Exploring 5G Key Technologies for Helicopter Aviation Medical Rescue

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Exploring 5G Key Technologies for Helicopter Aviation Medical Rescue

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Abstract

Purpose: This study aimed to explore the application of 5G key technologies in helicopter aviation medical rescue.

Methods: This study used retrospective analysis to statistically analyze 11 aviation medical rescue cases at the Shenzhen University General Hospital from November 2019 to March 2023. To assess the time and efficiency of the rescue, we paid attention to the data such as flight time, distance, disease types, and rescue scenarios. The application of 5G low-altitude network communication technology, body area network disease sensing technology and 5G air-ground collaborative rapid diagnosis and treatment technology in aeromanical rescue was contrasted and explored.

Results: The helicopter rescue flight distance was 60–600 kilometers, and the flight time was 10–136 min. The study used a 5G private network and 5G module vital sign monitoring equipment. The
low-altitude 5G network had high communication quality and high-precision localization by the domestically produced Beidou. The air body area network technology used multi-pose mannequins, depth learning estimation algorithm, and encryption algorithm information entropy 7.9993. The encryption time was short. The 5G air-to-ground collaborative rapid diagnosis and treatment technology supported 5G direct connection, with a packet loss rate of 0.2%, and achieved 1080P high-definition multi-party remote consultation.

Conclusions: The combination of helicopter rescue and 5G technology could significantly improve rescue efficiency, shorten response time, and achieve a remote diagnosis. The quality of low-altitude 5G network communication was high, and the domestic Beidou satellite high-precision positioning technology supported precise rescue. The airborne body area network disease perception technology adopted advanced human channel models and encryption algorithms to ensure timely and secure information. The 5G air-to-ground collaborative rapid diagnosis and treatment technology enabled high-quality remote consultation. Applying these innovative technologies might significantly enhance the ability of emergency medical rescue and provide strong support for future rescue operations.

**Keywords:** low airspace, helicopters, medical aid, 5G technology

1. Introduction

The demand for emergency medical assistance has increased with the increase in world population and accelerating urbanization. Traditional ground rescue methods cannot meet the needs of patients for quick and accurate arrival in certain situations. Therefore, helicopter medical rescue has become an effective option[1]. Helicopters must quickly and accurately determine the target location, cooperate closely with ground medical personnel, maintain stability during high-speed flight, and achieve real-time data transmission and efficient medical treatment during medical rescue[2,3]. The highly developed 5G communication technology is essential to achieve the aforementioned objectives. As one of the most advanced mobile communication
technologies at present, 5G technology has advantages such as large bandwidth, low latency, and high reliability\(^{[4,5]}\). Furthermore, 5G technology can also achieve remote medical rescue. Also, medical experts can guide on-site medical personnel to provide treatment through remote video and other means, thereby improving the efficiency and quality of medical rescue\(^{[4,5]}\). Therefore, studying the key technologies and clinical applications of helicopter aviation medical rescue based on 5G technology is of great significance.

Globally, the development of 5G technology is gradually maturing. The development of 5G technology started in 2018, and the first 5G network was put into use in South Korea. Since then, 5G technology has rapidly developed globally. At present, many countries, including the United States, Japan, South Korea, and Europe, have begun commercial deployment of 5G networks. Countries have also started to explore the applications of 5G technology. For example, in the United States, 5G technology has been widely applied in fields such as intelligent transportation and intelligent manufacturing. In Europe, 5G technology is also applied in fields such as industrial automation and robot control\(^{[6]}\). In the Asian region, countries such as South Korea and Japan are exploring the applications of 5G technology in fields such as intelligent manufacturing and intelligent health care. China has also led the world in the research and applications of 5G technology\(^{[7,8]}\). China has built the world's largest 5G network since the end of 2019. At present, 31 provinces and cities across the country have opened 5G commercial services. China has applied 5G technology to fields such as intelligent manufacturing, intelligent logistics, and smart cities. In the field of health care, 5G technology is also applied in areas such as telemedicine and medical image transmission. Further, China has made significant progress in innovative research on 5G technology. For example, companies such as Huawei and ZTE are leading in the research and development of 5G technology. At the same time, the Chinese government is actively promoting the development of 5G technology and has formulated a series of policy measures to support the promotion and applications of 5G technology. On August 22, 2022, the aviation rescue drill at Shenzhen
University General Hospital successfully adopted 5G private network access\textsuperscript{[9]}. Overall, 5G technology has received widespread attention and applications both domestically and internationally, with no application found in the field of helicopter medical rescue.

This study aimed to explore the 5G key technologies for helicopter aviation medical rescue to address the shortcomings of traditional air rescue methods in information transmission, positioning accuracy, flight stability, real-time data transmission, and medical treatment efficiency. We analyzed the potential of the applications of 5G technology in helicopter medical rescue in terms of improving rescue efficiency, shortening patient treatment time, and enhancing the collaborative combat ability of rescue teams. Ultimately, this study aimed to provide a scientific basis for innovation and development in the field of aviation medical aid in the future, and to provide more efficient, safe, and accurate technical support for emergency rescue services.

2. Materials and Methods

2.1 Overview of exercise and practical operations

Aviation medical rescue has been an important means of responding to emergency medical events in recent years. The Shenzhen University General Hospital has signed a cooperation agreement with Shenzhen Eastern Navigation Co., Ltd., provided a guarantee for developing aviation medical rescue programs and services. The work started with four aviation medical rescue drills held from September 2019 to December 2022 in order to lay the technical foundation. The types of diseases considered during these drills included multiple injuries to the whole body and spinal cord, and the scenarios included traffic accidents and tunnel scenes. From November 2019 to March 2023, seven aviation medical rescue operations were conducted covering multiple systemic fractures, spinal injuries, drowning pulmonary edema,
multiple organ failure, hemopneumothorax, and other diseases. The types of rescue operations were as follows: joint mountain search and rescue, seaside drowning rescue, and traffic accident rescue, with a flight distance of 60–600 km and a flight time of 10–136 min. These operations involved the first aerial pulmonary resuscitation, medical staff delivery, and emergency medical treatment. Among the rescue operations, the joint mountain search and rescue used highly complex technologies such as hovering, winches, and aerial lifting, providing significant support for treating patients\(^{[10]}\). The on-site treatment was extremely difficult. In each operation, medical institutions and helicopter rescue teams collaborated for the smooth conduct of on-site treatment and transportation, achieving good results. The successful completion of these aviation medical rescue drills provided insights for future studies on the medical rescue of similar types. At the same time, these operations helped promote the development of aviation medical rescue technology, providing more comprehensive and technological solutions for emergency medical care. Among these, the application of 5G key technologies is one of the important directions in developing aviation medical rescue technology, which may further improve the collaborative efficiency and rescue quality of helicopter rescue teams and medical institutions.

2.2 Applications of 5G technologies in two cases

On August 22, 2022, the aviation rescue drill successfully adopted 5G private network access, achieving advanced functions such as remote video consultation, vital sign data transmission, and Beidou high-precision positioning and rescue trajectory. This drill was novel in testing domestically produced portable ECMO on a helicopter, laying the technical foundation for practical rescue \([9]\). These achievements were successfully applied in the first international cross-regional long-distance aviation medical rescue case on November 9, 2022. This case further optimized the application of advanced technologies such as remote video consultation, innovative 5G module equipment, vital sign data transmission, and Beidou high-precision positioning;
improved rescue time and efficiency; and shortened transit time\textsuperscript{[11]}. The aforementioned case validated the low airspace medical rescue 5G network technology, air body area network disease perception technology, and 5G air-to-ground collaborative rapid diagnosis and treatment technology. The entire rescue process seamlessly connected the accident scene via the applications of 5G technologies, medical ambulances/helicopters, and hospital emergency departments, achieving "admission as soon as boarding" and "integration of pre-hospital and in-hospital diagnosis and treatment," significantly improving the level of medical rescue.

3. Innovative Technology

Three major problems facing the air during the aviation medical rescue operations are as follows: difficulty in communication, difficulty in disease monitoring, and difficulty in collaborative diagnosis and treatment. Our team put forward a series of important technological innovations such as developing airborne 5G network communication technology and achieving efficient and stable communication to overcome the aforementioned challenges. The body area network disease perception technology provided precise real-time monitoring and 5G air-to-ground collaborative rapid diagnosis and treatment technology, which strengthened the collaborative capacity and efficiency of emergency response teams. Hence, these innovations brought unprecedented breakthroughs to the field of aviation medical rescue, significantly improving rescue effectiveness.

3.1 Low airspace medical rescue 5G network technology

3.1.1 Low-altitude 2.6 + 4.9 GHz collaborative networking

The low-altitude medical rescue helicopter provided sidelobe coverage of a 2.6GHz 5G downtilt base station as a 5G private network access signal during takeoff and landing, with a true height less than 150 m. The main/side lobes of a 4.9GHz 5G uptilt
base station provided 5G private network signal access during takeoff/landing and flight at a true height of 150 m or above. The collaborative coverage of two frequency bands of base stations provided seamless switching of 5G private network access for helicopter vertical takeoff and landing and horizontal flight\cite{12}. The network switching delay was ≤30 ms (Fig. 1).

![Figure 1 Schematic diagram of 2.6 GHz + 4.9 GHz dual-frequency collaborative 5G networking\cite{12}](image)

3.1.2 Adopting 5G + GNSS (Global Navigation Satellite System) external suction cup antenna

The aircraft body mainly comprises aluminum, significantly attenuating the signal after blocking radio waves. Therefore, we designed an external pull-away suction cup antenna to dock with the onboard 5G router. The external suction cup antenna could be installed on the glass window side of the helicopter (Fig. 2), and directionally received 5G signals from the external airspace of the aircraft body through glass (window) materials with low signal attenuation.
This installation was made on a domestic medical rescue helicopter, with the novel and successful deployment of 5G-CPE equipment. After testing, under this installation method, the attenuation difference of 5G signal inside and outside the body was only 8dB, while 5G-CPE’s built-in rubber rod antenna deployed inside the cabin, and the attenuation of 5G signal by the metal material of the aircraft body is 20dB, which is a significant difference.

3.1.3 **Collaboration of 5G + Beidou positioning technology**

Next, we examined the Beidou positioning capability provided by the 5G-CPE module (Fig. 3). The data were transmitted back to the emergency platform deployed by the hospital via the 5G private network to locate the real-time flight position of the rescue helicopter\[10\].
The traditional positioning scheme for airspace helicopters generally uses a global positioning system (GPS) for the helicopter's built-in flight-positioning module. It does not output positioning data to external systems. It only interfaces with local airspace management departments (regional civil aviation bureaus or air traffic control bureaus) for airspace flight management. For this scheme, we adopted the Guanghetong FM160 model 5G air rescue equipment (Fig. 4) and used the GNSS capability of the 5G module and the antenna to provide GNSS reception, obtaining real-time positioning information for low-altitude medical rescue.
**Figure 4** 5G module–integrated 5G air rescue equipment with GNSS capability. The module was derived from Guanghetong FM160

### 3.2 Air body area network disease awareness technology

#### 3.2.1 Construction of a body area network transmission scheme based on body features and channel quality

Communication energy consumption is the key factor that restricts the wider applications of a network with limited energy resources. Human activities drastically affect near-body communication channels, leading to strong time-varying characteristics. This limits the performance of communication energy consumption optimization methods based on wireless sensor networks\[13,14\]. Therefore, designing an intelligent communication mechanism for body area networks should consider the strong time-varying characteristics of the channel so that the overall transmission energy efficiency can be improved. This study designed a near-body channel estimation algorithm based on deep learning. Treating the time–frequency response of the pilot point as a low-resolution two-dimensional image, using convolutional neural networks and memory networks to generate high-resolution images, and obtaining
complete time–frequency response characteristics helped predict and evaluate the current channel quality (Fig. 5). Further, we combined human dynamic channel quality estimation and prediction procedures and studied energy-efficient and adaptive access protocols and resource allocation schemes for improved service quality to achieve stable, flexible, and low-power transmission effects.

![Figure 5](image)

**Figure 5** Detection of channel characteristics in body area networks

### 3.2.2 Proposing a volume domain network data encryption method based on physical signal features and chaotic mapping

The body area network involves sensitive data and hence requires a high-level security system. The limited sensor resources limit the applicability of traditional encryption schemes. As shown in Figure 6, this study used the characteristics of physical signals as the initial chaotic values to design a high-strength and sensitive encryption scheme, providing asymmetric encryption with one key at a time. The main procedures followed in this study were as follows: (1) Calculation of feature vectors for sign signals, precise classification of signal characteristics of physical signs using discrete wavelet transform, and design of multidimensional convolutional neural networks; (2) design and quantification of the algorithm for generating heterogeneous combination chaotic sequences, proposing power spectral entropy as
the evaluation criterion, and designing a quantified heterogeneous combination chaotic sequence that met the security requirements of the body area network; (3) implementation and verification of data encryption scheme, proposing a heterogeneous combination chaotic encryption scheme based on sign signal feature vectors and conducting hardware implementation and performance verification based on the FPGA platform (Fig. 6).

![Figure 6 Body area network data encryption method](image)

### 3.3 5G air-to-ground collaborative rapid diagnosis and treatment technology

#### 3.3.1 Development of a plug-and-play highly reliable 5G emergency equipment

The 5G module has high power consumption, insufficient USB power supply capacity for online medical devices, and unreliable long-term continuous data transmission and
communication through a USB-developed 5G single-slot module. (1) We developed a 5G single-slot module using the existing 12-V power supply and direct communication between network ports of online medical equipment. Additionally, we used anti-interference and heat treatment technologies to achieve 5G standardization of devices such as monitors and ventilators. There is no need to change the software and hardware of the online equipment and special installation. This provided us a plug-and-play 5G emergency equipment for use in hospitals (Fig. 7). (2) We established a highly reliable 5G medical equipment. Our team invented the antenna technology in the form of multiple antennas and coupled devices, anti-power and inter-device interference technology, highly stable software design technology, and wireless parameter tuning. This antenna technology also included switching performance improvement under high-speed movement, network outage alarm optimization, alarm strategy and other designs, and high reliability of 5G monitors, 5G transport monitors, 5G ventilators, 5G defibrillators, and other equipment. The packet loss rate of the data was within 0.5% at high speeds and edge locations with the RSRP of –95 dBm for extended periods, which was much higher in reliability compared with other wireless communication consumer products (packet loss rate of 3%–5%) and could facilitate the high-reliability applications to the medical industry. The 5G rescue equipment developed in this study completed the first domestic air rescue and remote intensive care unit rescue application, playing an essential role in epidemic prevention and control (Fig. 7).
3.3.2 Establishing an air-to-ground collaborative information sharing platform

We developed a panoramic archive storage and retrieval system for pre-hospital emergency patients. A panoramic archive of pre-hospital emergency patients was formed based on the patient health archive, combined with the vital signs collected by 5G emergency equipment, which helped achieve real-time data exchange with the hospital system. We focused on building a standard for emergency rescue data in open spaces, considering that the panoramic archive of pre-hospital emergency patients included emergency dispatch and diagnosis and treatment information to support comprehensive and complete access and transmission of cross-institutional rescue information. We developed an air-to-ground emergency rescue information exchange and scheduling system. We used microservices, distributed, and message service technologies to develop an application platform relying on the 5G private network and information security infrastructure, achieving information collaboration covering the entire chain of pre-hospital first-aid, inter-hospital transportation, and in-hospital treatment. These technologies supported information exchange and business
collaborative applications among cross-regional, cross-institutional, and cross-departmental application systems. Collecting satellite positioning information through the Beidou module and the high-speed and low-latency characteristics of 5G technology supported aviation transportation tracking, injury assessment and disposal, and remote real-time physical sign monitoring and diagnosis. It also opened up an air green channel, significantly improving the overall rescue success rate. We developed a remote and multidisciplinary consultation system for open spaces, established a multi-channel collection and transmission of vital signs, and transmitted the archival information and treatment images of critically ill patients outside the hospital to the hospital's emergency expert group or multidisciplinary consultation on time. This provided technical guidance and full monitoring for the diagnosis and treatment of critically ill patients outside the hospital, and improved the efficiency of diagnosis and treatment (Fig. 8).

Figure 8 Air-to-ground collaborative information-sharing platform
4. Results

The 5G helicopter medical rescue had a faster response, high-level accuracy, and better patient transport capacity compared with the traditional non-5G helicopter medical rescue and ambulance traditional rescue[15]. We conducted a comparative analysis and research on the clinical effects of these three different types of medical rescue methods, and also conducted comparative research on key technologies domestically and internationally, which are internationally leading technologies, to provide advanced scientific and effective decision-making basis for future medical rescue operations.

4.1 Clinical rescue effectiveness

4.1.1 Improvement in response time

The helicopter had a flight distance of 60–600 km and a flight time of 10–136 min to cover this distance. In contrast, ambulances typically traveled at speeds of 40–60 km/h depending on road conditions and distance and covered a distance of 60–600 km in 1–15 h. Hence, the flight time was less than a quarter of the traditional ambulance time, significantly reducing the rescue response time.

4.1.2 Innovative 5G medical equipment

On August 22, 2022, the aviation rescue trial first adopted the 5G private network access. On November 9, 2022, the 5G technology assisted the first international cross-regional long-distance aviation medical rescue operation, using the novel airworthy 5G module vital sign monitoring equipment jointly developed with Mindray. The 5G emergency equipment could improve treatment efficiency[16-18].

4.1.3 Expanding the rescue scope

The traditional rescue radius is generally 5–10 km. However, in this study, the helicopter rescue radius was 60–600 km. The helicopter rescue could significantly
expand the rescue scope and improve rescue efficiency compared with traditional ambulance vehicles expanding the rescue radius to 600 km.

### 4.1.4 Improving rescue effectiveness

A helicopter using 5G technology can transmit real-time high-definition images and videos through high-speed networks, helping doctors conduct remote diagnosis and treatment in the air. Further, 5G technology can also provide high-precision positioning and map navigation functions, helping rescue personnel locate patients more accurately, shortening search and rescue response time, and improving rescue efficiency.

### 4.2 Technical application effect

Comparison of similar aviation technological parameters at home and abroad

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<td>Positioning technology</td>
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5. Discussion

This study explored the 5G key technologies and applications in helicopter aviation medical rescue. We found significant improvements in the following clinical indicators based on the evaluation of 11 rescue cases: (1) response time: helicopter rescue shortened rescue response time, and the flight time was less than a quarter of that of traditional rescue vehicles; (2) 5G medical equipment innovation: 5G private network access and airworthy 5G module vital sign monitoring equipment were adopted for the first time, improving treatment efficiency; (3) expansion of rescue...
The helicopter rescue radius was expanded to 600 km, significantly improving rescue response time and efficiency; and improved rescue effectiveness: 5G technology helicopter rescue could achieve high-speed network transmission in terms of real-time high-definition images and videos, helping doctors conduct remote diagnosis and treatment. At the same time, the 5G technology provided high-precision positioning and map navigation functions, helping rescue personnel accurately locate patients, shorten search and rescue response time, and improve rescue efficiency. The 5G key technologies used in this study demonstrated an internationally leading level in practical applications. The key technological innovations of this study were as follows. 5G low-altitude communication technology: (1) It used ground tilt coverage technology in the 4.9GHz frequency band, specifically designed for low airspace coverage, with signal coverage within 300 m of low airspace. (2) Beidou positioning technology: It adopted a small wearable Beidou positioning terminal, specifically providing accompanying flight-positioning output for crew members to ensure their personal safety. Body area network transmission scheme: It was a near-body channel estimation algorithm based on deep learning and human body posture recognition. Body area network data encryption method: It was a body area network data encryption method based on signal characteristics of physical signs and chaotic mapping. 5G emergency equipment: It was the equipment having plug-and-play hardware design, 5G modular equipment, as well as highly reliable multi-antenna technology, anti-interference technology, and so forth. The data packet loss rate was within 0.2%, achieving real-time image transmission. Air-to-ground collaborative emergency platform: Aviation rescue was upgraded from a single voice method to real-time audio and video, supporting multi-party remote consultation under 1080P high-definition video image transmission. Hospital operations could be carried out 10–40 min in advance during the aviation rescue stage.

Technical advantages: Compared with the traditional domestic technology and similar foreign technologies, the technologies used in this study had an internationally
leading position, such as 5G low-altitude communication technology, Beidou positioning technology, body area network transmission solutions and data encryption methods, 5G emergency equipment, air-to-ground collaborative emergency platform, and so forth. Technical deficiency: 5G network coverage: Although this study adopted ground tilt coverage technology in the 4.9GHz frequency band, low-altitude coverage in some remote areas still needed improvement. 5G network stability: Currently, 5G networks still have certain stability issues in high-speed mobile scenarios, which may affect the real-time communication performance of helicopter aviation medical rescue. Technology popularization and promotion: Although this study made breakthroughs in 5G key technologies, its global popularization and promotion still need strengthening.

The key 5G technologies for helicopter aviation medical rescue need the following improvements: (1) improvement in the 5G communication coverage range and signal stability: Higher frequency band ground tilt coverage technology can be studied to meet a wider range of low-altitude coverage needs, and multi-antenna technology and anti-interference technology can be optimized to improve signal coverage range and stability. (2) Improvement in personal positioning technology: Besides the existing Beidou positioning terminal, hybrid positioning technology that integrates multiple satellite navigation systems (GPS, GLONASS(Global Navigation Satellite System), etc.) can be studied to improve positioning accuracy and reliability [19]. (3) Optimizing the transmission scheme of the body area network: The near-body channel estimation algorithm based on deep learning and human body posture recognition can be further optimized to adapt to more complex human motion states and improve data transmission efficiency. (4) Enhanced body area network data encryption method: More efficient encryption algorithms and protocols can be studied to improve data transmission security based on signal characteristics of physical signs and chaotic mapping [20]. (5) Improving 5G emergency equipment: 5G modular devices with higher transmission rates, lower latency, and lower power consumption can be explored to better adapt to various environments and application scenarios [17,21]. (6)
Improvement in the functions of emergency platforms: Besides real-time audio and video communications, emergency platforms with more intelligent functions can be developed, such as real-time data analysis, intelligent diagnostic advice, and so forth, to improve the effectiveness and efficiency of aerial medical treatment\cite{22,23}. The 5G key technologies used in helicopter aviation medical rescue can better meet practical application needs through the aforementioned technological improvements and play a significant role in improving medical rescue efficiency and treatment level.

The 5G technology outlook for future helicopter aviation medical rescue includes faster response and diagnosis and the use of 5G networks and remote medical platforms to shorten rescue response time. More advanced 5G medical equipment can improve treatment efficiency and accuracy. The rescue scope and rescue areas can be extended by improving helicopter performance and 5G network coverage\cite{24}. The technology integration, especially the integration of 5G technology with artificial intelligence, virtual reality, and other technologies, can help achieve innovative capabilities. The international collaboration and exchange, by sharing experiences and technological achievements, will improve global rescue capabilities. It can strengthen data security and ensure effective protection of medical data and patient privacy. The technology integration can also help improve intelligent scheduling and management, achieving optimized allocation of rescue resources. Policy support and standard formulation are needed to ensure and improve 5G technology applications in the field of aviation medical rescue\cite{25,26}. Industrial application expansion, 5G technology is applied to disaster rescue operations, traffic accident handling, and so forth.

6. Conclusions

This study evaluated 11 rescue cases and found that 5G technology had significant advantages in terms of improvement in response rescue time, innovative medical equipment, expansion of rescue scope, and improvement in rescue effectiveness. Although existing technologies have shortcomings in terms of network coverage,
network stability, and other aspects, the 5G technologies for helicopter aviation medical rescue can better meet practical application needs. We believe that 5G technology can make breakthroughs in terms of rapid response, advanced equipment, and expanding rescue coverage, playing a significant role in improving the efficiency and level of global emergency medical rescue. Furthermore, research and practice on industrial application expansion, intelligent scheduling and management, and data security assurance can be important directions in developing 5G technologies for helicopter aviation medical rescue in the future.

**Declarations**

**Competing interests**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contributions

Wei Han designed the research framework and conducted summary and analysis. Yuanting Li is responsible for the research on 5G air-ground collaborative rapid information coordination technology. Changgen Chen is responsible for the technology and application of 5G emergency medical equipment. Danni Huang is responsible for the research on 5G technology and Beidou positioning technology. Junchao Wang is responsible for the research on the network disease sensing technology of wearable devices. Xiang Li is responsible for the implementation and analysis of coordinated air transport. Zhongliang Ji is responsible for the evaluation and improvement of clinical applications. Qin Li is responsible for data collection and analysis. Zhuang Li is responsible for writing and revising the paper. All authors are responsible for the implementation and results of this study, confirmed the final version of the manuscript, and approved its submission for publication.

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