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Review Article

Recent Advancements in Cardiology: Wearable Smart Device Review

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Abstract

Wearable cardiovascular devices have emerged as essential tools for continuous heart rate monitoring. Especially for the early detection and management of heart related conditions. This article explores the advancements and functionalities of four categories of the wearable heart monitoring products like, smart patches, in – ear heart monitoring devices, smartwatches and smart rings. The smart patches offer clinical grade heart rhythm data with mobility, allowing real- time analysis without hospital equipment. In- ear monitors, utilizing photoplethysmography (PPG) sensors, provide accurate readings from the ear canal due to its rich blood supply. Smartwatches combine multi sensor capabilities, including heart rate, blood oxygen levels, and ECG, with smartphone integration for user friendly health tracking. Smart rings, the most discreet among them, prioritize minimalism while offering essential metrics like heart rate variability (HRV), sleep, and activity data. These technologies collectively push the boundaries of personalized healthcare, providing accessible, real time cardiovascular monitoring.

Keywords: Cardiology, smart patches, in - ear heart monitoring devices, PPG, ECG & HRV.

1. INTRODUCTION

Recent developments highlight the growing diversification of wearable technology applications. The emergence of smart textiles with embedded sensing capabilities in 2019 and the advancement of brain-machine interface technologies, such as Neuralink in 2020, point toward a continuing trend of increasingly sophisticated and integrated monitoring systems. [1] The origins of modern wearable health devices can be traced back to 1978, when the Finnish company Polar Electro developed the first wearable heart monitors for endurance athletes. These devices became available to consumers in 1982, enabled by advancements in semiconductor technology. [2]

Wearable devices serve a variety of purposes and are not uniform in their design or intended use. Medical-grade wearables such as Holter monitors, mobile cardiac telemetry systems, and FDA-cleared ECG patches are developed to meet high standards of diagnostic accuracy and are intended to support clinical decision-making. By contrast, consumer-grade devices like smartwatches and fitness trackers, although useful in promoting health awareness, are not subject to the same regulatory scrutiny or performance standards. While both categories may offer ECG monitoring capabilities, they differ significantly in terms of accuracy, validation, and clinical applicability. Recognizing these distinctions is essential when interpreting wearable data within the context of clinical cardiology. [3]

A wide variety of wearable devices are available today, ranging from basic fitness trackers to advanced medical-grade monitors. Common consumer-grade wearables include smartwatches (e.g., Apple Watch, Samsung Galaxy Watch) and fitness trackers (e.g., Fitbit, Garmin), which monitor metrics such as heart rate, sleep, physical activity, and sometimes even offer basic ECG functionality. Some of smart wearable device discussed in below

A. Smart ECG Patches

Overview: The wearable cardiovascular smart patches monitor detects heart rhythm irregularities, palpitations, respiration rate, oxygen saturation, and body temperature and Electrocardiogram (ECG) data. These are lightweight, as they are designed to be worn directly on the body. It is a small device which includes adhesive to stay intact on the body. These adhesives are usually silicon-based adhesives. There are three types of smart patches: wired, wireless and self-powered (Energy-Harvesting).

Technology: Smart heart patches are IoT based devices which use a mobile app or display screen to display the data of the device. *Figure 2* shows the product and the UI interface for the product. The patches are smaller in size and rectangular, which are placed on the chest of the user near the heart. The display often shows the respiratory rate (RR) and heart rate (HR) and other parameters of the body.

Wireless patches: The wireless patch is quite effective, is water resistant and can stay active for 14 days. Wireless patches usually use IoT to transmit biometric data, wirelessly, they also use a hospital monitoring system and a cloud-based analytics platform. The technology used in wireless communication is Bluetooth low energy (BLE, Wi-Fi). There are no external wires used for these patches, which makes the patch more effective than the wired patch. Hydrogel dry electrode picks up ECG signals from skin surface. There is usually a thin lithium- ion or zinc battery, either rechargeable or disposable. The adhesive layer is for skin to hold the patch in the proper place. *Figure 1* shows the exploded view of the ECG wireless patch.

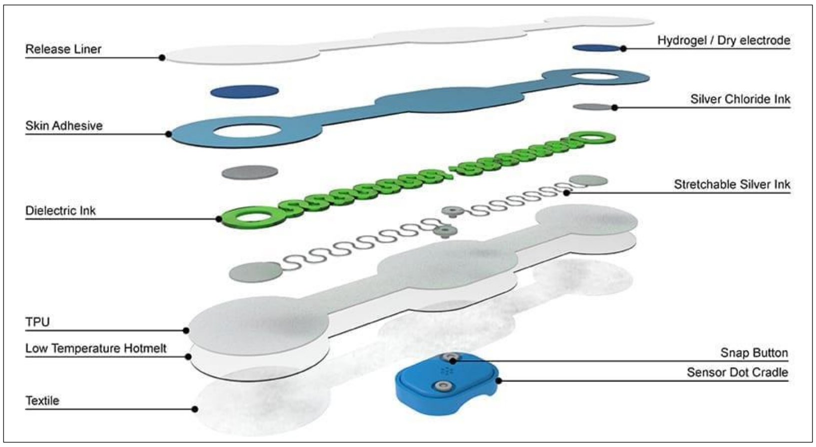

Figure 1: Exploded view of an ECG patch

Figure 2: IoT based Technology

Technology and sensors: Wearable ECG patches use ECG sensors (Electrocardiogram). ECG sensors work by detecting and measuring the electrical signals generated by heart as it contracts and relaxes. The impulses are picked up by electrodes placed on the skin usually on the chest. The sensor then amplifies these signals, filters out noise, and converts them into digital data. This data forms an ECG waveform, which shows the timing and pattern of heartbeats. It helps with monitoring heart rate, rhythm, and detecting issues like arrhythmias or irregular heartbeats.

In wearable, ECG sensors use a single lead, making them compact and suitable for continuous, noninvasive monitoring. A Single lead ECG sensor uses 2 electrodes often placed on the chest, detecting the small voltage difference created by the heart's electrical impulses. And the third electrode may be used as reference or ground to improve accuracy. Single lead sensors use lower power and are ideal for portable use. These make them cost effective compared to hospital grade 12 lead ECG. ***Figure 3*** shows the open view of a smart patch.

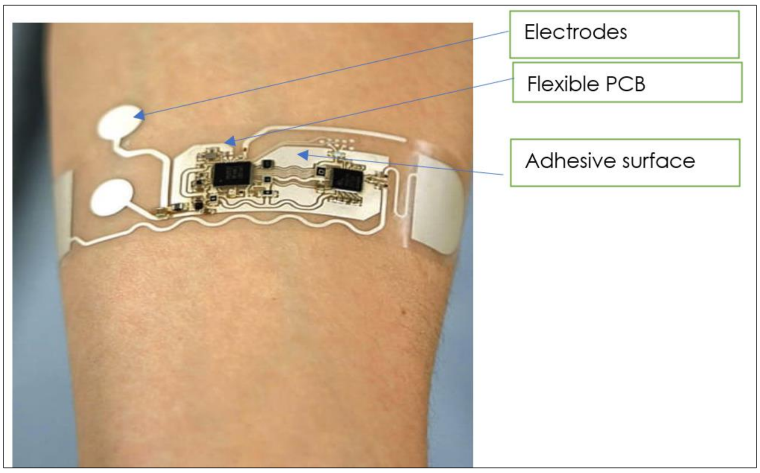

Figure 3: Opened view of a smart patch

Location and user guidelines

The patch is applied to the skin at the location corresponding to the heart. The user must make sure stays on for 1-2 days, wherein, the user must prevent from water from entering the system, since the wires are sensitive. The wireless patches stay for 14 days and are waterproof and the user can shower every day to shower and shave body hair and dress in loose-fit clothes before wearing the patch. The wired patch wearing those patches. The user should make sure that the no high intensity exercises should be carried out while wearing the patch and the user should wear loose clothing. *Figure 4* shows the user demonstration of the smart patch.

Figure 4: User demonstration of smart patch

Key players:

i. Zio patch (I Rhythm)

Figure 5: Zio patch overview

The Zio patch by iRhythm is a wearable, prescription-based ECG monitor used for long term cardiac rhythm tracking for 14 days. ***Figure 5*** shows the Zio patch by iRhythm. The Zio patch offers 14-day continuous ECG tracking with high patient comfort, excellent compliance, and superior arrhythmia detection compared to standard monitors. It incorporates a non – invasive, single use deign.

ii. Up beat (Monitra healthcare)

Figure 6: Up beat overview

Up beat by Monitra healthcare uses the same mechanism as Zio patch. Monitra is an Indian based company. This company usually work on developing heart/ ecg related products. The data is displayed on the associated app with the device. Figure 6 shows the overview of the Up beat patch by Monitra healthcare. This patch also helps with early detection of deterioration and reduces unnecessary hospital visits.

B. In-ear heart monitors

Overview

A promising sub-area of cardiology-based wearables is the in-ear heart monitoring (IEM) device. These are proving to be a better alternative to other locations on the body, both in terms of accuracy of monitoring data and comfort hinderance to the public. The market growth for these devices is promising due to an increase in demand for personal health and fitness tracking, especially keeping better accuracy and comfort in mind. Their shape, which is like hearing aids or wireless earbuds, gives them an added advantage due to their implementation for the consumer being non-novel. This section explores the current technology and level the in-ear devices are in the cardiology space.

Technology and logic overview

The technology of most in-ear heart monitors revolves around the Photoplethysmography (PPG) sensor. This is an inexpensive and uncomplicated mode of heart monitoring in wearables. While some devices also make use of Electrocardiogram (ECG) sensors, either along with or replacing the PPG sensor, it is generally not preferred due to an easier and more reliable alternative (PPG) being present in the market. These devices also sometimes contain temperature and accelerometers. These IEM devices have a similar structure to hearing aids or earbuds to make use of the familiarity the existing market has and to ensure a seamless integration into people's lives. This section discusses the main sensor used and the reason why ear-based monitoring is being preferred.

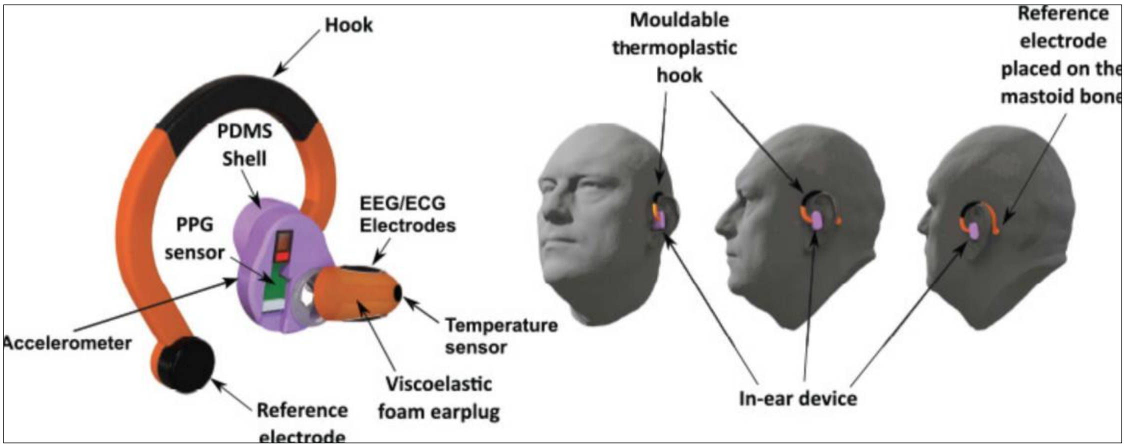

Figure 7: Overview of an In-Ear Monitoring (IEM) device

PPG sensor

The PPG sensor works simply by using a light source and a photodetector in tandem, both placed against the surface of the skin. The light source emits light, either visible or infrared, and the photodetector measures the amount of light reflected. The green and red bars in the Figure 7 is the light source and photodetector respectively. Green LED is used as a light source due to its better penetration capabilities through skin. The amount of light reflected correlates to blood volume variations in the arteries and blood vessels around the ear. When there is an increase in blood volume, less light is reflected as the higher blood volume absorbs more of it. A decrease in blood volume causes the opposite effect. These cycles of increasing and decreasing blood flow is a direct result of heartbeats and hence, the PPG sensor waves are used to detect the Heart Rate (HR). Inferred data like Heart Rate Variability (HRV) can be determined too by calculating the timer intervals between each cycle. Further data like Blood Pressure (BP) can be determined too by inputting data points from the PPG graphs into a machine learning model to analyse high or low BP.

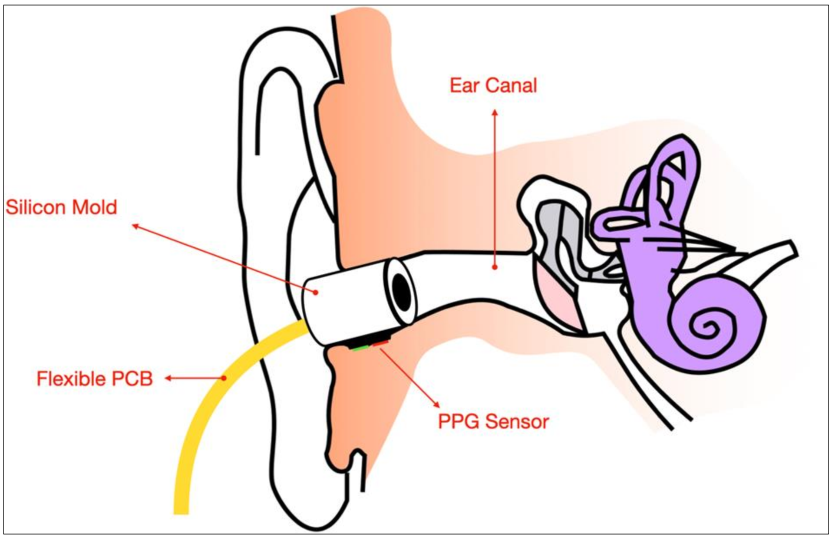

Figure 8: In-ear PPG sensor placement example

Why the ear is an optimum location?

A PPG sensor placed on an optimum location can offer superior data and help in delivering more reliable and accurate results to the consumer. The ear is far more optimum for PPG sensors that any other part of the body, including the traditional wrist location. The most important factor is that the ear has a higher composition proportion of cartilage and arterioles, which means fewer disturbance factors in the sensor process. The ear's proximity to the carotid artery system provides a direct picture of heartbeat cycles, which makes it great for HR detection. The ear is also relatively stable even during excessive motion, which provides a more stable detection for the wearable. All these factors enable the PPG sensors to produce better accuracy to be on-par with clinical setting monitoring. As mentioned earlier, the ear also provides an added level of familiarity as the consumer base is used to wearing earbuds or hearing aids, which makes integration into daily routines seamless.

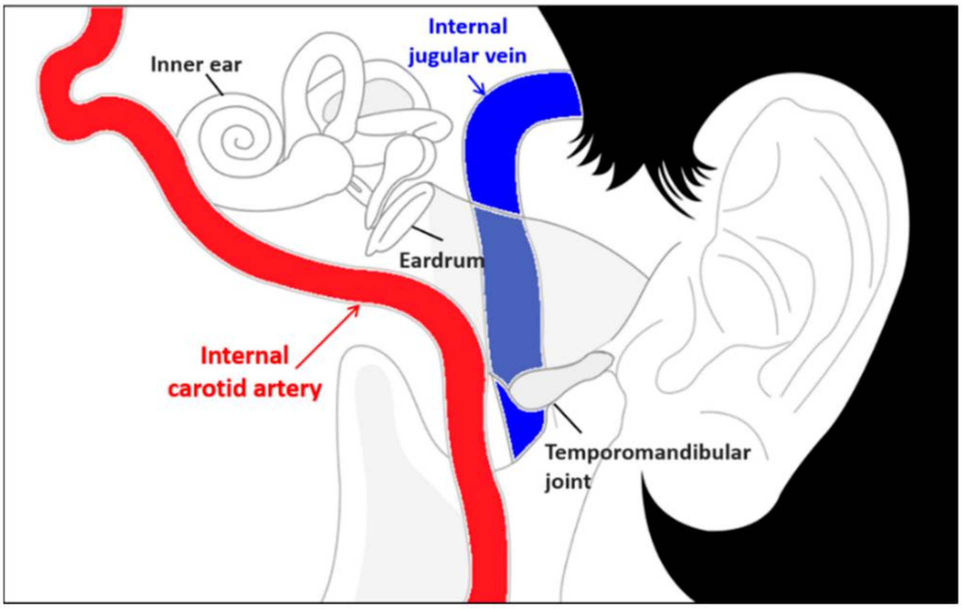

Figure 9: Proximity of crucial blood vessels to the ear

Key device players

While there are several companies shifting to or starting up in the "hearables" industry, two key players have built impressive versions of IEM devices: Cosinuss One and Lumia.

i. Cosinuss One

Built for monitoring heart rate, heart rate variability and body temperature, the cosinuss one is mostly a sports/recovery-based wearable. It uses the same principle of PPG sensing and a temperature sensor to monitor heart performance and core body temperature. The device then uses Bluetooth or ANT+ to transmit raw data to its application on a smartphone or smartwatch, which is then run through machine learning algorithms to generate an overall heart health and fitness report.

Figure 10: Cosinuss One operation protocol overview

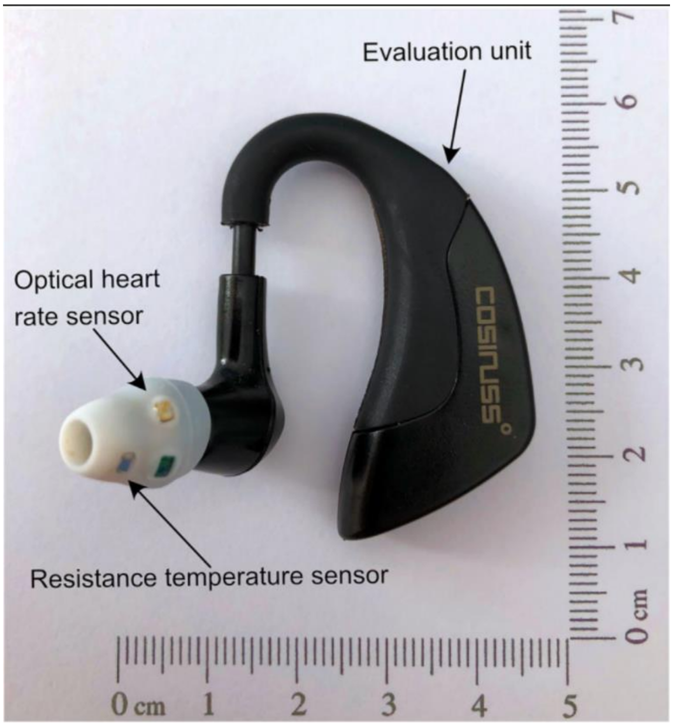

Figure 11: Cosinuss One earpiece size and component labels

Lumia

This is another player than uses the same logic and technology for their IEM devices, however they use the raw data to focus more on people with chronic blood flow problems. Their two main parameters of focus are heart rate and blood pressure. Their design language is also very different, with the unique selling point being how small and discreet their device is, fitting into the inner lobe just outside the ear canal. Their second differentiating factor is the use of infrared (IR) light instead of visible green light. This enables the sensor to pick data almost directly from the internal carotid artery due to the high penetrative power of the IR light.

Figure 12: Lumia Product overview

Figure 13: Small size and discreet fit

Summary

IEM devices are a relatively smaller portion of the cardiovascular wearables industry; however, they are fast approaching as the most reliable and accurate means of heart monitoring. Its optimal location for PPG sensing to operate gives it near clinical grade monitoring abilities and its added comfort over other wearables like wrist-based and chest straps make it a solid product. Overall, they are set to be a dominant player in the cardiology med-tech field.

C. Fitness Bands/Smartwatches

Overview

The most readily available and dominant category of cardiology-based wearables is the fitness band/smartwatch. While smartwatches operate primarily to serve other services, with health tracking just an add-on, the fitness band category has gone above and beyond with health parameter tracking. These use advanced sensors, mostly optical, to provide continuous monitoring of various cardiology-related parameters. This along with their lightweight form factor and longer battery life make them an in-demand product. While the wrist is not the most optimal location for tracking cardiology parameters, physiologically speaking, it has several factors that make it the more comfortable and favoured option among these devices.

Technology overview

Fitness bands use the same basic technological framework as any other wearable device, with PPG being the main sensor again. This is due to its affordable nature and no requirement of excessive physically components. This makes these bands relatively affordable while providing high quality monitoring of HR and HRV. Some bands also include an Sp02 sensor that is used to determine blood oxygen saturation along with the heart-based parameters. These combined with accelerometers and gyroscopes, which help adjust for motion artifacts (movement during the monitoring process), provides more accurate cardiovascular data interpretation. These data points are fed into algorithms that help interpret pattern data and provide users with scores and metrics.

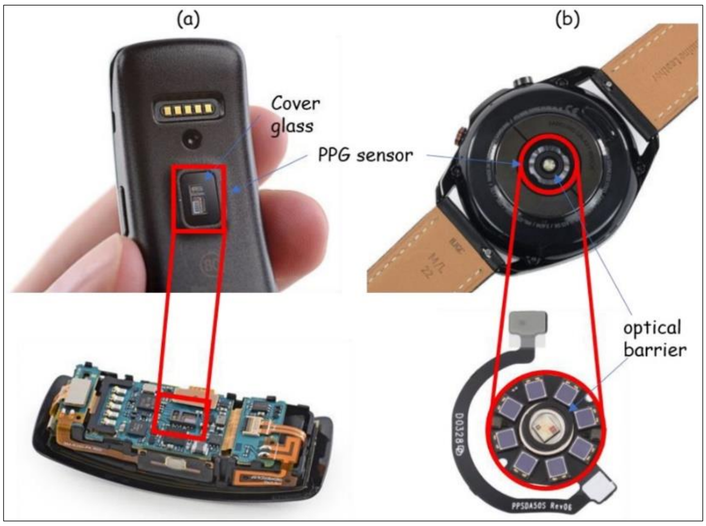

Figure 14: PPG sensor on an example fitness watch

ECG capability is added in more high-end smartwatches due to their increased form factor compatibility and higher price range. These make use of a single lead to interpret electrical signals from the heart. While these are not as effective as the 12-lead setup in clinical settings, the inclusion of an ECG can help in early detection and prediction of certain heart disorders.

Figure 15: ECG lead and result with a Whoop band

Key device players

Fitbit Charge 6: Primarily the Fitbit Charge 6 uses a PPG sensor to carry out continuous heart tracking as it can work in the background endlessly. The Charge 6 also incorporates ECG capabilities for a more in-depth reading into heart rhythms and potential irregularities. This, however, involves the user pressing and holding the two metal bars on the sides of the watch to complete the circuit and get a reading. The Charge 6 also monitors Sp02 (blood oxygen saturation) levels using its in-house Sp02 monitor (red and infrared light sensors). Both the PPG sensor and the Sp02 sensor are housed at the back of the band (figure 16), in direct contact with the skin. These, along with skin temperature and breathing rate, provide a holistic overview of an individual's heart health and can be used to not only monitor but also carry out early detection of any irregularities.

Figures 16 & 17: Front (left) and back (right) view of the Fitbit Charge 6

Whoop Strap 5.0

Whoop is one of the only health-based wearables to launch a medical-grade certified version of their wrist-wearable. This advanced version offers a high-grade ECG heart scanner and blood pressure monitor (the only wrist wearable to do so). These sensors, along with their medical grade certification, can give clinical-level insights into an individual's heart health, including early detection of major disorders like atrial fibrillation. The PPG, Sp02 and other sensors are housed in the back of the watch casing as any other fitness band, with the ECG heart scanner being located on the sides of the casing. The overall product is impressive, and a huge advancement is personal cardiology-based tracking and monitoring.

Figure 18 & 19: Front (left) and back (right) view of the Whoop 5 MG

Summary

While wrist-based wearables lack the optimal location for heart monitoring, their physical form and ability to fit more high-grade sensors and communication technology to relay data to an advanced app-based algorithm, makes them the most preferred choice in the market. The ability to keep them on for much longer durations due to their unparalleled comfort and lack of hinderance in daily life makes them even more desirable. The increase in popularity with Fitbit and Whoop show that this is a key entry point into large-scale continuous heart monitoring.

Smart rings

Overview

Smart rings are the most promising minimalist technology to detect heart rates (HR), body temperature, blood oxygen, respiratory rate (RR), steps and some other parameters of the body. They are also able to pre-determinate the symptoms of a few irregularities in the body like high blood pressure, etc. Smart rings are light weight and can be worn daily. They have "Internet of Things" (IoT) based technology, which uses AI to analyze data on the app. The app interfaces use visual graphs to showcase the patterns of Heart rate and respiratory rate, etc. Smart rings use the body blood oxygen flow rate and detect the oxygen level of the body and heart rate. Smart rings are significantly smaller and more discreet than smartwatches, offering users a sleek, lightweight, and hassle-free experience without compromising on essential health and activity tracking features, making them a more convenient and stylish alternative for everyday use.

Technology

Smart rings use PPG sensors to detect the Heart rate (HR) and Respiratory rate (RR). Smart rings are supposed to be paired up with a specific app on a smart phone. The AI companion of the app will help analyze the parameters of the body. Bioimpedance and NTG (Negative temperature coefficient) sensors are also used in the product to detect the skin temperature and metabolism of the body. Smart rings are rechargeable; they usually use a magnetic charging disc or a magnetic charger to charge the ring. The batteries used in the smart rings are lithium – ion batteries. Smart rings are waterproof. Figure 20 shows the components of smart rings.

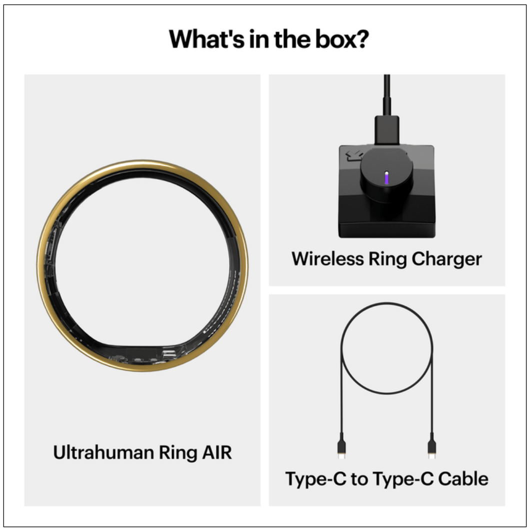

Figure 20: Components of smart rings

User guide and Technology

Smart rings are supposed to be worn on the fingers and are supposed to be paired with the app associated with the product. The app is supposed to be installed on a phone for the analysis of body parameters. The app showcases the analysis through the charts and the graphs manner. The AI algorithm makes it easier to collect the data and analyze it. It is the comfortable, lightweight, minimalist and most convenient smallest device to be used. The data is stored in the ring temporarily and it is transferred to the app and stored in it. So that one can review history and keep track of the health risks, etc. Figure 21 shows the ring pairing and interface of the associated app.

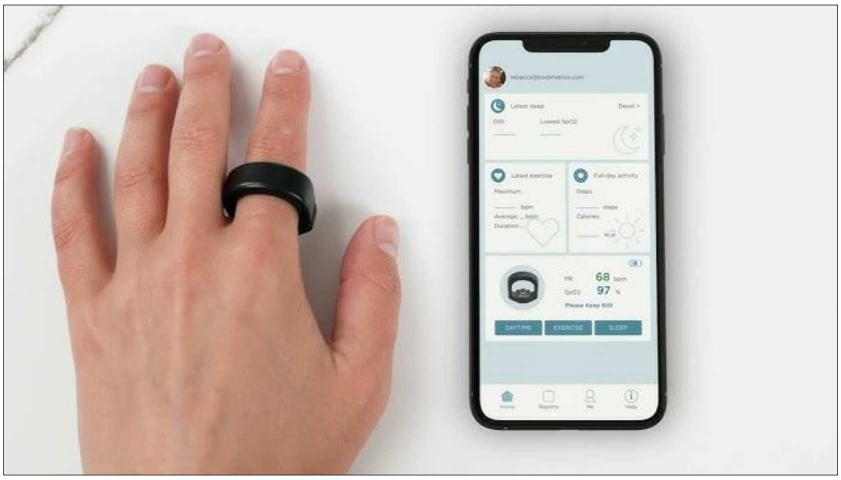

Figure 21: Ring pairing and interface of the associated app

Summary

Smart rings are redefining the future of wearable tech. With their sleek, compact design and functionality, these tiny marvels bring together style and substance in a way few gadgets can. Beyond simply tracking health metrics, smart rings offer real-time access to data that can anticipate potential medical conditions, empowering users with proactive insights into their future well-being. Accessible to anyone, they mark a bold step toward personalized healthcare and smarter living all wrapped around your finger.

Table 1: Summary of advance wearable devices

Sl. No.	Device Category	Technology	Key players
1	Smart ECG Patches	Smart patches monitor detects heart rhythm irregularities, palpitations, respiration rate, oxygen saturation, and body temperature and Electrocardiogram (ECG) data. Smart patches use ECG sensors to calculate the electrical signals of the heart. There are three electrodes, in which the two of them capture the voltage difference, created by the heart impulses. And the third electrode is grounded electrode or neutral one.	**Zio patch** (by I Rhythm) **Upbeat** (by Monitra Heathcare)
2	In – ear heart Monitors	Heart rate and heart rate variability detector based in the ear. Help build an overall picture of heart functioning. Optimal location for PPG sensors to carry out primary monitoring. It also uses motion and skin surface temperature to monitor multiple parameters that affect cardiological conditions. Physiologically the most optimal location in the body is due to minimal disturbance factors like bones and excess motion. It's very close proximity to the carotid artery helps PPG sensors to give the most optimal readings. Generally the public is used to ear-based devices like earbuds and hearing aids so form factor adoption is much easier as well.	**Cosinuss One** **Lumia Health**
3	Smart Watches	Widely adopted as the main fitness and health-based wearable in the market. Built for continuous monitoring as it can be worn for much longer periods of time. It can also fit the greatest number of sensors as well. Uses a plethora of sensors: PPG, ECG, accelerometers, skin temperature and SpO2 sensors. PPG and ECG help with heart rate and heart rate variability monitoring, with some higher-end watches containing medical-grade ECG sensors as well. SpO2 sensors help monitor blood saturation levels, another indicator of heart health. Accelerometers and skin temperature provide further secondary information to give a better overview of the heart. Connected to an app like the other devices, these companies have incorporated cutting-edge AI algorithms for watches which provide superior cardiology reports	**Whoop Strap 5.0** **Fitbit charge 6**

4	Smart Rings	Smart rings are the most promising minimalist technology to detect heart rates (HR), body temperature, blood oxygen, respiratory rate (RR), steps and some other parameters of the body. Like smart watches, smart rings use PPG sensors. Smart rings are IoT based devices, which works with the app associated with the device. The app is supposed to be installed on a phone for the analysis of body parameters. The app showcases the analysis through the charts and the graphs manner. The AI algorithm makes it easier to collect the data and analyze it.	**Ultrahuman ring Air** (By ultrahuman) **Samsung Galaxy Ring** (By Samsung)

3. CONCLUSION

Overall, the current consumer base is shifting to a health and wellness focused lifestyle, with extra focus on heart health and functioning. This has prompted the cardiology-based wearables to start making bigger strides in development and refining the quality of the results and reports generated. This is clearly seen in the increase in exploring of ear-based monitoring and the achievement of medical-grade equipment in wrist-worn wearables devices. While the ear-based devices still have a few hurdles like motion artifacts, regulatory issues and data accuracy, investment in sensor miniaturization and precision aims to tackle these and transform the industry. Altogether, the rapid development in all of these categories is a significant step towards empowering users and clinical institutes alike with actionable real-time cardiovascular insights.

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