

Smart wearable technologies for continuous and proactive blood pressure monitoring

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Cardiovascular diseases cause millions of deaths annually, accounting for approximately one-third deaths worldwide. Fortunately, proactive, continuous, and reliable monitoring of blood pressure can effectively reduce the risk of cardiovascular system-related death caused by sleep apnoea, stroke or hypertension, and improve quality of life.¹ High-precision and accurate blood pressure monitoring plays a key role in early diagnosis, cardiovascular risk classification, and the implementation of optimal treatment strategies. In clinical practice, invasive blood pressure monitoring, which involves implanting a transducer directly into an artery, is widely regarded as the gold standard. However, this method is typically restricted to critical care or surgical settings due to the associated risks of infection, bleeding, and arterial damage. Conventional non-invasive blood pressure monitoring relies on cuff-

based sphygmomanometers, which provide only intermittent measurements and thus may limit the ability to accurately assess blood pressure fluctuations.

On August 11, 2023, *Science Advances* published a study on intelligent wearable blood pressure monitoring system led by the researchers from Tsinghua University.² By combining a conformal and flexible strain sensor array with deep learning neural networks, the system can monitor blood pressure and cardiac function accurately, eliminating the need for precise positioning and professional knowledge. However, to realize a truly wearable and non-invasive monitoring system, seamless integration of custom-designed flexible circuits, integrated data acquisition and analysis, and wireless transmission modules are required.

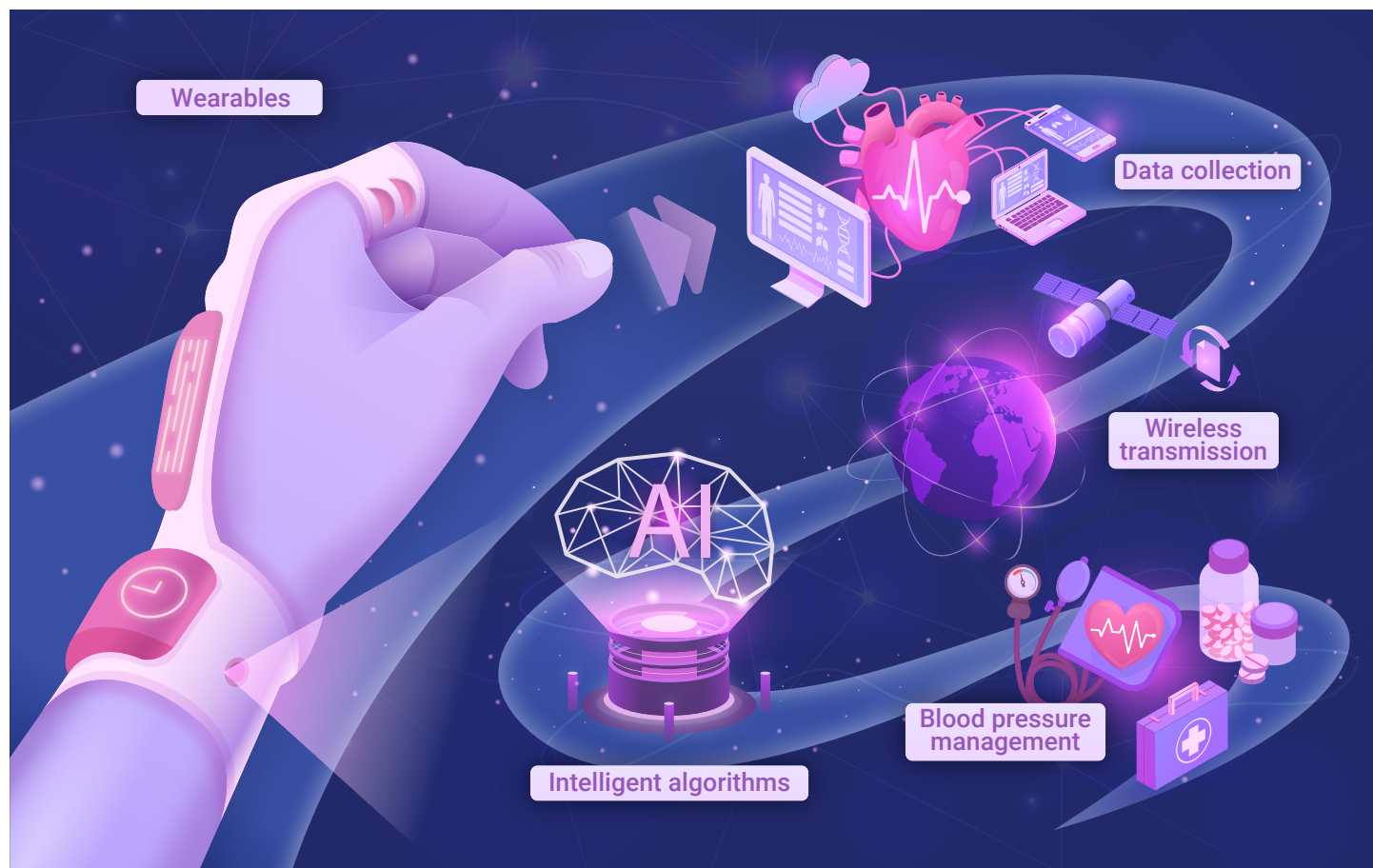


Figure 1. Wearable technologies for continuous and proactive blood pressure monitoring.

The field of continuous non-invasive blood pressure monitoring using wearable devices is rapidly advancing. Smart wearable devices for blood pressure monitoring offer convenient and continuous monitoring, real-time feedback and alerts, early detection and disease management, as well as increased patient engagement. Consequently, an increasing number of medical practitioners, scientific researchers, and business enterprises are participating in blood pressure monitoring projects driven by clinical needs and

technological advancements. As a result, significant advancements in blood pressure monitoring have been reported, leading to the emergence of wearable sensors and devices in the marketplace. Wearable devices must be comfortable, non-restrictive, and user-friendly to ensure effective long-term monitoring. User compliance and dressing concerns such as improper device placement, fit, and duration of device usage play a critical role in ensuring the accuracy and reliability of blood pressure measurement and management

(Figure 1).

On August 17, 2023, the researchers from City University of Hong Kong reported a thin, soft, and miniaturized system for wearable, continuous wireless monitoring of ambulatory artery blood pressure.³ The system successfully integrated a flexible piezoelectric sensing array, an active pressure adaptation unit, a signal processing module, and an advanced machine learning method. Initial trials involving 87 volunteers, as well as clinical tracking of two individuals with hypertension, validate the wearable system's capability, reliability, feasibility, and practical usability in achieving precise blood pressure control and personalized diagnosis. By addressing challenges related to materials, device design, mechanics, data processing methods, and integration strategies, the practical application of real wearable blood pressure monitoring is becoming a reality.

Currently, the challenges of miniaturizing and powering wearable devices have been alleviated. Real-time blood pressure monitoring using wearable devices necessitates continuous data collection and processing, driving the need for intelligent algorithms and processing methods. The aforementioned cases employed machine learning methods or models to process the feature-rich pulse data and obtain precise blood pressure measurements for detailed evaluation of cardiovascular function. We expect that further intelligent and adaptive algorithms, transfer learning, and time-series analysis techniques can be developed to mitigate potential interferences from electromagnetic radiation or movement artifacts, ensuring the accuracy and reliability of blood pressure measurements.

The 2023 edition of the guidelines for the prevention and treatment of hypertension in China announced, for the first time, the recommendation of wearable devices as a tool for blood pressure monitoring. In 2022, the HUAWEI WATCH D achieved international certification as a recommended smart wearable device for blood pressure management. Additionally, the Galaxy Watch 5 is capable of blood pressure measurement. However, users need to calibrate the wearable device every month using a traditional cuff-based method. Samsung's official statement confirms that the blood pressure function of Galaxy Watch 5 cannot be used for diagnosis of hypertension or check for signs of a heart attack. This particular function of blood pressure measurement has not yet received FDA approval in the US, thereby hindering the practical and clinical applications of wearable devices.

Bridging the gap between fundamental research and market application involves various aspects. Technically, wearable sensors have not yet attained a universally accepted level of functionality compared to static cuff-based devices. Comprehensive sensing parameters that encompass sensitivity, linearity, and batch consistency are essential for acquiring high-fidelity blood pressure-related signals.⁴ Simultaneously, developing robust and anti-interference interfaces between wearable sensors and the human skin can minimize movement artifacts during daily activities. Utilizing advancements in machine learning and cloud computation, it is possible to extract optimal

blood pressure-related features, thereby reducing the burden of data processing, transportation, and power consumption. In addition, a multidisciplinary approach involving material, mechanical, medical, electronic and engineering sciences should be proposed to integrate wearable sensors with wearable architecture seamlessly.

Effective integration of wearable blood pressure monitoring units into existing healthcare systems is also a challenge. This involves compatibility with electronic health record systems, collaboration with healthcare professionals, and incorporation into clinical guidelines. The complexities of healthcare integration can impede the market application of wearable devices.⁵ In addition, rigorous testing and regulatory requirements, as well as clinical trials and certifications result in serious delays in market availability. Establishing standards and protocols is necessary to ensure consistent and reliable measurements across different wearable devices.

Bridging the gap between fundamental research and market application of wearable blood pressure monitoring devices necessitates addressing the challenges in technology, regulation, standardization, commercialization, and healthcare integration. Collaborative efforts between researchers, industry stakeholders, regulatory bodies, and healthcare professionals are crucial in overcoming these obstacles and ensuring the successful translation of current scientific research into practical and applicable products.

REFERENCES

1. Kireev, D., Sel, K., Ibrahim, B., Kumar, N., et al. (2022). Continuous cuffless monitoring of arterial blood pressure via graphene bioimpedance tattoos. *Nat. Nanotechnol.* **17**: 864–870. DOI: 10.1038/s41565-022-01145-w.
2. Li, S., Wang, H.M., Ma, W., et al. (2023). Monitoring blood pressure and cardiac function without positioning via a deep learning-assisted strain sensor array. *Sci. Adv.* **9**: eadh0615. DOI: 10.1126/sciadv.adh0615.
3. Li, J., Jia, H.L., Zhou, J.K., et al. (2023). Thin, soft, wearable system for continuous wireless monitoring of artery blood pressure. *Nat. Commun.* **14**: 5009. DOI: 10.1038/s41467-023-40763-3.
4. Liu, S.J., Song, Z.Q., Chen, M.Q., et al. (2023). Modulus difference-induced embedding strategy to construct iontronic pressure sensor with high sensitivity and wide linear response range. *iScience* **26**: 107304. DOI: 10.1016/j.isci.2023.107304.
5. Mukkamala, R., Stergiou, G. S., Avolio, A. P. (2022). Cuffless blood pressure measurement. *Annu. Rev. Biomed. Eng.* **24**: 203–230. DOI: 10.1146/annurev-bioeng-110220-014644.

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DECLARATION OF INTERESTS

The authors declare no competing interests.