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Wireless multisite sensing systems for continuous physiological monitoring

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Respiratory diseases rank as the third leading cause of adult mortality [1], while cardiopulmonary and gastrointestinal issues are the primary cause of death within the first five years of a child's life [2]. The monitoring of cardiac, respiratory, and gastrointestinal sounds plays a vital role in routine care, as alterations or absence of these body sounds can serve as indicators of underlying diseases. These subtle, broadband acoustic-mechanical signals hold significant potential for continuous physiologic monitoring [3–6]. However, existing monitoring devices face limitations in terms of restricted measurement locations and inability to be used outside of controlled environments, resulting in limited applications beyond hospital settings [7–11].

With the advancement of bioengineering, the limitations of traditional human biomonitoring devices are being gradually resolved [7,12,13]. Writing in *Nature Medicine*, Yoo *et al.* [14] developed a wireless broadband acoustic-mechanical sensing (BAMS) network system that enables synchronized and continuous measurement of human body movements and sound information from various locations on the body. This innovative system holds immense potential in guiding clinical decision-making and enhancing outcomes through continuous monitoring of physiological signals [15,16]. Notably, the versatility of the BAMS network system allows for its application in both hospital and home environments.

The BAMS device demonstrates a remarkable broadband operation spanning from approximately 0.01 Hz to about 1000 Hz. Its wearable system design, complemented by a time synchronization mechanism across multiple devices, enables the spatiotemporal mapping of body sounds across different locations. Fig. 1a provides a visual representation of three clinically relevant applications of the BAMS network system: placing a device at the suprasternal notch for continuous monitoring of cardiopulmonary activity, positioning devices on the abdomen for spatiotemporal detection of gastrointestinal sounds, and strategically positioning 13 devices on the chest front and back to monitor lung health.

The BAMS device boasts compact dimensions measuring 40 × 20 × 8 mm, and a lightweight design weighing merely 6 grams. Encapsulated in a silicone elastomer, it ensures excellent wearability and can be comfortably worn on various body parts, making it suitable for individuals of all ages, including premature infants and the elderly. Fig. 1b visually depicts the device's application on a newborn model for cardiopulmonary monitoring. Each BAMS device comprises five essential components: a pair of microphones, an inertial measurement unit (IMU), flash memory, a Bluetooth module, and a power source. The exploded view of the BAMS device in Fig. 1c provides a detailed illustration of these components.

The BAMS device combines the functionality of an IMU and a pair of microphones to achieve its broadband operation. The IMU captures three-axis acceleration data, providing precise body movement data in the range of 0–20 Hz, unaffected by environmental sound [17,18]. The microphone system is responsible for capturing sounds associated with respiratory, cardiac activity, and gastrointestinal motion. Fig. 1d illustrates the schematic diagram of the microphone system, wherein microphones facing towards the body and the environment capture sound information from two directions. Adaptive algorithms are employed to minimize the interference of environmental noise. Remarkably, even under the interference of 90-dB white noise, the BAMS device effectively captures cardiopulmonary sounds. Its performance surpasses that of the current widely used digital stethoscopes, namely the 3M Littmann CORE and Eko, by 12% and 15% respectively, thereby expanding its application beyond hospital settings.

To assess the functionality of the BAMS network system, the researchers conducted clinical evaluations and collected data in relevant settings. In one study, the BAMS network system was used to monitor restricted airflow and gastrointestinal motility in 15 neonates within a neonatal intensive care unit (NICU). Additionally, the system was employed to evaluate the local lung function in 55 patients who underwent thoracic surgery. Notably, these data demonstrated high clinical accuracy, as they were benchmarked against devices approved by the US Food and Drug Administration (FDA). Fig. 1e presents a comparative analysis between the clinical results from the BAMS device and those derived from the FDA-approved device, with data from a 19-month-old patient within the NICU.

The BAMS network system, with its simultaneous measurement of body movement and sound, introduces exciting possibilities for monitoring physiological signals in both patients within hospital and home settings. It offers novel perspectives on spatiotemporal monitoring of cardiopulmonary and gastrointestinal disorders, as well as new methods for identifying and classifying subtypes of apnea in preterm infants and quantifying gas retention levels in high-risk neonates. While comprehensive evaluation across all disease contexts is still pending, the BAMS network system has already showcased its potential to enhance clinical decision-making, improve patient outcomes, and alle-

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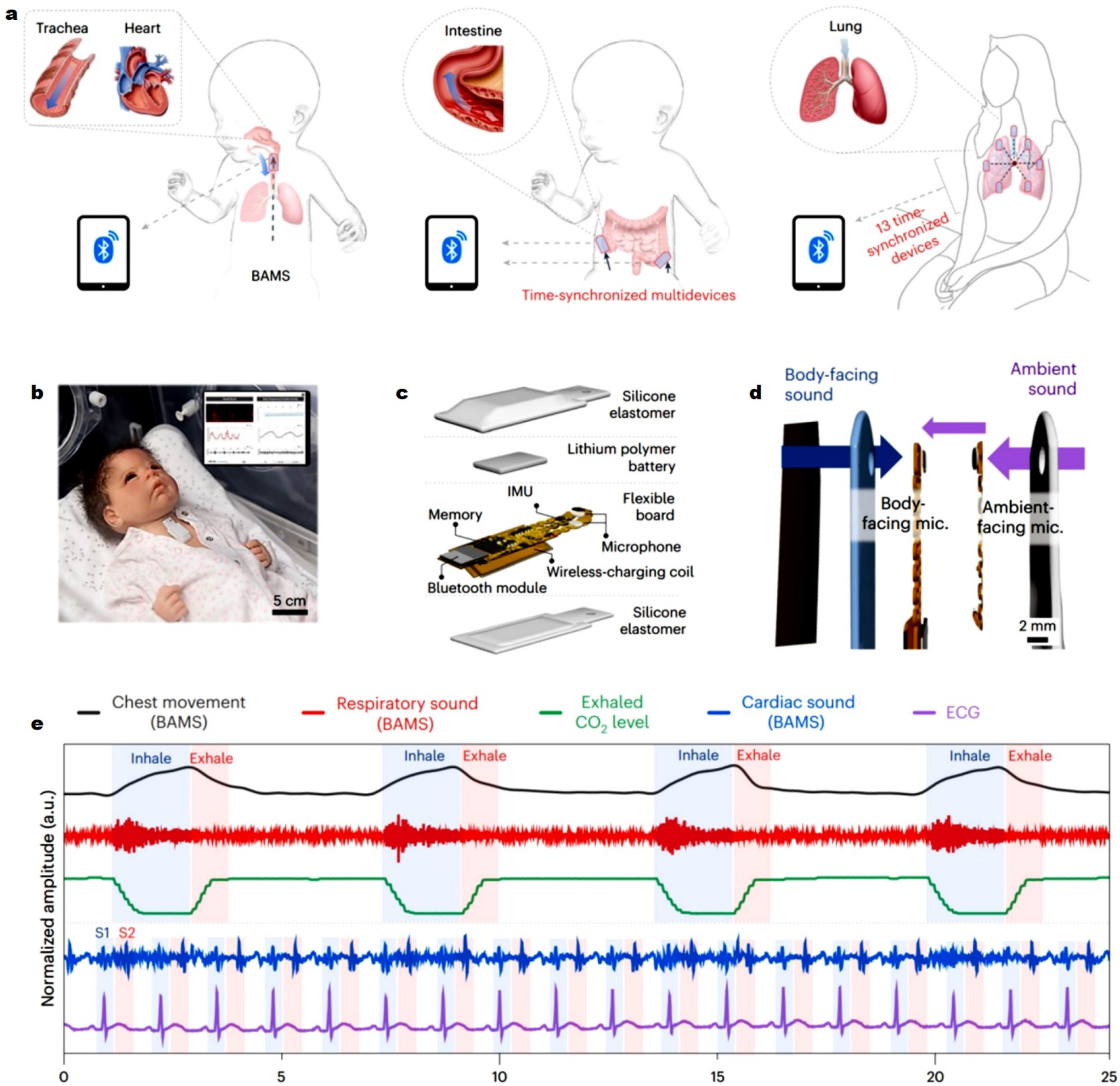

Figure 1 Wireless BAMS device with clinical-grade continuous physiologic detection and diagnostic capabilities. (a) Schematic of the BAMS device used to track cardiorespiratory activity, gastrointestinal sounds, and multi-location respiratory sounds. (b) Photograph of the BAMS device on a neonatal model. (c) Schematic of the explosion of the BAMS device. (d) Schematic of the sound separation system device. (e). Comparison of clinical results of the BAMS device. Reprinted with permission from Ref. [14], Copyright 2024, Nature Portfolio.

viate the burden on healthcare institutions [19]. With ongoing research and development, the BAMS network system is poised to deliver more efficient and personalized services for both hospitals and homes, further advancing the field of physiological monitoring.

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