**Enzymes**	**Antibodies**	**Nucleic Acids**
Type of molecule	Proteins	Proteins	Sugar-phosphate chains with nitrogenous bases
Function in organism	Catalyze biochemical reactions	Bind specifically to antigens	Store and transmit genetic information
Bioreceptor use	Biosensors, drug discovery, diagnostics, biocatalysis	Immunosensors, diagnostics, drug development, therapy	Biosensors, diagnostics, gene therapy, DNA fingerprinting
Specificity	High for specific substrates	Very high for specific antigens	High for complementary sequences
Affinity	Moderate to high	Very high	High
Sensitivity	Can be very high	High	Variable, depends on sequence length and modifications
Detection method	Requires conversion of substrate to measurable product	Direct or indirect labeling methods	Fluorescence, hybridization with labeled probes
Regeneration	Often reusable under specific conditions	Limited reusability unless engineered	Not reusable after hybridization
Cost	Variable, depends on enzyme and purification method	High, due to antibody production and purification	Variable, depends on sequence length and modifications
Stability	Variable, depends on enzyme and storage conditions	Stable under controlled conditions	Stable under controlled conditions
Size and complexity	Relatively large and complex structures	Relatively large and complex structures	Smaller and simpler structures
Limitations	Limited substrate range, can be affected by inhibitors	High production cost, potential immune response	Limited target range, potential cross-reactivity

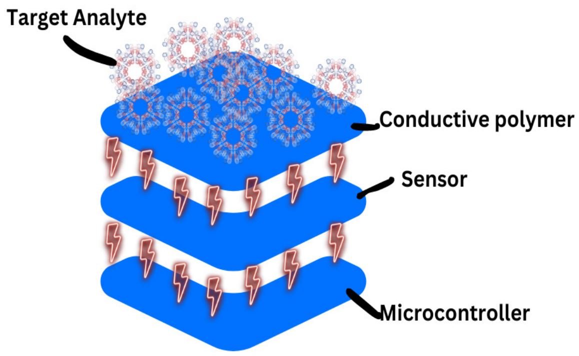

Figure 1. Electrochemical sensors for smart textiles.

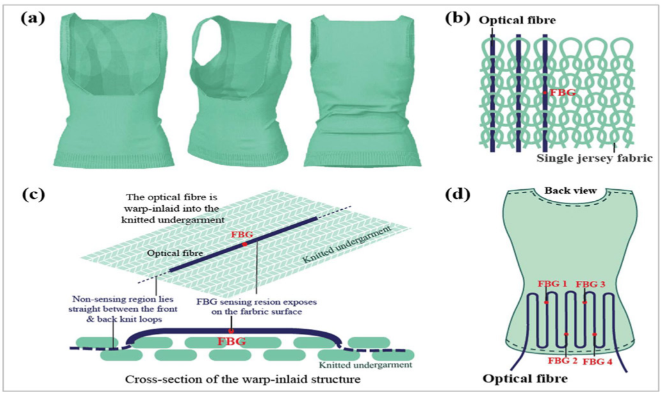

Figure 2. (**a**) Three-dimensional illustration of smart textile, (**b**) structure of optical fiber warp-inlaid into the single jersey fabric, (**c**) cross-section of the warp-inlaid structure, and (**d**) configuration of the optical fiber and allocation of FBG 1 to 4. (Source: Lee, et al., 2023).

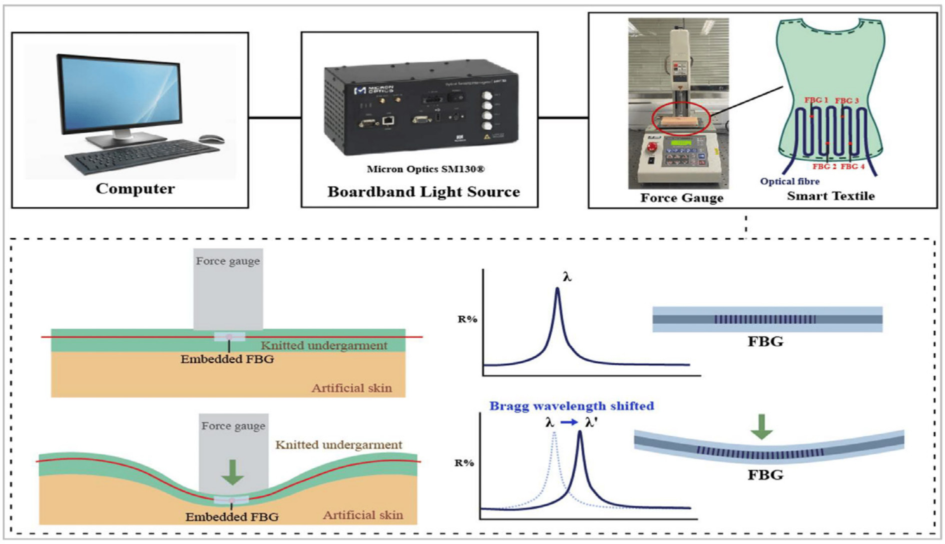

Figure 3. Equipment setup and schematic of transverse force applied to smart textile on artificial skin. (Source: Lee, et al., 2023).

Integrating them into smart textiles allows for seamless monitoring of physiological parameters with minimal interference in daily activities (Zhao, Y., et al., 2019).

5.6 Piezoelectric Biosensors

Piezoelectric biosensors measure changes in resonance frequency resulting from mass changes on a crystal surface. In textiles, these biosensors contribute to label-free detection methods, enhancing applications in protein-protein interactions and molecular sensing. Their sensitivity and stability make them valuable for wearable health technology (Su, Y., et al., 2021).

6. Target Analytes and Applications:

6.1 Vital Signs Monitoring

Smart textiles with integrated biosensors excel in real-time monitoring of vital signs, including heart rate, respiratory rate, and body temperature. These textiles act as continuous health companions, providing individuals and healthcare professionals with immediate insights into key physiological parameters (Joyce, K. 2019).

6.2 Metabolite Monitoring

Beyond traditional vital signs, smart textiles extend their capabilities to monitor key metabolites such as glucose and lactate. This opens new avenues for managing chronic conditions like diabetes and enhancing athletic performance by offering real-time feedback on metabolic processes (Koydemir, H. C., & Ozcan, A. 2018).

6.3 Environmental Pollutants

Smart textiles equipped with biosensors are not limited to personal health monitoring. They find applications in sensing environmental pollutants. By detecting and measuring specific substances in the environment, these textiles contribute to environmental monitoring and pollution control efforts (Windmiller, J. R., & Wang, J. 2012).

6.4 Pathogen Detection

Immunosensors integrated into smart textiles play a crucial role in the detection of pathogens. This application is particularly relevant in healthcare settings, enabling the early identification of infectious agents and supporting preventive measures (Ferrer-Vilanova, A., et al., 2021).

6.5 Stress and Emotional Monitoring

Innovative biosensor technologies integrated into textiles are increasingly being utilized for stress and emotional monitoring. By analyzing physiological markers associated with stress, these textiles contribute to mental health awareness and well-being (Mukhopadhyay, S. C. 2015).

6.6 Wearable Diagnostics

Smart textiles with integrated biosensors serve as wearable diagnostic tools, providing a platform for on-the-go health assessments. This has transformative implications for point-of-care diagnostics and telemedicine, bringing healthcare closer to individuals (Lin, F., et al., 2016).

7. Challenges and Future Directions.

7.1 Biocompatibility and Skin Irritation

7.1.1. Challenges:

Balancing Act: Achieving a delicate balance between effective biosensing and ensuring biocompatibility to prevent skin irritation or allergic reactions (Karamchand, L., et al., 2023).

Long-Term Wear: Ensuring biosensors remain comfortable during prolonged wear to encourage continuous monitoring without compromising user comfort (Zhou, J., et al., 2023).

7.1.2. Future Directions:

Innovative Materials: Researching and developing innovative materials with enhanced biocompatibility to minimize skin reactions (Tang, S. L. P., & Stylios, G. K. 2006).

User-Centric Design: Prioritizing user experience by integrating feedback into the design process to create biosensors that are both effective and comfortable for extended wear (Jiang, Q., et al., 2018).

7.2 Advancements in Materials and Integration

7.2.1. Challenges:

Durability: Enhancing the durability of biosensors and their integration into textiles to withstand daily wear, washing, and environmental factors (Stoppa, M., & Chiolerio, A. 2014 a).

Scalability: Addressing challenges related to the cost and scalability of manufacturing biosensor-integrated textiles for broader accessibility (Wang, H., et al., 2021).

7.3.2. Future Directions:

Advanced Fabrication Techniques: Exploring cutting-edge textile fabrication methods to improve the durability and scalability of biosensor integration (Shawan, M. S. I., et al., 2023).

Cost-Effective Solutions: Investigating cost-effective materials and production processes to make biosensor-integrated textiles more accessible to a wider audience (Shawan, M. S. I., et al., 2023).

8. Conclusion

In the culmination of our comprehensive review, we reflect on the profound impact of smart textiles integrated with biosensors in healthcare. This integration of textile technology and biosensors is reshaping the landscape of health monitoring, introducing transformative possibilities for individuals and beyond.

Smart textiles, housing embedded biosensors, represent a paradigmatic shift in healthcare dynamics. The capability to monitor vital signs and metabolites in real-time offers a novel approach to health management. The seamless integration of health monitoring into everyday clothing empowers individuals to actively engage in their well-being.

From monitoring vital signs to detecting environmental pollutants and pathogens, these textiles extend their applications beyond personal health. This versatility opens avenues for personalized health monitoring, environmental sensing, and diagnostic capabilities.

While celebrating achievements, it is essential to acknowledge challenges such as biocompatibility concerns, data security issues, and the need for material advancements. Addressing these challenges becomes a catalyst for refining and improving the integration of biosensors into textiles. Future advancements in materials, user-centric design, and data security protocols promise to overcome these hurdles.

As we peer into the future, the integration of biosensors into smart textiles is anticipated to become more sophisticated, user-friendly, and widely accessible. This vision encompasses textiles seamlessly blending into daily life, fostering proactive health management. With continued progress, the future holds promise for biosensor-integrated textiles playing integral roles in preventive care, personalized medicine, and environmental monitoring.

In conclusion, the integration of biosensors with smart textiles goes beyond a technological innovation; it serves as a catalyst for empowering individuals in their health journey. The real-time health monitoring and user-friendly designs position biosensor-integrated textiles as catalysts for a new era of proactive health management.

Author contributions

H.A.R. formulated the study objectives, constructed the hypotheses, and revised the manuscript. M.A.D. conducted the literature review, collected the data, and performed the data analysis. Both authors reviewed and approved the final manuscript.

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Competing financial interests

The authors have no conflict of interest.

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