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Chapter 8: Biosensors for Cardiovascular Disease Monitoring: Technologies, Applications, and Future Perspectives

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Abstract: Cardiovascular Disease (CVDs) are one of the major causes of death worldwide. Most importantly, there is an urgent need for accurate, continuous, and non-invasive monitoring technologies. Biosensors have currently emerged as one of the promises tools that enable real-time detection of a diversity of biochemical and physiological markers associated with CVDs. In this chapter, we provide a review of the state-of-the-art biosensors for cardiovascular monitoring, especially focusing on electrochemical, optical, gravimetric, thermal, acoustic, and radio-frequency biosensing kind. Particular attention is given to wearable and implantable systems capable of integration with e-health and Internet of Medical Things (IoMT) fields. Advances in this domain (e.g., dual-mode electrochemical-optical devices for cardiac troponin detection, photoplethysmography-based wearables, fiber Bragg grating sensors, and RF radar), are discussed in detail with a focusing on their advantages and limitations. As well, in this chapter, we reveal how biosensors are progressively playing an important role in multi-parametric monitoring, data connectivity, and predictive analytics toward early interventions and diagnosis.

Keywords: Biosensors, IoMT, Cardiovascular Disease, Vital Signs Monitoring, Biochemical Markers, Physiological Parameters.

1 Introduction

Cardiovascular diseases are silent and one of the main causes of morbidity and mortality worldwide. Seriously, this malady impairs people's health everywhere. Every statistic has a story behind it. For example, a patient coping with the daily difficulties of chronic hypertension which is a family recovering from a hit, or a person whose life has been profoundly altered by his heart disaster. This disease reaches the limits of country economies, world societies, and global healthcare systems. Beside to being a personal

issue. However, every challenge either offers an opportunity: each early detection and continuous monitoring, or tailored care are serious not merely for managing CVDs. Nonetheless, most disastrous outcomes have the possibility to be preventing.

Over the past years, digital health has evicted to be an even more powerful solution. Beginning in 2005 year, the WHO encouraged e-health strategies as a way of establishing people-centered, reactive, and robust health systems (Lorenzi, 2005). E-health solutions help real-time collection of data, enable for virtual consultations, and permit patients through self-management, thereby modernizing the distribution of healthcare.

The IoMT is an active, quickly growing network of smart linked devices, that connects clinical insight with quotidian life, forming a critical component in this revolution (Vishnu et al., 2020; El-Saleh et al., 2025). Biosensors going from continuous glucose monitors, which provide metabolic context, to wrist-worn smartwatches that control heart-rate variability and implanted pacemakers that dispatch cardiac rhythms and produce a steady stream of physiological data. Since this real-time visibility is now available to patients and clinicians alike, health has progressed from intermittent interventions to ongoing, practical stewardship of well-being (good health and life style).

During the COVID-19 pandemic, the increasing of need for these technologies and applications has become even more into the real-world. As hospitals were extremely loaded and in-person visits decreased, remote monitoring has developed from specialized use to clinical need (Duplaga et al., 2022). Biosensor-enabled surveillance was one of the lifelines for people with cardiovascular maladies. Commonly, this latter become an important subject to dangerous consequences in viral infections case. Besides recording raw metrics, wearables and implants started to include predictive analytics, capable of identifying instantaneous deviations in vital signs, such as, heart rate blood pressure, oxygen saturation, and patterns of breathing. Because this could symptom early discovers, clinicians are capable to intermediate as soon as possible. More precisely, this action tailor therapies, and, consequently, avoid an overall hospitalization.

Nonetheless, this advancement was not a coincidence. The electrocardiogram, invented by Professor Willem Einthoven in 1895, remains a reference for cardiac diagnostics well over an era later. No more modality can correspond to its precision in the clinical setting. But, the traditional ECG has intrinsic drawbacks that cannot be overcome outside of a clinic or a hospital shape, since it is boosted by several electrodes, huge material, and controlled settings. Based on these challenges, researchers, developers, and engineers have been working hardly in last three decades to release the next generations of biosensing platforms. They are small, wireless, and often discreet,

leading to monitor cardiovascular diseases into homes, offices, streets, and everywhere. These innovations enable access to life-saving insights that extend beyond simple accessibility.

In this chapter, a science extended overview is given. Technology, and human impact of these developments are also provided. Section 2 starts with an overview of the principles of biosensors. We examine their components, principle of designs, and the physical or chemical processes that transform biological signals into valuable information. An important cardiovascular biomarkers and physiological parameters of interest are then identified, in Section 3. The dynamic physiological signals are distinguished (heart rate, rhythm, vascular tone) from biochemical indicators such as cardiac troponins or inflammatory markers. The different domains of biosensing currently used in clinical or under development are discussed in Section 4. A review of biosensor types including electrochemical, optical, gravimetric, thermal, acoustic, and radiofrequency systems, is also presented in this section. At the end, Section 5 reveals the future: new opportunities in AI-driven analytics, multi-modal sensing, and personalized preventative cardiology, as well as persistent concerns over data privacy, clinical validation, and equity. Along the way, we aim to convey how biosensors are quietly rewriting cardiovascular care, one heartbeat at a time, aside from providing information.

2 Fundamentals of Biosensors

What is a biosensor? Simply, a biosensor is an electronic component designed to detect a biological reaction and transforms it into a measurable signal (electrical, optical, mechanical, thermal…). Commonly, its architecture integrates three essential elements represented in Fig 8.1. First, there is the bioreceptor, which gives specificity by recognizing the target molecule or physiological parameter. Depending on the application, this recognition may be done through enzymes, antibodies, nucleic acids, or even cellular systems. The second element is the transducer, which converts the recognition event into a physical or chemical signal. And lastly, a signal processor amplifies, analyzes, and displays the output, making the biosensor data accessible to clinicians and patients. Biosensors thereby provide a direct interface between complex biological processes and digital health systems.

As depicted in Fig. 8.1, biosensors can be divided based on their principles of transduction (Ramesh et al., 2023). Under medical practice, electrochemical biosensors are by far the most established ones and rely on measuring current, voltage, or impedance (Grieshaber et al., 2008; Ronkainen et al., 2010). They have seen wide application in glucose monitoring, while analogous strategies nowadays are being

applied for cardiac biomarkers such as troponin and brain natriuretic peptide (BNP) that are critical for early diagnosis of myocardial infarction and heart failure. Optical biosensors make use of light-matter interactions through mechanisms such as fluorescence, surface plasmon resonance, or photoplethysmography (PPG) (Damborský et al., 2016). PPG has lately become prominent within wearable devices such as smartwatches that monitor heartbeat, blood oxygen saturation, and respiration activity in real time. Gravimetric biosensors detect changes in mass or mechanical loading, often through quartz crystal microbalance or surface acoustic wave devices, and have been explored to assess changes in blood composition and biomolecular interactions relevant to cardiovascular health (Cali et al., 2020).

By detecting instantaneous temperature variations accompanying biochemical reactions, thermal biosensors provide a delicate but extremely strong variety into the inner margin of the body (Ramanathan et al., 2001). These thermal data can deliver important information about metabolic or enzymatic activity related to cardiovascular insufficient. Among that, changed energy consumption in ischemic tissue and/or inflammatory reactions after myocardial injury, even though they are indirect.

Particularly, when integrated within a multimodal platform, thermal sensing gives complementary physiological intelligence, even still it is not as intuitively connected to cardiac function as an ECG hint.

On the other hand, acoustic biosensors have a function to listen to the body. They are based on the use of sound waves, especially at ultrasonic frequencies, to extract structural and/or mechanical changes in tissues, vessel walls, or blood flow. According to reference (Fogel et al. 2016), their potential in cardiovascular monitoring is responsible for the growing recognition they receive for functioning dependably in dynamic, real-world settings. For the moment, by monitoring arterial stiffness or detecting turbulent flow indicative of stenosis, acoustic sensors deliver a non-invasive and passive method to track vascular health over continuous time

Electronic biosensor fields have witnessed a remarkable development. Recent evolutions have boosted the field into the electromagnetic (EM) spectrum, even though conventional electrochemical systems are still necessary for the detection of particular biomarkers like lactate or troponins. Really contactless monitoring is being today possible owing to radio-frequency (RF) and platforms based on microwave (mmW) (Mehrotra et al., 2019). These systems remotely monitor and store heart/respiration rates, and analyze thoracic motion by emulating the principles of Doppler radar, skin without user intervention or contactless. This open a new era of invisible monitoring through these devices: it can be implemented and integrated into beds, clothing, or living spaces. Indeed, critical data can be collected while patients sleep, work, or engage in daily activities without interruption.
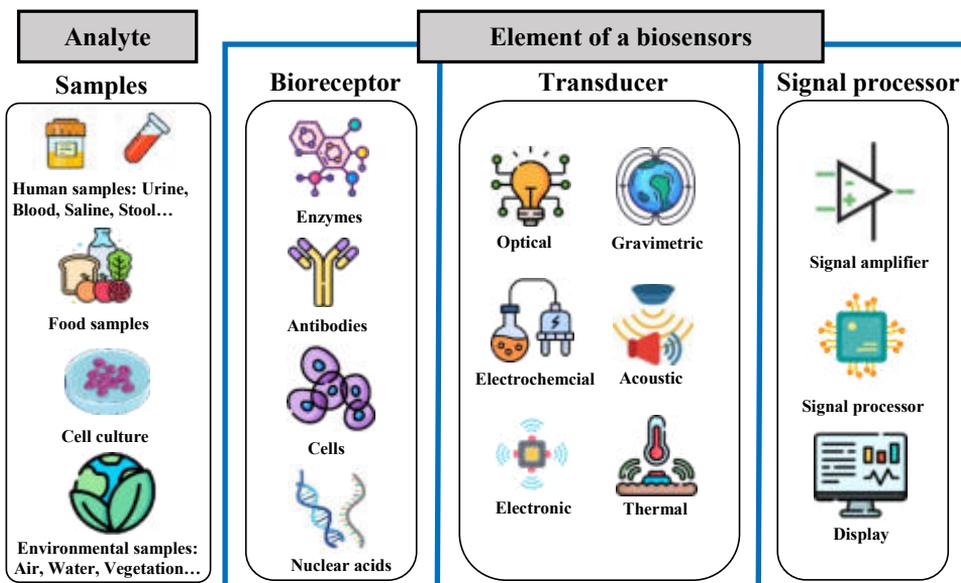
Fig. 8.1 Analyte and elements of a typical biosensor system.

Particularly in the high-stakes field of cardiovascular care, those technologies' potential depends on their ability to meet a number of demanding performance requirements, (Abensur Vuillaume et al., 2022). However, to eliminate incorrect alarm signals weakening clinical assurance, biosensors should be highly sensitive to early warning signs. Moreover, they should be compact, non-invasive, and enough comfortable to be resistive for an extended period of time. In addition, given to the frequently abrupt nature of many cardiac events, continuous real-time data streams are crucial. Furthermore, robustness against motion artifacts is indispensable in the real-world life (walking, exercising, and gesticulating).

Biosensors are becoming increasingly important components of digital health ecosystems. This role requires new responsibilities which is now a design requirement and no longer simply an afterthought: (1) secure and low-latency data transmission, (2) perfect interoperability with IoMT platforms and electronic medical registers, and (3) ensuring perfect protection of patient data confidentiality.

These factors confirm that novelty boosts patient autonomy, ethical integrity, and clinical efficiency. When these constraints are respected, biosensors transform cardiovascular care into an ongoing: a contextual story of health. They give researchers previously unheard-of insight into a patient's physiological trajectory when integrated into e-health and IoMT systems. This will allow early interventions, precise therapy titration, and ultimately a proactive.

3. Cardiovascular Biomarkers and Physiological Parameters

Fig. 8.2 represents cardiac function and systemic cardiovascular health. These heart indicators can be categorized into two main types:

- **Physiological signals group**: representing the dynamic behavior of the cardiovascular system.

- **Biochemical biomarkers group**: showing the molecular fragments of disease.

These grouping allow for unmatched precision in the diagnosis, prognosis, and ongoing monitoring of cardiac conditions.

3.1 Biochemical Biomarkers

Biochemical biomarkers are molecules that operate as molecular characteristics of cardiovascular stress, dysfunction, or injury. They are naturally found in blood or other bodily fluids (Netala et al., 2025). Among them, the clinical reference biomarkers for the diagnosis of critical myocardial infarction are cardiac troponins: (e.g. cTnI and cTnT). Because their release into the bloodstream is specific to cardio-myocyte destruction, clinical reference biomarkers are sensitive and reliable sentinels of a heart attack. BNP is more stable peptide precursor, NT-proBNP is equally important as they increase in response to volume overload. These peptides controller prognosis and therapeutic adjustment while contributing to diagnosis. Also, due to its strong correlation with endothelial dysfunction and instability of atherosclerotic plaques, C-reactive protein (CRP: general indicator of inflammation) shows a fundamental role in indicating a future cardiovascular risk.

A less specific biomarker which is the Myoglobin. It increases within minutes change of myocardial injury. This biomarker provides a premature caution indication. Other biomarkers add significant nuance. A fibrin degradation product called D-dimer is used to rule in or out thromboembolic events like deep vein thrombosis or pulmonary embolism, which frequently coexist with or make managing CVD more difficult. When taken into consideration, each of these molecules improves clinical judgment and lowers diagnostic uncertainty.

When biosensors bring these laboratory-grade insights to the point of care and beyond, that is where the real transformative potential lies. Because of the redox reactions occurring at the functionalized electrode surface, electrochemical biosensors can identify picomolar concentrations of troponin in whole blood in a matter of minutes. Gravimetric platforms, like quartz crystal microbalances, are remarkably sensitive at tracking mass changes brought on by biomarker binding. In the meantime, label-free,

real-time BNP and CRP quantification is made possible by optical methods, particularly those based on either surface plasmon resonance or localized plasmonic effects, frequently with little sample preparation. When combined, these biosensing technologies shorten the crucial time between the onset of symptoms and intervention. Time is saved by moving tests from centralized labs to clinics, ambulances, pharmacies, or even patients' homes. Every minute saved in an acute situation like chest pain triage is equivalent to myocardium preservation. Regular biomarker monitoring for long-term care can reveal subclinical decline long before symptoms manifest, enabling early and proactive treatment modifications.
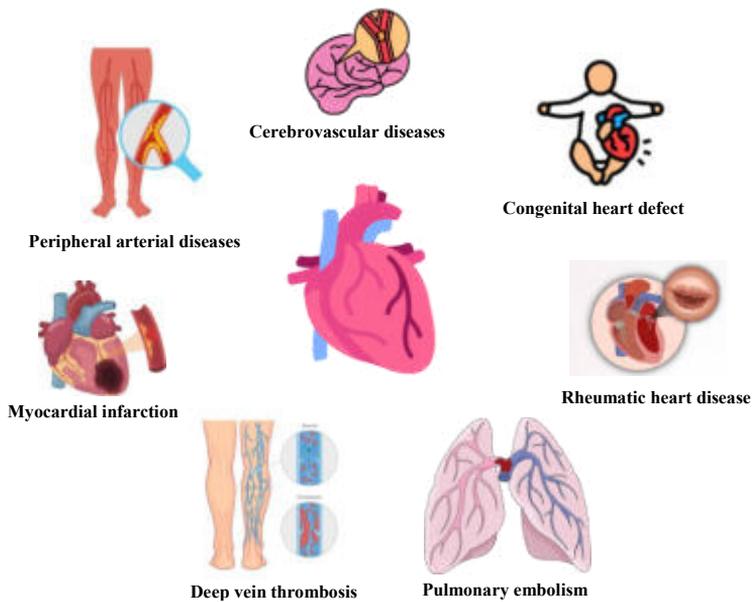

Fig. 8.2 Illustration of various exiting cardiovascular diseases.

3.2 Physiological Parameters

Apart from biochemical detection, physiological parameter measurement is essential for the proper treatment of CVD. Electrocardiography has remained the gold standard for detecting ischemic patterns, arrhythmias, and conduction abnormalities. However, conventional ECG systems depend on multiple electrodes which are mostly limited to clinical environments. Recent innovations, such as wearable ECG patches and textile-based electrodes, have expanded their capability into quotidian life to enable long-term monitoring and the early detection of transient cardiac events.

Other parameters of interest include heart rate and heart rate variability, which provide information on autonomic nervous system balance and levels of stress. Another important determinant of cardiovascular risk is blood pressure and there is active interest

in replacing cuff-based measurements by cuffless and continuous sensing technologies, (many of which are based on PPG or pulse transit time analysis). Respiratory rate is increasingly recognized as an early predictor of clinical deterioration in cardiac patients, and a number of biosensors have been created to monitor breathing patterns non-invasively based on both optical and RF circuits. Oxygen saturation, a vital sign measured by optical pulse oximetry, is a parameter of particular relevance in the context of heart failure and ischemic conditions.

3.3 Why Multi-Parametric Monitoring is preferred?

While individual biomarkers and parameters yield valuable information, often the complexity of cardiovascular disease requires an integrated approach. Combinations of measures, (e.g. troponin combined with ECG or BNP with continuous blood pressure and oxygen saturation) offer a far more complete insight into patient status. While tracking vital signs, multi-parametric biosensors are powerful emerging tools for precision cardiology, indeed detecting biochemical markers Thus, such systems are well-suited to IoMT platforms, through which data can be continuously transmitted to healthcare providers and AI-aided analysis performed to identify early signs of decompensation.

4. Recent Technology of Cardiovascular Disease Biosensing.

The demand for noninvasive real-time continuous assessment of patient health has motivated major developments in biosensors for the monitoring of CVD over the last few years. Several sensing modalities developed and tested in both clinical and wearable contexts ranged from electrochemical to optical and electromagnetic. In this section, we reveal and review the important technologies dedicated to biosensors. We describe their working principles, applications concerning CVD, and their strong points and limitations.

4.1 Electrochemical Biosensors

Electrochemical biosensors are one of the most deployed classes of sensing technologies and find well-known application in biochemical detection. These biosensors rely on the measurement of electric signals (potential, current, or impedance) that is produced in a biochemical reaction. Their attractiveness is due to their high sensitivity, relative low-cost, and compactness.

Within cardiology, electrochemical biosensors allow a special value for the detection of biomarkers: troponin is still the gold standard for acute myocardial infarction diagnosis, while brain natriuretic peptide is a marker for heart failure. Recent development of point-of-care electrochemical devices has allowed bed-side or even at-home detection of such biomarkers, avoiding long-time related to laboratory testing. Furthermore, microfluidic and nanomaterials integration have continued to improve their sensitivity, enabling compact diagnostic platforms that might transform CVD emergency care.

Besides conventional methods, recent efforts have been directed toward hybrid biosensing systems that leverage the advantages of different modes for improved sensitivity and robustness. An illustrative example of a dual-mode biosensor was developed by Lee et al. for the detection of cardiac troponin I (cTnI), by using a multi-functional DNA (MF-DNA) construct immobilized on AuNCs deposited on an indiumtin oxide substrate (Lee et al., 2019). The platform, illustrated in Fig. 8.3, collocated EIS with localized surface plasmon resonance (LSPR), combining electronic and optical transduction mechanisms on a single device. Their MF-DNA probe consisted of three functional regions: an aptamer that recognizes troponin I, a methylene blue moiety acting as the electrochemical reporter, and a thiol group to attach the oligonucleotide to the surface of the nanocrystals.
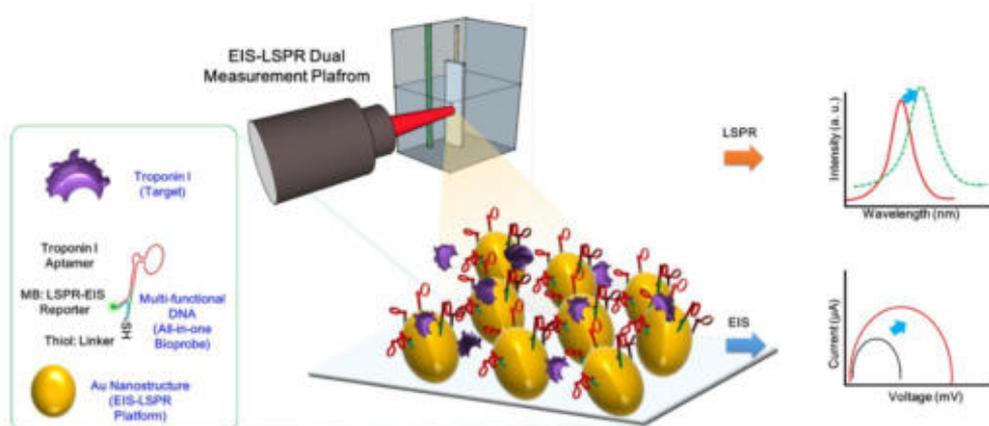

Fig. 8.3 Schematic illustration of the fabricated electrochemical (EC), proposed by Lee et al.

Experimental validation showed that this system was able to detect cTnI with very high sensitivity, with a limit of detection of 1.0 pM in both buffer solution and diluted human serum. In addition, the device showed excellent selectivity against nontarget proteins, underlining its robustness for application in clinics. Such dual-mode strategies are ideal for point-of-care diagnostics in emergency settings where the rapid and accurate detection of troponin is essential for the early diagnosis of myocardial infarction.

4.2 Optical Biosensors

The reason behind the significance of optical sensing is that it is non-invasive and wearable systems can easily be created based on this. Photoplethysmography has been a key method for wearable cardiovascular monitoring, detecting changes in blood volume in the microvascular bed with a light source (Allen, 2007). Figure 8.4 illustrates how PPG is usually applied for monitoring heart rate, respiratory rate, and blood oxygen saturation.

Fig. 8.4 Understanding PPG: working principle and real-world sensor implementations in wearable and clinical devices.

Nevertheless, PPG suffers from significant motion artifact sensitivity, despite its popularity. In order to make it more robust, sophisticated algorithms using ICA, CNN, and EMD are being developed. Case studies showcase the challenges associated with utilizing PPG. For example, Hough et al. compared wrist-worn heart rate monitors from Apple Watch, Fitbit, Tomtom, Mio against chest-worn and clinical-grade ECG references (Hough et al., 2017). Chest straps consistently produced the most accurate readings, but wrist-based devices showed accuracy variation in activity and recovery phases, respectively, which is indicative of poor noise compensation in wearable PPG.

Another promising optical approach is fiber Bragg grating technology, showing in Fig. 8.5, based on periodic changes of the refractive index of an optical fiber, which creates a grating reflecting specific wavelengths of light (Suryandi et al., 2022). FBG sensors offer high sensitivity, immunity to electromagnetic interference, and adaptability for wearable integration. Smart textiles with integrated FBG arrays have been tested in real-time monitoring of respiratory and heart rates while transitioning through different body positions, and their functionality proves their potential for daily life cardiovascular monitoring.
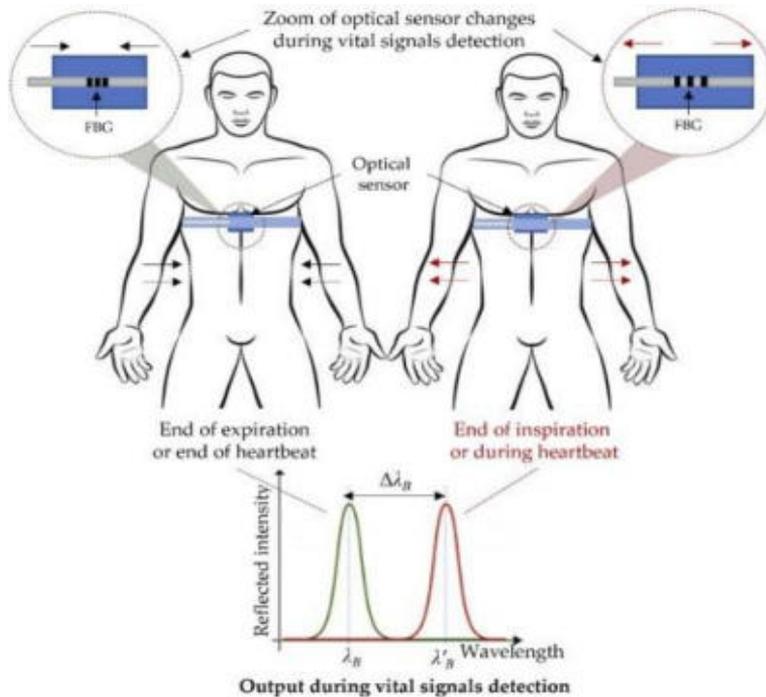
Fig. 8.5 Schematic illustration of the FBG and its operating principal.

4.3 Gravimetric Biosensors

Gravimetric biosensors detect changes in mass or mechanical loading and can be implemented using piezoelectric or magneto-elastic technologies. Such sensors are extremely effective in detecting biomolecular interaction, hence suitable for measurement of blood composition changes associated with CVDs. For instance, QCM-based devices have been used to detect viruses (Afzal et al., 2017) and to obtain biorecognition elements related to biological analysis (Akgönüllü et al., 2022), while piezoelectric devices (Guo et al., 2021) have been used to monitor blood pressure, among others (Aleixandre et al., 2025). Their high sensitivity makes them promising for early detection of biochemical changes preceding cardiovascular events, although many challenges remain in miniaturization and integration into wearable systems.

4.4 Thermal Biosensors

Thermal biosensors make use of heat release or absorption associated with biochemical reactions. While the information they provide on metabolic activity and enzymatic processes is indirect, nonetheless it is very valuable (Ramanthan et al., 2001). In relation

to cardiovascular aspects, thermal sensors have been suggested to detect inflammation-related processes, such as in atherosclerosis or myocarditis, by tracking the exothermic biochemical reactions of patient samples. Though not as common in commercial wearables, thermal biosensors are an alternative to biochemical sensing and might be combined with lab-on-chip systems toward rapid diagnostics for cardiovascular conditions.

4.5 Acoustic Biosensors

Acoustic biosensors use sound waves to detect mechanical or structural changes in biological tissues and fluids. Among the acoustic modalities, SAW devices have been applied to sensitive detection of cardiovascular biomarkers and physical properties of blood (Fig. 8.6). Acoustic sensing further extends to wearable applications monitoring respiratory patterns through chest-wall vibrations. These devices provide robust and continuous measurements; their combination with other modalities further enhances multi-parametric monitoring of CVD patients. Adoption and applications of acoustic biosensors in healthcare have been a subject of a thorough review; interested readers may refer to Ref. (Kong et al., 2024).
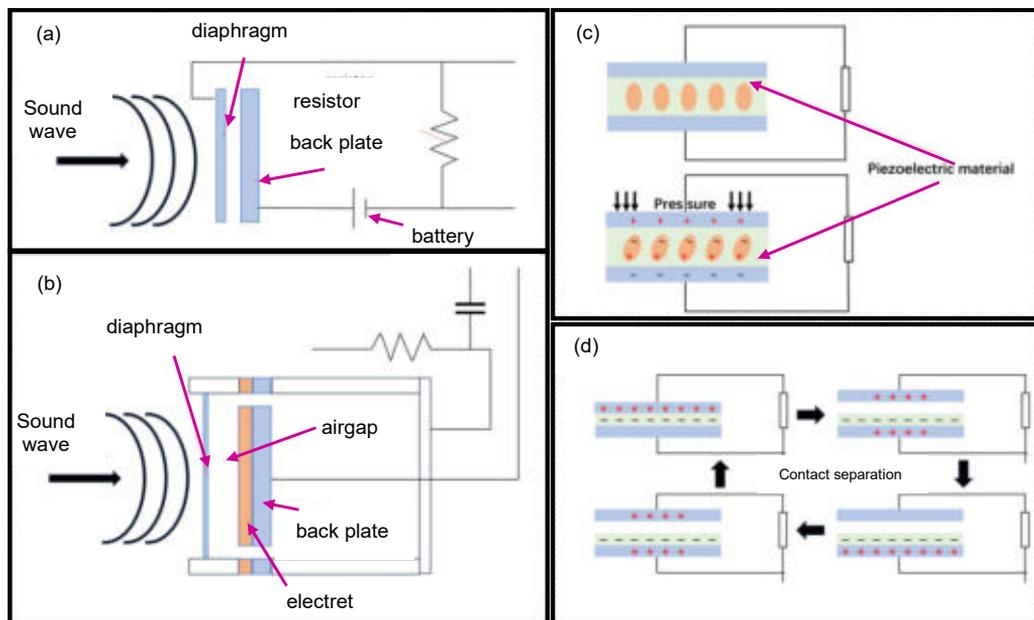

Fig. 8.6 Operating principles of common acoustic sensor types: (a) capacitive microphone, (b) electret microphone, (c) piezoelectric sensor, and (d) triboelectric sensor, from Kong et al.

4.6 Electronic and RF Biosensors

Among the fastest-growing areas in non-contact cardiovascular monitoring, electronic biosensors include those based on electromagnetic and radio-frequency RF technologies. RF biosensors use the variable dielectric properties of tissues with physiological activity. For example, Doppler radar sensors transmit continuous wave signals that are modulated by thoracic wall movements during respiration and cardiac cycles. The reflected signals can then be demodulated to extract heart rate and respiratory information.

Specifically, studies demonstrated high correlation of radar-derived waveforms with seism cardiogram signals, enabling the accurate detection of fiducial points such as the aortic valve opening (Rai et al., 2021). The principal scheme is shown in Fig. 8.7. More recently, proximity RF sensors have been proposed for vehicular applications, enabling real-time monitoring of driver heart rate and respiratory rate from distances of up to 34 cm (Park et al., 2019). Such systems provided accuracy comparable to reference sensors and thus illustrated the potential of RF technologies for unobtrusive monitoring both in medical and everyday environments.
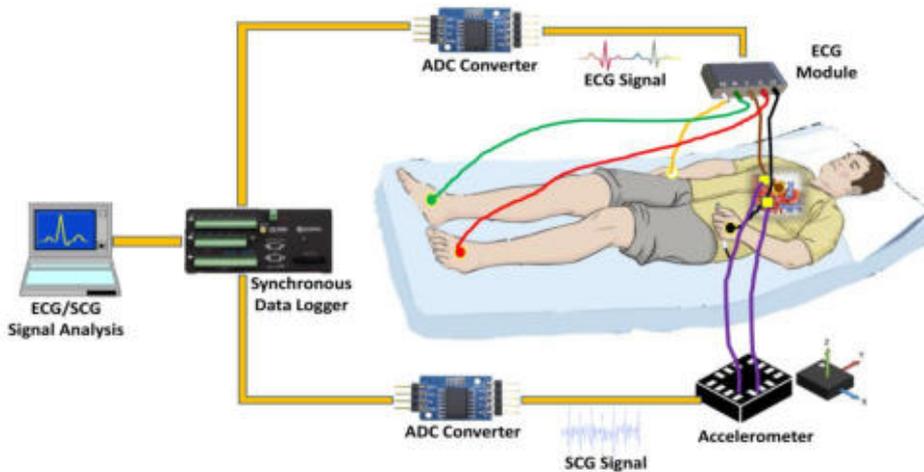

Fig. 8.7 System architecture of the integrated ECG (electrocardiogram) and SCG (seismocardiography) data collection model, illustrating sensor placement, signal acquisition, pre-processing, and data transmission modules, from Rai et al.

4.7 Future Perspectives

Hybrid and multi-parametric biosensors, which operate on the basis of combining multiple transduction mechanisms or measuring multiple biomarkers simultaneously, are among the future directions that are gaining a lot of traction.

The integration of biosensors into wearable, flexible, and implantable platforms illustrates a significant advancement in their area development. Driven by progress in domains such as energy-harvesting, smart textiles, and nanomaterials, this evolution will enable sensors implementation that will be discreet and battery-free. In addition, this progress, able to continuously run biosensor for long period of time. Like a second layer, epidermal patches are now interlaced into regular clothes, be stickled to the skin, allowing implementation driving by movement or body heat, or cardiac monitors.

Nevertheless, hardware implementation is not sufficient on its own. The emerging role of machine learning (ML) and artificial intelligence (AI) in processing the big data receiving from these sensors. Once vast in volume and complexity, continuous bio-signal streams are now a rich source for sophisticated algorithms that can identify subtle pre-symptomatic patterns well in advance of a clinical event. For example, AI models trained on multimodal data can detect early signs of ischemia, predict decompensated heart failure, or predict arrhythmias. Additionally, by correlating tendencies in heart rate variability, respiration, biomarker levels, and activity, the predictive results are able to transform medicine from reactive to proactive.

These biosensors will not operate independently. It will be associated into telemedicine and IoMT ecosystems, establishing ongoing patient-provider feedback loops through a personal space. There are various problems with this vision. Several obstacles still include data security, regulatory approval, and platform interoperability.

Conclusion

In this chapter we have presented a review of biosensors destined for cardiovascular disease. Table 8.1 summarizes various biosensing properties and each the main performances, benefits and drawbacks that range from the high sensitivity of electrochemical devices to the inconspicuous monitoring capabilities made possible by RF-based systems. When taken as a whole, they mark the advancement of truly individualized and preventive cardiology. Biosensors may be important players in cardiovascular health given the need for additional research and data science-assisted medical-engineering interfaces. It can lessen illness issues and enhance millions of people's quality of life worldwide.

Table 8.1 Comparative summary of biosensor technologies for cardiovascular disease monitoring.

Biosensor Type	Detection Principle	Biomarker	Strengths	Limitations	CVD Application Example
Electrochemical	Measures electrical signal (V, I, Z) during biochemical reactions	Troponin, BNP, CRP, glucose	High sensitivity, low cost and compact size	Requires sample preparation; biofouling issues	Troponin detection for early MI diagnosis
Optical	Light absorption/reflection/ or scattering changes	Heart rate, SpO$_2$, respiratory rate, BNP, CRP	Non-invasive; suitable for wearables and multi-parametric sensing	Motion artifacts; reduced accuracy during activity	Smartwatches for HR/SpO$_2$ monitoring; FBG textiles for respiration
Gravimetric	Frequency shift due to biomolecular binding	Blood viscosity, H-FABP, molecular interactions	High sensitivity to mass changes and label-free detection	Difficult miniaturization; sensitive to environment	QCM for early cardiac biomarker detection
Thermal	Monitors heat generated or absorbed by biochemical reactions	Inflammation markers (CRP, cytokines)	Simple; label-free and useful for metabolic activity	Limited clinical use; low specificity	Detecting inflammation in atherosclerosis
Acoustic	Mechanical/structural changes detected via sound waves	Blood properties, respiration, HR via vibrations	Robust, continuous and wearable integration possible	Sensitive to noise; requires calibration	SAW devices for blood biomarker detection
Electronic/RF	Electromagnetic wave interaction with tissue permittivity	HR, RR, chest wall motion, seism-cardiogram	Contact-less, continuous monitoring and suitable for remote care	Signal interference; limited validation in clinics	Doppler radar for HR/RR; RF driver monitoring system

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