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Research article

Construction of a 5G-based, three-dimensional, and efficiently connected emergency medical management system

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ABSTRACT

Background: Shenzhen is unique in its need for ad hoc responses to emergencies. The need for emergency medicine also demonstrates a trend of sustained growth.
Objective: A three-dimensional and efficiently connected emergency medical management model using fifth generation mobile communication technology (5G) was established to improve the efficiency and level of management in emergency medicine.
Method: A mixed-frequency band private network collaborative emergency treatment mode was built under daily emergency scenarios using 5G. The efficiency of a three-dimensional telemedicine treatment mode was tested using prehospital emergency medicine. Also, the feasibility of quickly establishing a temporary network information system using unmanned aerial vehicle (UAV) and/or high-throughput communication satellites under disaster-caused power outages and network interruptions was examined. A monitoring system was constructed for suspected cases using 5G amid public health emergencies, which raised the Emergency Department's efficiency and security in responding to the pandemic.
Results: The three-dimensional rescue system supported by 5G showed that the radius of the emergency medical rescue services expanded from 5 to 60 km, and the cross-district emergency reaction time reduced from 1 h to <20 min. Thus, it was feasible to construct a communication network expeditiously with devices carried by UAV under disastrous scenarios. The system developed based on 5G could be used in managing suspected cases of public emergencies. Among the 134 suspected cases in the early stage of the pandemic, no nosocomial infection was detected.
Conclusion: A three-dimensional, efficiently connected emergency medical management system based on 5G was constructed, following which the emergency rescue radius quickly expanded and the emergency response time reduced. Thus, with the aid of new technology, an emergency information network system was built expeditiously under specific scenarios, such as a natural disaster, and the level of management under public health emergencies advances. The confidentiality of patient information is a critical issue regarding the application of new technology.

1. Introduction

Emergency medicine forms an integral part of the social, medical security system and plays a critical role in daily medical

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treatments and ad hoc responses to public emergencies. It also serves as a major indicator for measuring the standard of emergency medicine and emergency response capability of a city. In the past three decades, China's emergency medicine has formed a unique theoretical framework and operation mode and has undergone rapid development. However, compared to emergency medicine in developed countries, China's emergency medicine information network is lagging; the shortage of prehospital first aid personnel is acute, and informatization of prehospital emergency treatments remains underdeveloped. These problems restrict the rapid development of Chinese emergency medicine. Thus, the failure of emergency medicine development in meeting societal needs has to be resolved urgently [1].

In addition to the continuous growth in the economic level, the urban population in first-tier cities like Shenzhen is also experiencing a similar rise. People's demands for emergency medicine resources are continually increasing. According to the data published by the Shenzhen Emergency Center in China, a total of 258,505 ambulances trips were dispatched in 2021, recording an annual increase of 13.98%; subsequently, 219,976 patients were rescued, marking an annual increase of 11.40% [2]. In the past 5 years, Shenzhen residents' demands for prehospital first aid have demonstrated a trend of constant increase (Fig. 1). However, due to the uneven distribution and the insufficient allocation of resources, the efficiency of first aid is less [3], thereby exacerbating the contradiction between first-aid resources and their demand.

2. Status and goals of Shenzhen emergency medicine

As one of the national pilot demonstration areas, Shenzhen has characteristics related to emergency medical rescues. Shenzhen's forest coverage accounts for 40% of its total area, and there are 241 urban villages across the city. The city is crisscrossed by the modernized well-planned area and the disorderly planned urban villages. Low hills, gentle plateaus, terraces, mountains, and the ocean comprise the landscape of Shenzhen. Thus, the emergency rescue environment of Shenzhen differs from others with respect to the plain landscape in the northern area cities or the absence of demands for rescue at sea in the inner area cities. The eastern and western part of Shenzhen is long and narrow in shape. Tourist spots, such as Dapeng district located thereat, are 70 km away from the city center, with about 1–1.5 h drive. The problem of shortage in emergency rescue resources in some areas of Shenzhen is compounded by the uneven distribution of resources. Although this phenomenon can be remedied, it is challenging to build new hospitals and emergency sites due to the long cycle and high costs. Therefore, how to use the existing conditions and technologies in quickly constructing a responsive three-dimensional emergency medical rescue model is of paramount significance in improving the efficiency of emergency medical treatment and meeting people's growing demand for emergency medicine.

The characteristics of the fifth generation (5G) network are high data transfer rate, low latency, low energy consumption, high systematic capacity, and the ability to connect large-scale devices, which provides novel opportunities for improving the efficiency of the medical service system [4]. Thus, how to utilize new technologies, such as 5G, in solving various issues is currently under intensive focus. This includes how to construct a seamless connection between the prehospital rescue sector, the Emergency Department, and the Intensive Care Unit (ICU); how to integrate management inside and outside of the hospital; how to innovatively design an emergency medical rescue process and service system; how to raise the efficiency of emergency medical rescue while reducing the rate of mortality in critically ill patients. Based on these findings, we aimed to establish a high-standard, regional, three-dimensional Emergency Medical Treatment Center that provides efficient treatment to critically ill patients and an expeditious response to mass injuries and disasters. To achieve this goal, we have teamed up with the China Mobile Shenzhen Company, Tianjin University, and other institutions to construct a 5G-based, three-dimensional, efficiently-connected emergency medical management model utilizing a multi-frequency band hybrid network for the Emergency Department in our hospital.

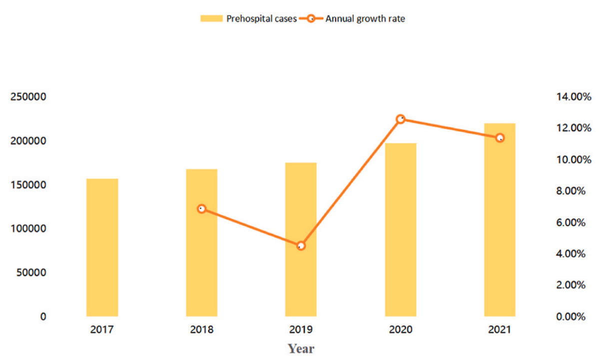

Fig. 1. The growth trend of prehospital emergency cases in Shenzhen from 2017 to 2021 (Shenzhen, China, 2022).

3. Methods in constructing a 5G-based, three-dimensional, and efficiently connected emergency medical management system

3.1. Constructing a 5G hybrid band private network collaboration in daily emergency scenarios

In daily emergency rescue scenarios, our ambulances were connected to 5G public frequency band signals. Thus, data are exchanged by connecting the designated 5G-Customer Premise Equipment (CPE) terminal on the vehicle with various vital signs-detecting devices on the ambulance that include electrocardiogram monitor, portable ultrasound, and webcam. Patients' information collected by the monitoring devices on the vehicle and the medical staff on the ambulance can be sent to the hospital information platform in real-time through the 5G network. Remote experts in the hospital can obtain the patients' data collected by several devices through the remote information system; for example, electrocardiogram, blood oxygen, respiration, blood pressure, and body temperature. They can evaluate the patient's condition together with prehospital emergency doctors and provide guidance on treatments to achieve the goal of telemedicine.

The 5G airborne terminal on the medical rescue helicopter is connected to a low-altitude 5G private base station with a private network frequency band. The 5G private station adopts Multiple-Input-Multiple-Output (Massive MIMO) and Beamforming in reducing the downlink interferences. It also uses air interface technologies, such as various Numerology and Bandwidth Party (BWP) resources on land and in the air to raise the air mobility and management of rescue helicopters by reducing the interference between the air and the land. Against this backdrop, 5G signal coverage and precise location within the height of 300 m and within the radius of 5 km horizontal distance are made possible, thus achieving the three-dimensional rescue under daily scenarios. In prehospital emergency treatment, emergency personnel can quickly send patients' information to the emergency department or request remote expert consultation via 5G. After consultation, critically ill patients can bypass the Emergency Department and enter the operation rooms or ICU directly. The network construction diagram and flowchart are shown in Figs. 2 and 3. The equipment adopted a special industry standard to ensure the safety of patient information; for instance, the designated 5G-Customer Premise Equipment (CPE).

3.2. Constructing 5G temporary private network in disaster-caused scenarios of power outage and network disconnection

Extreme situations of power outages, network disconnections, and circuit breakages are bound to occur due to destruction by natural disasters. As a result of these damages or power outages, the base station cannot provide communication services. Such interruption in the network greatly hinders rescue efficiency. Using the UAV + 5G high-altitude base station emergency communication networking solution, we installed 64R 64T- Active Antenna Unit (AAU) sharing public network on tethered UAV. Extended to up to 10 km, the optical fiber can connect to the base station or the proximal communication support vehicle. In the case where the

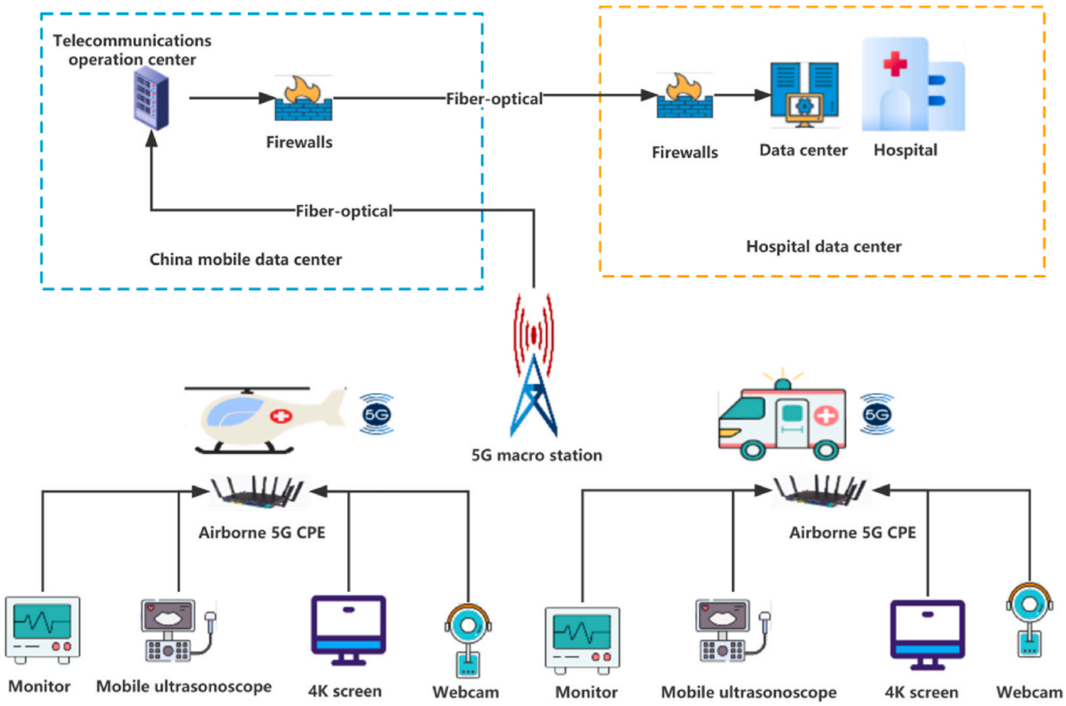

Fig. 2. The 5G network construction of the daily emergency medical treatment in Shenzhen University General Hospital. CPE: Customer Premise Equipment (Shenzhen, China, 2022).

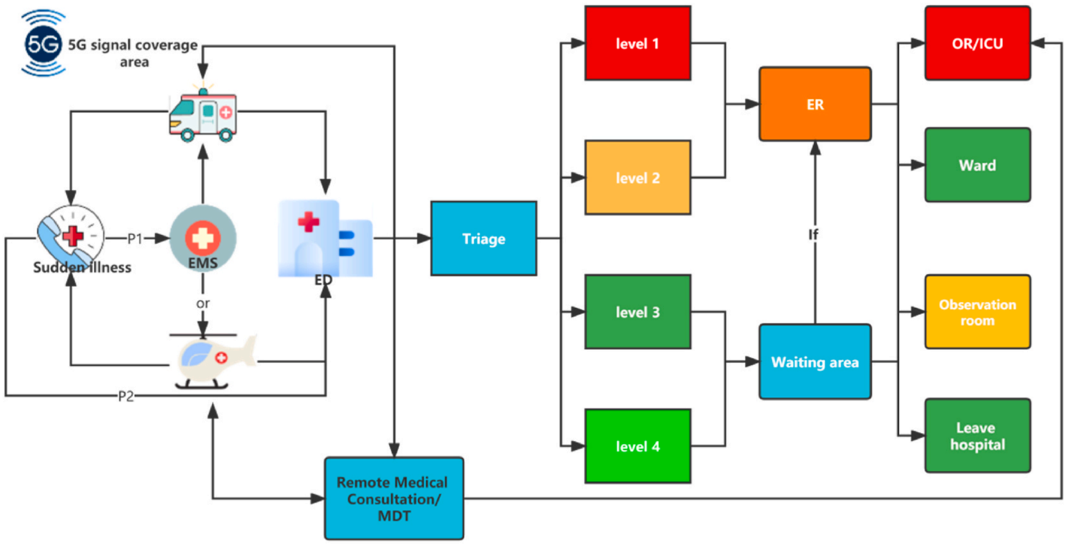

Fig. 3. The flowchart of daily emergency medical treatment in Shenzhen University General Hospital. P1: The first plan in the sudden illness, P2: The second plan in the sudden illness. If: If the condition of the patient worsens in the waiting area, the patient will be transferred to the emergency room. EMS: Emergence Medical Service System. ED: Emergency Department. ER: Emergency Room. OR: Operation Room. ICU: Intensive Care Unit. MDT: Multi-Disciplinary Treatment (Shenzhen, China, 2022).

communication devices carried by UAV cannot be connected to the base station or the communication support vehicle nearby, we alternatively linked them to high-throughput communication satellites. The satellites hover at a fixed point in the low-altitude space of the disaster-stricken city or the disaster-stricken area to obtain 4G/5G wireless communication signals (Fig. 4). Based on a temporary aerial base station, the communication coverage of the emergency base station can be widened. Amid the communication outage, long-distance communication coverage can be restored expeditiously and widely used for rescue communication networks in the events of freezing rain, snowstorms, typhoon, earthquake, and flooding.

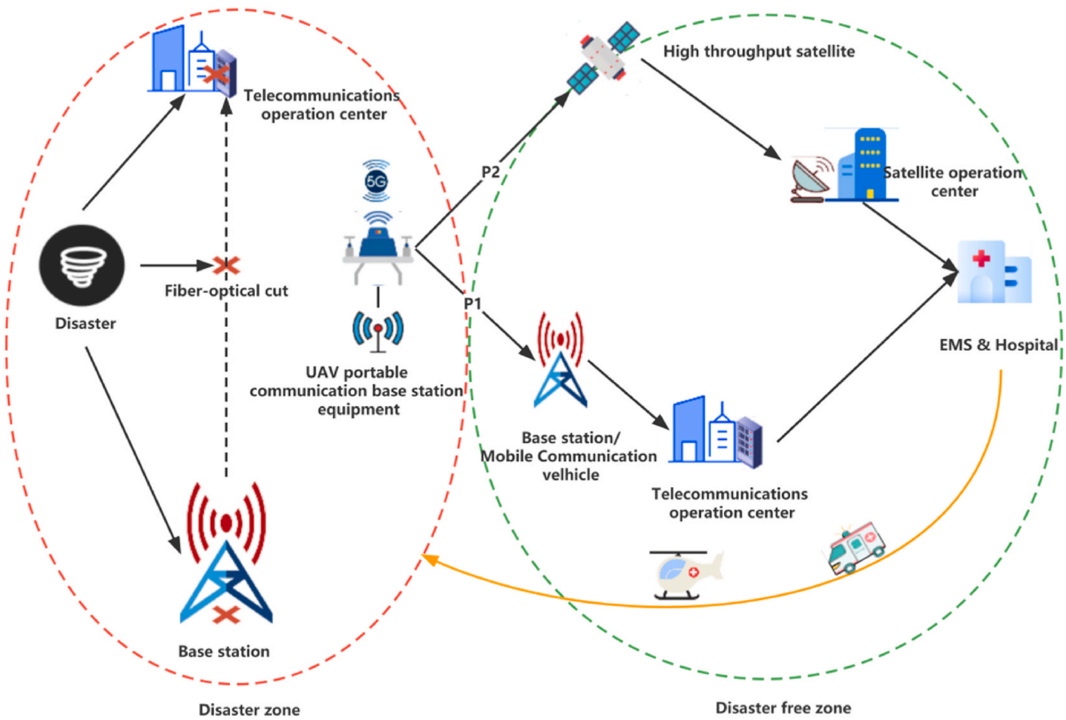

Fig. 4. The 5G network construction with UAV in the event of a power failure and network disconnection caused by disaster. UAV: Unmanned aerial vehicle; EMS: Emergence Medical Service System. P1: The first plan in the scene, P2: The second plan in the scene (Shenzhen, China, 2022).

3.3. Planning accurate monitoring system scheme for quarantined personnel amid pandemic based on 5G + medical Internet of Things (IoT) coverage

During the outbreak of coronavirus disease-2019 (COVID-19), our Emergency Department undertook the task of pandemic surveillance, prevention, and control. In order to avoid the intrahospital spread of the disease, we reconstructed the emergency treatment process (Fig. 5) and the layout of the Emergency Department (Fig. 6). This is a preliminary solution that uses the existing public frequency band of the 5G network in the quarantine zone, adopts an "exclusive private network mode," and deploys a 5G-CPE + Bluetooth angle of arrival (AOA) gateway at the end. Using the 5G private network, the monitored data of the end personnel could be transmitted back to Hospital's data center (Fig. 7). Therefore, the remote monitoring of personnel in the quarantine zone and patients with the infectious disease during the quarantine is made possible. Also, wearable devices are used for monitoring the real-time location and vital signs of the quarantined personnel and infectious disease patients. The devices regularly report the temperature, location, and vital sign parameters of quarantined personnel and infectious disease patients to the medical staff, who managed and judged their situations. This phenomenon reduces the contact of people and thus narrows the risk of widespread.

4. Results

4.1. Realizing 5G + remote emergency rescue

Through the construction of the 5G telemedicine network, our hospital successfully built up a telemedicine network between prehospital emergency and the Emergency Department (Fig. 8) and their three-dimensional rescue (Fig. 9). Next, we ensured the efficient connection and transmission of the three-dimensional rescue information between the prehospital emergency treatment sector and the Emergency Department. Post-realization of the three-dimensional efficiently-connected emergency mode, we successfully completed multiple cross-district helicopter rescues. The radius of the emergency medical rescue services expands from normally 5 km to >60 km. The cross-district emergency medical rescue services that usually require 1–1.5 h are shortened to 15–20 min.

4.2. Construction of 5G + UAV ad hoc network in complex disaster-related scenarios

Based on the 5G temporary private network construction plan under disastrous scenarios, we successfully simulated the construction of ad hoc rescue network communication within 30 min using the 5G + UAV ad hoc network under situations of power outages and network disconnections. These findings support the application of this plan in emergency rescue using 5G communication during a disaster (see Fig. 10).

4.3. Construction of the safe protection net of patients and medical team amid the pandemic

By constructing the precise monitoring system of quarantined personnel, we successfully implemented the real-time precise location and transmission of vital signs. During February and March 2020, the early stage and the peak of the pandemic, our Emergency Department was listed as the first designated hospital for suspected cases in Shenzhen city. We admitted a total of 134 suspected cases, of which 12 were diagnosed positive. While managing suspected and confirmed cases, we set up disease prevention, surveillance, and control goals of zero-infection, zero-severe-cases, and zero-death amongst the patients and medical personnel within the hospital. This phenomenon was successfully achieved with the aid of a 5G + medical IoT-covered precise monitoring system on the quarantined personnel.

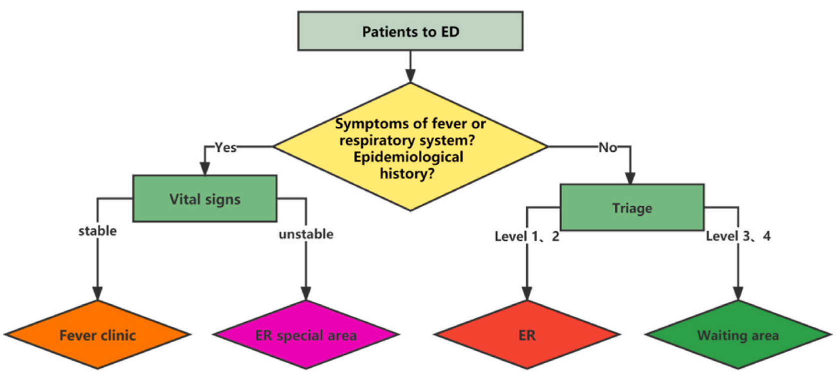

Fig. 5. The flowchart of ED visit in Shenzhen University General Hospital during COVID. ED: Emergency Department. ER: Emergency Room (Shenzhen, China, 2022).

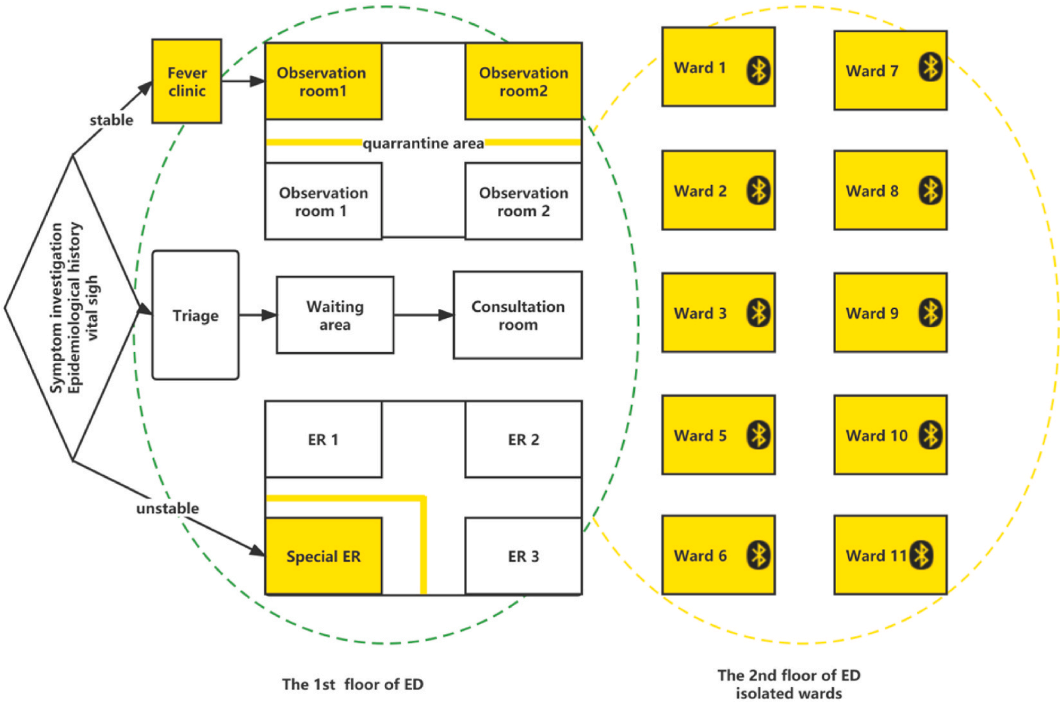

Fig. 6. The simple sketch of ED in Shenzhen University General Hospital. ED: Emergency Department. ER: Emergency Room (Shenzhen, China, 2022).

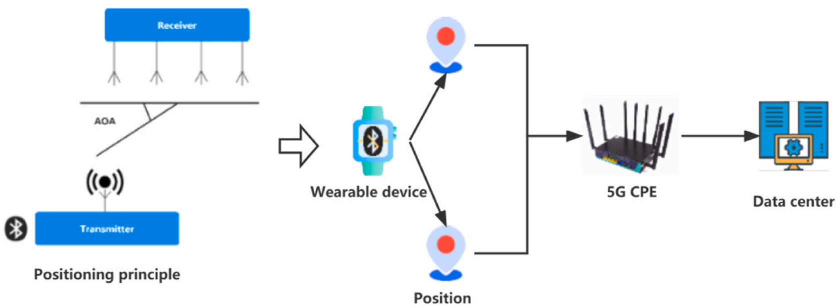

Fig. 7. The simple sketch of Bluetooth AOA indoor positioning. AOA: Angle of Arrival. CPE: Customer Premise Equipment (Shenzhen, China, 2022).

Fig. 8. Telemedicine in prehospital (Shenzhen, China, 2022).

Fig. 9. Helicopter rescue (Shenzhen, China, 2022).

Fig. 10. The 5G network construction with UAV (Shenzhen, China, 2022).

4.4. Becoming the "5G + Healthcare Application Demonstration Project" of the Ministry of Industry and Information Technology and National Health Commission

Our 5G-technology-based three-dimensional emergency rescue medical management system was awarded the support of the "5G + Healthcare Application Demonstration Project" of the Ministry of Industry and Information Technology and the National Health Commission, as well as the funding of "5G Innovative Application Development Support" by Shenzhen Development and Reform Commission.

5. Discussion

Emergency medicine is a specialized discipline that investigates the questions of how to handle critically ill and wounded patients, how to provide them first-aid and on-the-spot monitoring and treatment, and how to optimize in-hospital treatment, organization, and management. Prehospital rescue sector, in-hospital emergency treatment, and ICU emergency treatment are major constituents of the social medical protection system. These constituents form a part of emergency medicine and act as critical indicators of a city measuring its emergency medical standard and responsiveness to emergencies. With an increasing number of emergencies, the efficiency of emergency medical services plays an instrumental role in rescuing lives [5]. In multiple contexts, the emergency department has been the center of emergency medical rescue as the first contact point of medical treatment hospitals upon the occurrence of emergencies [6]. It is the core of the emergency medical service system for the professional handling of critically ill patients, sudden public events, massively wounded events, natural disasters, and collective poisoning [1]. Emergency medical departments need to be prepared for long- and short-term management of crises and disasters [7]. Shenzhen, as a first-tier city in China, has a unique topography, a fast-growing population, and the constantly increasing residents' demands for prehospital first-aid. Such features make the city's efficiency and responsiveness to emergencies rather demanding. As the first directly affiliated hospital with Shenzhen University, Shenzhen University General Hospital embarked on a cross-district and cross-profession cooperation in the city's study of emergency medicine. It was the earliest institution that cooperated with Tianjin University Institute of Disaster and Emergency Medicine and started the first "Air 120" medical rescue drill in Shenzhen city, which provided a rewarding experience to the research of this three-dimensional rescue.

Owing to the accessibility of the Emergency Department [8], peoples' habit of using the emergency department 24/7 to treat simple and chronic health issues [6] and the growing trend of natural disasters in China [9], people's demands for emergency medicine have demonstrated a constant increase. The question of how to raise the capacity and efficiency of emergency medical services in satisfying societal demand remains the hotspot of medical research. Although the capacity of emergency services can be raised by building more and expanding the current hospitals, adding prehospital emergency spots, or facilitating the nurturing of emergency medical personnel, the high costs incurred and the long cycle cannot fulfill the growing demand for better capacity of emergency medicine in the short-term. Nonetheless, the capacity and level of emergency can be enhanced quickly by integrating existing social resources, optimizing workflow for responding to emergencies, and raising the efficiency of emergency response. This study is based on Shenzhen's unique strengths in emerging technology industries, and therefore, cooperates with the China Mobile Shenzhen Company, Mindray, and other enterprises. Utilizing 5G, this study constructed an efficiently-connected three-dimensional emergency medical management system according to the various factors of prehospital emergency treatment, the emergency department, and the emergency ICU. Based on the three-dimensional emergency medical management system, we could save the patients of remote regions by medical rescue helicopters. The radius of the emergency medical rescue services expands from 5 km to >60 km and even expands to 100 km in a specific situation.

In addition to the development of new technologies, the questions of how to utilize the new technology in raising the efficiency of emergency rescue and how to improve the low efficiency or delay in treatment among critically ill patients need to be resolved urgently in the course of emergency medicine development. Facilitated by modern integration in telecommunication technologies, abundant remote medical facilities were developed based on international emergency treatment experiences, which reduces unnecessary medical transport. Yet, the level of informatization in prehospital emergency rescue lags in China. The emergency rescue information lacks a close connection with hospital. Also, remote medical assistance and online diagnosis with photographic transfer technology are absent [1]. With widespread COVID-19, worldwide medical systems are forced to adapt to telemedicine and digital innovation in order to reduce the spread of the virus. Currently regarded as the "new normal" in the field of medical innovation [4], COVID-19 made medical institutions accept that telemedicine plays a pivotal role in clinical tasks [10]. By setting up 5G communication devices on ambulances and rescue helicopters, this project testifies the feasibility of their application to ensure an expeditious and real-time transition of prehospital information to the hospital. Further consultation revealed that critically ill patients can pass through the emergency department and be admitted to the operation room or ICU for treatment. It saves time for medical treatment in the emergency department, which elevates the treatment efficiency in critically ill patients. The current study could also be considered as the application of telemedicine in emergency medicine. Nonetheless, the connection between the prehospital rescue sector, the emergency department, and MDT is efficient, and with the help of this system, the young medical staff can confidently deal with all types of patients.

In the medical literature of 1974, telemedicine was broadly defined as supplying medical information and services using telecommunication technologies [11]. Using modern information, communication, electronics, and computer technology, telemedicine fosters the remote collection, storage, progress, transmission, and query of medical information. It expands the physical areas for which patients can be provided with medical services without limitation by geographical barriers. This subject offers clinical support to patients with the aim of improving their health [12]. Because of its low-latency, high-speed, enhanced high-resolution bandwidth, extraordinary reliability, and low energy consumption, 5G transforms telemedicine and the entire medical industry [13]. Its major impact is raising the speed of the Internet. Its maximum download speed is about 3.4 Gbps, and its maximum upload speed is about 182 Mbps. This enables real-time transmission of 4K and high-quality video signals, which helps remote diagnosis between doctors and patients or among doctors. The expert can join the attending doctor with the patient's diagnosis while watching the videos of the examination in the patient's home in real-time [14]. Due to the shortage of medical resources caused by COVID-19, telemedicine has become an effective way for the appropriate distribution of medical resources. The multi-modal telemedicine network in Sichuan Province in western China was launched immediately after the first wave of the pandemic in January 2020. Furthermore, this system has testified its feasibility by collaborating with the newly established 5G service, smartphone apps, and existing telemedicine system [15]. The feasibility of using 5G to achieve the goals of remote medical treatments and rescue helicopters was proven through drills and clinical practice. Also, an expert consultation system or multi-disciplinary assistance team increased the efficiency of the treatment of critically ill patients.

China is one of the countries with the most serious natural disaster. Although China has made progress in responding to disasters, it may still face tremendous challenges in controlling disasters in the future [9]. Upon the occurrence of natural disasters, such as earthquakes, flooding, landslides, and winter storm, communication devices will be destructed in the short term. The affected areas face difficulties of large-area disruption in communication, power outage, and destructions on roads. Ordinary ad hoc communication measures cannot resume communications expeditiously. In the early stage of disaster emergencies, a wide range of social concerns or panic might be triggered. Typically, the volume of communication experiences an abrupt increase, causing network congestion. In extreme situations, a large communication network area might be interrupted. Emergency communication is difficult to be arranged and resume quickly, which severely hinders disaster rescue operations. Based on the above disaster scenarios, we used UAV to carry 5G portable base station devices and construct a temporary 5G high-altitude emergency base station. This secures the functioning of the necessary communication channels in rescue. Finally, a feasible scheme is constructed through simulated verification for emergency rescue in the event of disaster-related communication interruption.

The COVID-19 outbreak has reminded us of the importance of telemedicine in medical services provision, especially as a tool to reduce the risk of cross-infection caused by close contact [16]. Similar to most emergency departments, we are also facing the challenges of the pandemic [6,17]. Also, like the emergency departments in other hospitals, we have developed a stringent triage process to avoid nosocomial infections [18,19]. Concurrently, the ward is managed with the help of 5G [20]. Although we managed a large number of suspected and positive cases in the early stage of the pandemic [21,22], neither nosocomial infections nor deaths occurred in patients and medical staff. Thus, the target of "zero-infection, zero-death" is achieved.

Although the COVID-19 pandemic has significantly accelerated the application of telemedicine, providing an effective solution in medical healthcare amid public health emergencies, it faced clinical opportunities and legal challenges [23]. Except for emergencies, the overall development of telemedicine remains slow [16]. Previously, the limited use of telemedicine was mainly attributed to the reluctance of clinical doctors in adopting telemedicine [24], as well as limited telehealth training [25]. On the other hand, the low popularity of telemedicine can be attributed to various reasons; nonetheless, factors, such as the willingness of clinical doctors and financial compensation might be some critical reasons [16]. Herein, we speculated that the development of communication technology is also one of the major reasons. 5G is one of the recently developed new generations of communication technology [26]. Previously, communication technology did not have the characteristics of low-latency, high-speed, and high-capacity like 5G, which restricted the application and promotion of telemedicine. Also, 5G has brought new opportunities for emergency medicine.

In the present study, we verified the successful application of 5G in emergency medicine; however, the security of 5G pertaining patient information is still a key issue in technology application. In addition, the costs and benefits of 5G in emergency medical applications need to be compared in the future. The system is based on the construction of 5G base station, and the growing health concern about the radiofrequency electromagnetic field exposure is a noteworthy issue [27].

6. Conclusion

5G provides better technical conditions for the progress of telemedicine. The COVID-19 outbreak has provided opportunities for the practice of telemedicine. By building a three-dimensional emergency medical management system using 5G and three-dimensional rescue and telemedicine, we greatly improved the efficiency in treating daily emergencies and critical illness, testified to the question of how to expeditiously rebuild the communication amid disaster-related communication disruption, and examined the ad hoc response to public health emergencies. Since the promotion of telemedicine faces problems with training, financial support, and legal support, it is difficult to promote a 5G three-dimensional emergency medical management system.

Declarations

Author contribution statement

Jiafa Lu: Conceived and designed the experiments; Performed the experiments; Wrote the paper.
Kevin Ling: Analyzed and interpreted the data.
Wanjing Zhong, Hui He, Zhongrui Ruan: Contributed reagents, materials, analysis tools or data.
Wei Han: Conceived and designed the experiments.

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Data availability statement

No data was used for the research described in the article.

Declaration of interest's statement

The authors declare no conflict of interest.

References

[1] X. Shi, J. Bao, P. Hou, et al., Emergency medicine in China: a review of the history of progress and current and future challenges after 40 years of reform, Am. J. Emerg. Med. 38 (3) (2020) 662–669, https://doi.org/10.1016/j.ajem.2019.11.008.
[2] Shenzhen news. 120 day",Shenzhen Emergency Center announced the relevant data of emergency medicine work in 2021(In Chinese).[EB/OL][2022-01-21/2022-07-28] https://www.sznews.com/news/content/2022-01/21/content_24892571.htm.
[3] J.Q. Zhuang, Q. Zhong, Z.H. Fu, et al., Study on the spatial-temporal distribution characteristics of prehospital emergency resources in Shenzhen[J], Chin. J. Emerg. Med.(Chinese) 28 (3) (2019) 391–396, https://doi.org/10.3760/cma.j.issn.1671-0282.2019.03.024.
[4] J.O. Li, H. Liu, D.S.W. Ting, et al., Digital technology, tele-medicine and artificial intelligence in ophthalmology: a global perspective, Prog. Retin. Eye Res. 82 (2021), 100900, https://doi.org/10.1016/j.preteyeres.2020.100900.
[5] T.H. Tan, M. Gochoo, J.C. Hsu, et al., Ubiquitous emergency medical service system based on wireless biosensors, traffic information, and wireless communication technologies: development and evaluation, Sensors (Basel) 17 (1) (2017) 202, https://doi.org/10.3390/s17010202.
[6] A.E. Kayipmaz, A. Demircan, Pandemic hospitals and reorganizing emergency departments, Turk. J. Med. Sci. 51 (SI-1) (2021) 3221–3228, https://doi.org/10.3906/sag-2106-169.
[7] K.E. Schreyer, D.A. Del Portal, R. McNamara, et al., Emergency department management of the Covid-19 pandemic, J. Emerg. Med. 59 (6) (2020) 946–951, https://doi.org/10.1016/j.jemermed.2020.07.022.
[8] E. Brasseur, A. Gilbert, A. Ghuysen, et al., Emergency department crowding: why do patients walk-in? Acta Clin. Belg. 76 (3) (2021 Jun) 217–223, https://doi.org/10.1080/17843286.2019.1710040.
[9] W. Han, C. Liang, Y. Zhang, et al., Major natural disasters in China, 1985-2014: occurrence and damages, Int. J. Environ. Res. Publ. Health 13 (11) (2016) 1118, https://doi.org/10.3390/ijerph13111118.

[10] C.M. Contreras, G.A. Metzger, T.M. Pawlik, et al., Telemedicine: patient-provider clinical engagement during the COVID-19 pandemic and beyond, J. Gastrointest. Surg. 24 (7) (2020) 1692–1697, https://doi.org/10.1007/s11605-020-04623-5.
[11] K.M. Zundel, Telemedicine: history, applications, and impact on librarianship, Bull. Med. Libr. Assoc. 84 (1) (1996) 71–79. PMID: 8938332.
[12] S. Duan, L. Liu, Y. Chen, L. Yang, Y. Zhang, S. Wang, L. Hao, L. Zhang, A 5G-powered robot-assisted teleultrasound diagnostic system in an intensive care unit, Crit. Care 25 (1) (2021) 134, https://doi.org/10.1186/s13054-021-03563-z.
[13] S. Dananjayan, G.M. Raj, 5G in healthcare: how fast will be the transformation? Ir. J. Med. Sci. 190 (2) (2021) 497–501, https://doi.org/10.1007/s11845-020-02329-w.
[14] K. Karako, P. Song, Y. Chen, W. Tang, Realizing 5G- and AI-based doctor-to-doctor remote diagnosis: opportunities, challenges, and prospects, Biosci Trends 14 (5) (2020) 314–317, https://doi.org/10.5582/bst.2020.03364.
[15] Z. Hong, N. Li, D. Li, J. Li, B. Li, W. Xiong, L. Lu, W. Li, D. Zhou, Telemedicine during the COVID-19 pandemic: experiences from western China, J. Med. Internet Res. 22 (5) (2020), e19577, https://doi.org/10.2196/19577.
[16] A.C. Smith, E. Thomas, L.J. Caffery, et al., Telehealth for global emergencies: implications for coronavirus disease 2019 (COVID-19), J. Telemed. Telecare 26 (5) (2020) 309–313, https://doi.org/10.1177/1357633X20916567.
[17] P. Mahajan, C. Shu-Ling, U. EKelund, et al., A global survey of emergency department responses to the COVID-19 pandemic, West. J. Emerg. Med. 22 (5) (2021) 1037–1044, https://doi.org/10.5811/westjem.2021.3.50358.
[18] X. Hu, S. Liu, P. Wang, et al., Management practices of emergency departments in general hospitals based on blockage of chain of infection during a COVID-19 epidemic, Intern. Emerg. Med. 15 (8) (2020) 1545–1552, https://doi.org/10.1007/s11739-020-02499-6.
[19] T. Chen, X. Ma, S. Zhou, H. Wang, Y. Pan, L. Chen, H. Lv, Y. Lu, Establishing a standardized FUO emergency department: design and practice in dealing with COVID-19, Ann. Transl. Med. 8 (12) (2020) 749, https://doi.org/10.21037/atm-20-4329.
[20] B. Zhou, Q. Wu, X. Zhao, W. Zhang, W. Wu, Z. Guo, Construction of 5G all-wireless network and information system for cabin hospitals, J. Am. Med. Inf. Assoc. 27 (6) (2020 Jun 1) 934–938, https://doi.org/10.1093/jamia/ocaa045.
[21] Z.R. Ruan, P. Gong, M. Han, et al., A case of coronavirus disease 2019 with twice negative nucleic acid testing within 8 days, Chin. Med. J. (Engl.). 133 (12) (2020) 1487–1488, https://doi.org/10.1097/CM9.0000000000000788.
[22] Y. Zhou, L. Yang, W. Han, et al., Case report on early diagnosis of COVID-19, Disaster Med. Public Health Prep. 14 (6) (2020) e22–e25, https://doi.org/10.1017/dmp.2020.66.
[23] J. Alipour, M.H. Hayavi-Haghighi, Opportunities and challenges of telehealth in disease management during COVID-19 pandemic: a scoping review, Appl. Clin. Inf. 12 (4) (2021) 864–876, https://doi.org/10.1055/s-0041-1735181.
[24] V.A. Wade, J.A. Eliott, J.E. Hiller, Clinician acceptance is the key factor for sustainable telehealth services, Qual. Health Res. 24 (5) (2014) 682–694, https://doi.org/10.1177/1049732314528809.
[25] A.C. Smith, S. Wickramasinghe, N.R. Armfield, It's important, but not important enough: eHealth as a curriculum priority in medical education in Australia, J. Telemed. Telecare 24 (10) (2018) 697–702, https://doi.org/10.1177/1357633X18793282.
[26] K. Maruta, T. Iwakuni, M. Iizuka, et al., First eigenmode transmission by high efficient CSI estimation for multiuser massive MIMO using millimeter wave bands, Sensors (Basel) 16 (7) (2016) 1051, https://doi.org/10.3390/s16071051.
[27] J.W. Frank, Electromagnetic fields, 5G and health: what about the precautionary principle? J. Epidemiol. Community Health (2021) https://doi.org/10.1136/jech-2019-213595 jech-2019-213595 Epub ahead of print. PMID: 33468601.