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Demonstration experiment of telemedicine using ultrasonography and telerehabilitation with 5G communication system in aging and depopulated mountainous area

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Abstract

Objective: The challenges of an aging population worldwide are the increased number of people needing medical and nursing care and inadequate medical resources. Information and communication technologies have progressed remarkably, leading to innovations in various areas. 5G communication systems are capable of high-capacity, high-speed communication with low latency and are expected to transform medicine. We aimed to report a demonstration experiment of telerehabilitation and telemedicine using a mobile ultrasound system in a depopulated area in a mountainous terrain, where 32% of the population are 65 years or older.

Methods: At the core hospital, a physician or physical therapist remotely performed ultrasonography or rehabilitation on a subject in a clinic. Five general residents participated in the telerehabilitation as subjects. The delay time and video quality transmitted with 5G and long-term evolution (LTE) communication systems were compared. The physician or physical therapist subjectively evaluated the quality and delay of the transmitted images and subject acceptability.

Results: Of seven physical therapists, six and three responded that the video quality was “good” for telerehabilitation with 5G/4K resolution and LTE, respectively. Five physical therapists and one physical therapist reported that the delay time was “acceptable” with 5G/4K resolution and LTE, respectively. For telemedicine using a mobile ultrasound system, the responses for 5G were “the delay was acceptable” and “rather acceptable.” In contrast, both respondents’ responses for LTE were “not acceptable.”

Conclusions: Multiple high-definition images can be transmitted with lower latency in telerehabilitation and telemedicine using mobile ultrasound imaging systems with a 5G communication system. These differences affected the subjective evaluation of the doctors and physical therapists.

Keywords

5G communication system, telemedicine, telerehabilitation, aging, depopulated area

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Introduction

The aged population is currently at its highest level in human history. The challenges of an aging population worldwide are the increased number of people needing medical and nursing care and inadequate medical resources.[1,2] Furthermore, while technological breakthroughs in the medical and nursing fields have brought many benefits to the healthcare sectors, the economic burden continues to increase.[3–5] There is a need to reduce the demand for resources through health management and prevention by early intervention in health issues and to use medical resources effectively by improving work efficiency in the medical and allied fields.[6,7]

In recent years, there has been remarkable progress in information and communication technologies, leading to innovations in various areas.[8–10] The promotion of advanced medical care and streamlining of surgeries through electronic medical records are already widespread.[11] In addition to the breakthrough in advanced medicine, the telemedicine system can provide medical care with fewer resources and restrictions on location. This is expected to reduce regional disparities in healthcare.[12] In addition, in combination with the internet of things (IoT), it is expected to understand health conditions from the pre-disease stage, which will contribute to preventive medicine and reduce the burden on medical resources.[13,14]

5G communication systems are capable of high-capacity, high-speed communication with low latency, and their use is expected to transform medicine.[15] In mountainous and depopulated areas, access to medical specialists and rehabilitation specialists is difficult, and the burden of transportation for medical personnel is high for home visit medical care and rehabilitation.[16,17]

There are few reports on telemedicine and health management in mountainous, aging, and depopulated areas using 5G communication technology.[18] Telemedicine enables patients to receive high-quality medical services without having to leave home or travel and to efficiently utilize medical resources. Telemedicine and healthcare systems will also be integrated into the social system transformation of the current centralized system to a decentralized system, accelerated by the coronavirus disease pandemic.[19]

Here, we report a demonstration experiment in which industry, academia, government, and the private sector collaborated to conduct telerehabilitation and implement telemedicine using a mobile ultrasound imaging system with 5G communications in a depopulated area in a mountainous terrain, where 32% of the population are 65 years or older.

Methods

Recruitment

The study was conducted from January to March 2020. The study was approved by the ethical review committee at Shinshiro Municipal Hospital (approval number: 18000081 R2-1), and informed consent was obtained from the participants.

Field and participants

This demonstration experiment was conducted in Shinshiro City, Aichi Prefecture, Japan. Shinshiro City is a municipality designated by the Ministry of Internal Affairs and Communications as a depopulated area. The population is approximately 47,000, and those 65 years or older account for 32%. The Tsukude area is a mountainous region in Shinshiro City with few medical resources. This demonstration was carried out in Shinshiro Municipal Hospital, the only core hospital in Shinshiro City, and Tsukude Clinic, designated as a base for telemedicine in mountainous areas. The subjects for telerehabilitation were selected from the general residents of southern Tsukude with a history of visits to or hospitalization at Shinshiro Municipal Hospital and are currently participating in Tsukude Clinic's functional training program. The subjects for telemedicine using a mobile ultrasound imaging system were selected from Shinshiro City employees as a part of the countermeasure against the spread of coronavirus infection.

Network configuration

The 5G communication base stations used in this demonstration included one permanent station installed in Tsukude Clinic. The specifications of the base station at Tsukude Clinic were 4.5 GHz for 5G and 800 MHz for long-term evolution (LTE). Each terminal device was connected to a 5G-enabled mobile router (SH-52A; NTT Docomo, Tokyo, Japan) by Wi-Fi, Bluetooth, or local area network (LAN) cable, and the data were transmitted to the 5G communication base station. The Docomo Open Innovation Cloud® (provided by NTT Docomo) was used for the cloud infrastructure. The connection to the cloud system at Shinshiro Municipal Hospital was made using an optical line network.

The mobile echo probe terminal was a Viewphii™ Linear-7.5 M type (Socionext, Kanagawa, Japan). The probe was connected to a tablet device with special software installed through the LAN cable. The tablet device was connected to a 5G-enabled mobile router using Wi-Fi. NIPRO HeartLine™ (NIPRO Corporation, Osaka, Japan) was used as the remote interview system. NIPRO HeartLine™ is an online medical system, which can be installed on a tablet device with a camera for remote interaction, and the following devices can be connected wirelessly (Bluetooth®) to check the biological data on the system; it consists of NIPRO electrical thermometer NSM-1BLE, NIPRO electrical sphygmomanometer NBP-1BLE, Masimo SET Finger Pulse Oximeter MightySat™, and ECG transmitter

Cocoron®. The tablet with the installed NIPRO HeartLine™ software was connected to a 5G-enabled mobile router via Wi-Fi. Simi Motion 2D/3D® (SIMI® Reality Motion Systems GmbH, Unterschleißheim, Germany) was used for markerless motion capture in telerehabilitation. Eight industrial high-resolution cameras were connected via a LAN cable to a laptop with Simi Motion software installed, and a 5G-enabled mobile router was connected to the laptop by a LAN cable. We prepared one camera for close-up photography to capture the remote demonstration, one head-mounted camera to be worn on the head of the remote healthcare worker to capture images close to the field of view, and one communication camera for conversations between remote sites. The close-up camera and communication camera were connected to the encoder by LAN cable, and the head-mounted camera was connected to the encoder by wireless connection (Bluetooth®).

Demonstration activities

Five subjects were selected for this study. Inclusion criteria included a history of consultation or hospitalization at the Shinshiro Municipal Hospital, participation in the functional training project conducted at Tsukude Clinic, cognitive function maintenance, and communication through remote monitoring. We judged the maintenance of cognitive function by whether the patient was able to communicate via a monitor in a nurse-assisted setting.

A physiotherapist at Shinshiro Municipal Hospital remotely checked the subject's vital signs at Tsukude Clinic before the commencement of rehabilitation. Before starting physical therapy, medical interviews were performed using the online medical care system (NIPRO HeartLine™). Data on body temperature, blood pressure, pulse rate, and peripheral capillary oxygen saturation were sent to the physical therapist at Shinshiro Municipal Hospital in real time. Gait training was performed during physical therapy. The subject, accompanied by a nurse, performed muscle strength training of the lower limbs and walked in parallel bars. The subject's gait training was filmed using a fixed 4K camera. In addition, a head-mounted camera was worn by the nurse accompanying the gait-training procedure to capture local images close to the field of view. These images were transmitted and monitored in real time by a physical therapist at Shinshiro Municipal Hospital, who provided guidance. Gait, walking speed, and joint positions were measured using markerless motion capture. Simultaneously, dynamic loads at the sole of the foot (Figure 1) were measured using an insole-type IoT device.

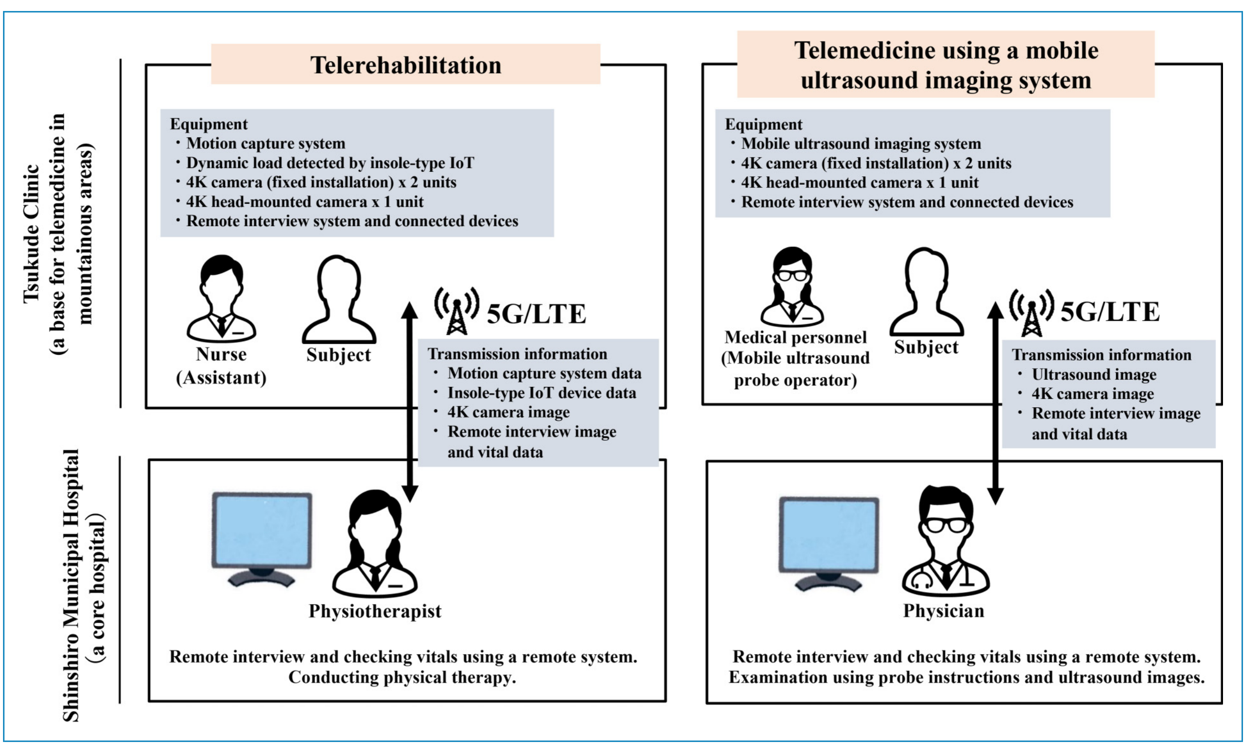

Figure 1. Overview of telemedicine using ultrasonography and telerehabilitation system. Telemedicine using ultrasonography and telerehabilitation is a system in which data are transmitted between a remote clinic and a core hospital via a fifth generation (5G) communication system, and the subject at the remote site receives medical treatment and rehabilitation under the direction and guidance of medical personnel at the core hospital. Long-term evolution communication system was used for comparison of transmission capacity with the 5G communication system. Vital data included SpO2, body temperature, heart rate, pulse rate, blood pressure, and electrocardiogram. 5G: fifth generation communication system; IoT: internet of things; LTE: long-term evolution.

Evaluation items and telerehabilitation methods

1. Sufficiency of video quality required for physical therapist's rehabilitation guidance: A physical therapist evaluated whether the resolution of 4K video at 15 Mbps and the latency of video transmission using 5G communication were within the acceptable range. In addition, the resolution of the transmitted video was changed to high definition (HD), 2K, and 4K at a bit rate of 5 Mbps using LTE communication, and the quality of each video was verified. The evaluation judgment was based on three levels: "good," "rather good," and "bad" for video quality, and "acceptable," "rather acceptable," and "not acceptable" for delay time.
2. Subject acceptability: We asked the subjects the following questions:
   - Did you feel comfortable with remote rehabilitation?
   - Compared with in-person, were you able to communicate with the remote physical therapist more smoothly?

Selection of subjects and implementation details of telemedicine using a mobile ultrasound imaging system

The subjects were three employees of Shinshiro. After a remote interview, the subjects underwent an ultrasound examination of the abdomen using a mobile ultrasound imaging system. A doctor at the Shinshiro Municipal Hospital gave instructions, and a medical worker at Tsukude Clinic operated the probe. The ultrasound images were transmitted and displayed on a monitor at Shinshiro Municipal Hospital. The medical staff operating the probe wore a head-mounted camera, and the images close to their field of view were transmitted to the Shinshiro Municipal Hospital in real time. In this demonstration, the medical personnel who operated the probes were radiologists. This was done to evaluate the performance of remote ultrasound examinations by remotely instructing medical personnel who do not perform ultrasound examinations in their daily work to operate the probe (also shown in Figure 1).

Evaluation items and methods of telemedicine using a mobile ultrasound imaging system

1. Sufficiency of video quality required for telemedicine in mobile ultrasonography: Two doctors evaluated whether the image resolution and delay time in transmission were within the acceptable ranges. The evaluation items were "good," "rather good," and "poor" for video quality, and "acceptable," "rather acceptable," and "not acceptable" for delay time. For 5G communication, the bit rate was set at 15 Mbps for 4K quality, and for LTE communication, the bit rate was set at 5 Mbps for HD quality.
2. Subject acceptability: The following questions were asked:
   - Did you have any concerns about remote ultrasonography?
   - Would you be willing to undergo remote echography in the future?
   - The answers to each question were in the following four levels: "very reassuring," "generally reassuring," "somewhat reassuring," and "very anxious" in response to question 1, and "want to take it in remotely," "would rather take it in remotely," "would rather take it in person," and "want to take it in person" in response to question 2.

Evaluation of data transmission

Data transmission in telerehabilitation. For the video frame rate, the resolution and frame rate of the camera images for motion capture transmitted to the Shinshiro Municipal Hospital were logged and confirmed using the functions in the system. The software for frame rate measurement (Open Capture and Analysis Tool version 1.6.0; AMD, Santa Clara, CA, USA) was used to measure the frame rate of the entire system. A camera captured a clock that can be synchronized at a distance to investigate the image delay between the base hospitals and the delay of remote operation from the core hospital.

Data transmission in telemedicine using a mobile ultrasound imaging system. The frame rate measurement software on the recipient computer was installed to measure the frame rate of the entire system. The time delay of the video was measured by visually comparing the time difference between the clock displayed on the destination computer and the clock displayed on the capture screen on the source tablet. The transmission capability was verified by comparing the transmission of low- and high-quality videos. The low-quality video had a bit rate of 2 Mbit and a resolution of 960×600 pixels, whereas the high-quality video had a bit rate of 8 Mbit and a resolution of 1440×600 pixels.

Results

Telerehabilitation

Video quality and transmission delay time. For the 5G communication system, six out of seven respondents answered that the quality was "good" for 4K resolution and 15 Mbps, and it was the largest number among the four groups. For

LTE communication, the three groups were similar, except for the single "bad" response in the LTE/2K/5-Mbps group (Table 1).

Of the seven respondents, five answered that the latency was "acceptable" for 5G communication, and it is the largest number among the four groups. In LTE, the higher the quality of the image to be transmitted, the lower the acceptance rating, and only one person in the LTE/4K/5-Mbps group responded with "acceptable" (Table 2).

Subject acceptability. For the answer to question 1, three respondents responded "very reassuring" and two responded "generally reassuring" for the sense of security in the first demonstration. In the second demonstration, four respondents answered "very reassuring" and one respondent answered "generally reassuring." One respondent who answered "generally reassuring" commented, "I felt uneasy when my legs did not move well." As the answer to question 2, in terms of communication with the physical therapist compared with face-to-face conversation, three respondents chose the response, "I was able to communicate as usual" in the first session, and two responded, "I was able to communicate generally." In the second round, all five chose "I was able to communicate with them generally" (Figures 2 and 3).

Table 1. Evaluation of video quality in telerehabilitation.

	Communication system, resolution, and transmission rate			
	5G/4K/15 Mbps	LTE/HD/5 Mbps	LTE/2K/5 Mbps	LTE/4K/5 Mbps
Good	6	3	3	3
Rather good	1	4	3	4
Bad	0	0	1	0

5G: 5G communication system; LTE, long-term evolution system; 4K, 4K resolution; HD: high-definition resolution.

Table 2. Evaluation of delay time in telerehabilitation.

	Communication system, resolution, and transmission rate			
	5G/4K/15 Mbps	LTE/HD/5 Mbps	LTE/2K/5 Mbps	LTE/4K/5 Mbps
Acceptable	5	4	3	1
Rather acceptable	2	3	3	6
Not acceptable	0	0	1	0

5G: 5G communication system; LTE: long-term evolution system; 4K: 4K resolution; HD: high-definition resolution.

Telemedicine using a mobile ultrasound imaging system

Video quality and transmission delay time. The respondents reported poor video quality for both 5G and LTE communication systems. This was because the quality was relatively poor compared with the images from the echo equipment owned by the Shinshiro Municipal Hospital. It was confirmed that various organs could be evaluated without any problems and that there was no problem in diagnosing the cases. Regarding the delay time, the responses for 5G communication were the delay was "acceptable" and it was "rather acceptable". In contrast, for LTE communication, both respondents answered that the delay was "not acceptable."

Subject acceptability. Two respondents chose "very anxious" in the first session, and one respondent chose "very reassuring." The second time, two respondents answered "generally reassuring," and one respondent answered "very reassuring." One respondent answered, "I would rather take it in remote" for the first and second time, and two respondents chose, "I would rather take it in person" for the first time and one respondent for the second time. One respondent answered "I want to take it remotely" for the second time (Tables 3 and 4).

Evaluation of data transmission

Data transmission in telerehabilitation. The frame rate of the video at the core hospital was an average of 28 frames per second (fps) at 4K resolution. The video delay was less than 1 s at the maximum delay in visual inspection based on the clock displayed on the capture screen.

Data transmission in telemedicine using a mobile ultrasound imaging system. The maximum frame rate on the tablet device was 25 fps for the linear mode and 18 fps for the convex mode. The frame rates on the recipient computer in the Shinshiro Municipal Hospital were 25 fps for low-quality images and 29 fps for high-quality images. The frame rate of the recipient computer was higher than the maximum frame rate of the sending tablet device for both low- and high-quality images. Therefore, the recipient computer can draw images at the maximum frame rate as a stand-alone device with a tablet terminal. The video delay was less than 2 s at the maximum delay in the visualization of the clock displayed on the capture screen.

Figure 2. A view of Shinshiro municipal hospital (core hospital). A physical therapist is conducting a medical interview. The motion capture system and dynamic load detected by the insole-type internet of things are shown on a large monitor.

Discussion

Principal results

In this study, telemedicine and telerehabilitation for abdominal ultrasound examinations were conducted in an aging medical depopulated area using 5G and LTE communication technologies. To the best of our knowledge, this is the first report demonstrating remote acoustic field testing and telerehabilitation using 5G communication technology in an aging mountainous region.

Comparison with prior work

The tele-ultrasound system was devised by the National Taiwan University Hospital for the Emergency Medical Services system.[20] A previous practical experiment of ultrasonography in telemedicine reported real-time transmission over 802.11 g ad-hoc and 3G cellular broadband networks with Video Graphics Array resolution and Quarter Video Graphics Array at a frame rate of 10–30 fps. In this experiment, the image quality in both 802.11 g and 3G wireless transmission was adequately preserved, while missed frames could momentarily decrease the diagnostic value.[21] In recent years, as communication technology has advanced, the usefulness of remote ultrasound testing has also improved. A practical experiment of ultrasonography in telemedicine using 4G internet transmission reported that the lowest median frame rate was found using a 4G internet connection. In this experiment, when the frame rate was poor, it was extremely difficult to assess whether it was a good image and to appraise pathologies.[22] Our demonstration outcome was similar to previous reports that LTE caused the images to be depicted frame by frame, and 5G communication technology has realized a lower latency and smoother video transmission to the extent that it has made a difference in the subjective assessment of the recipient's physician when compared with LTE.

In remote rehabilitation, the fixed-point images taken by the fixed camera were flat, and we thought that it would be possible to supplement the three-dimensional understanding by adding real-time measurements by markerless motion

Figure 3. A view of the Tsukude Clinic (a base for telemedicine in mountainous areas). A subject and an assistant nurse are on site. The monitor shows a physical therapist at the core hospital, communicating with the examinee.

Table 3. Evaluation of reassurance in telemedicine using mobile ultrasonography.

	First	Second
Very reassuring	1	1
Generally reassuring	0	2
Somewhat anxious	0	0
Very anxious	2	0

Table 4. Intentions for telemedicine in the future using mobile ultrasonography.

	First	Second
I want to take remotely	0	1
I would rather take in remote	1	1
I would rather take in person	2	1
I want to take in person	0	0

capture. The previous studies showed that the use of motion capture is useful even in telerehabilitation.[23,24] They were in the experimental phase, and their usefulness in clinical practice is not yet clear. Dynamic loading in the sole is used to learn more about the patient's subtle center of gravity and gait characteristics, but its usefulness is still under study.

In the interview conducted on the subjects of abdominal ultrasound, the responses were that they wanted an in-person examination. The reasons given were: "I don't communicate well with remote doctors" and "I was a little anxious the first time." This is a valid concern for tele-interaction because such 5G applications are rare. The subjects of this study have had little previous exposure to 5G-based tele-interactions. It was inferred that actual patients would be more anxious, and it was necessary to deal with the reliability of the subjects in the remote ultrasound examination. Because of the small number of responses in this study, further investigation of patient satisfaction with abdominal ultrasonography is needed.

Meanwhile, studies of patient satisfaction with telemedicine reported that 94%–99% reported being "very satisfied" in all telehealth attributes.[25,26] There is also a prospect for 5G tele-interaction to become commonplace in many aspects of daily life,[27,28] and it will affect how future patients will perceive tele-treatment.

The strength of this study is that it was conducted in aging and depopulated mountainous area in Japan, a country with an advanced aging population. In addition to evaluating the performance of the technology using 5G communications, feedback was obtained from the actual providers and recipients of healthcare in that area with the cooperation of the local government and the municipal hospital.

This demonstration experiment was not just a practical application of telemedicine technology but also an experiment designed to provide medical resources to an aging population in mountainous areas. It is expected to reduce the cost of transportation for physical therapists and doctors. The practice of telemedicine requires solving several challenges, such as regulation and legal issues, in addition to reducing its costs.[29,30]

Limitations

Several limitations of this demonstration experiment should be acknowledged. The subjects of the abdominal ultrasound examination were not actual patients but employees of Shinshiro City; the subjective evaluation of the subjects may differ from that of the actual patients. However, it was possible to obtain critical opinions about the remote examination based on statements such as "I would rather have the examination face-to-face."

Conclusions

Using 5G communication technology, we confirmed that multiple HD images could be transmitted with lower latency in telerehabilitation than in LTE communication systems. We also confirmed that images from mobile ultrasound imaging systems could be transmitted more conveniently. These improvements in data transmission also affected the subjective evaluation of the doctors and physical therapists who performed the treatment.

Telerehabilitation and telemedicine using mobile ultrasound systems with a 5G communication system will provide a useful resource for healthcare in aging and depopulated mountainous areas.

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References

1. Coleman D. Population ageing: an unavoidable future. *Soc Biol Hum Aff* 2001; 7: 1–11.
2. McGinnis SL and Moore J. The impact of the aging population on the health workforce in the United States—summary of key findings. *Cah Sociol Demogr Med* 2006; 46: 193–220.
3. Health Expenditure. Secondary Health Expenditure. https://www.oecd.org/els/health-systems/health-expenditure.htm (2020, accessed January 2021).
4. Cutler DM. Rising medical costs mean more rough times ahead. *JAMA* 2017; 318: 508–509.
5. Okunad AA and Murthy VN. Technology as a 'major driver' of health care costs: a cointegration analysis of the Newhouse conjecture. *J Health Econ* 2002; 21: 147–159.
6. Edmunds M, Tuckson R, Lewis J, et al. An emergent research and policy framework for telehealth. *EGEMS (Wash DC)* 2017; 5: 1303.
7. Noel HC, Vogel DC, Erdos JJ, et al. Home telehealth reduces healthcare costs. *Telemed J E Health* 2004; 10: 170–183.
8. Perry S and Thamer M. Medical innovation and the critical role of health technology assessment. *JAMA* 1999; 282: 1869–1872.
9. Bhavnani SP, Narula J and Sengupta PP. Mobile technology and the digitization of healthcare. *Eur Heart J* 2016; 37: 1428–1438.

10. Noel K and Ellison B. Inclusive innovation in telehealth. *NPJ Digit Med* 2020; 3: 89.
11. Hamet P and Tremblay J. Artificial intelligence in medicine. *Metabolism* 2017; 69: S36–S40.
12. Nouhi M, Fayaz-Bakhsh A, Mohamadi E, et al. Telemedicine and its potential impacts on reducing inequalities in access to health manpower. *Telemed J E Health* 2012; 18: 648–653.
13. Nangalia V, Prytherch DR and Smith GB. Health technology assessment review: remote monitoring of vital signs—current status and future challenges. *Crit Care* 2010; 14: 233.
14. Park YT. Emerging new era of mobile health technologies. *Healthc Inform Res* 2016; 22: 253–254.
15. Li D. 5G and intelligence medicine—how the next generation of wireless technology will reconstruct healthcare? *Precis Clin Med* 2019; 2: 205–208.
16. Weinhold I and Gurtner S. Understanding shortages of sufficient health care in rural areas. *Health Policy* 2014; 118: 201–214.
17. Matsumoto Y, Kizaki H, Ikeda Y, et al. Telepharmacy in mountainous depopulated areas of Japan: an exploratory interview study of patients' perspectives. *Drug Discov Ther* 2022; 15: 337–340.
18. Qureshi HN, Manalastas M, Ijaz A, et al. Communication requirements in 5G-enabled healthcare applications: review and considerations. *Healthcare (Basel)* 2022; 10: 293.
19. Shachar C, Engel J and Elwyn G. Implications for telehealth in a postpandemic future: regulatory and privacy issues. *JAMA* 2020; 323: 2375–2376.
20. Su MJ, Ma HM, Ko CI, et al. Application of tele-ultrasound in emergency medical services. *Telemed J E Health* 2008; 14: 816–824.
21. Telemedicine applications of mobile ultrasound. IEEE International Workshop on Multimedia Signal Processing; 5–7 October 2009. https://ieeexplore.ieee.org/xpl/conhome/5286205/proceeding (2009, accessed January 2021).
22. Jensen SH, Duvald I, Aagaard R, et al. Remote real-time ultrasound supervision via commercially available and low-cost tele-ultrasound: a mixed methods study of the practical feasibility and users' acceptability in an emergency department. *J Digit Imaging* 2019; 32: 841–848.
23. Ruiz-Fernandez D, Marín-Alonso O, Soriano-Paya A, et al. Efisiotrack: a telerehabilitation environment based on motion recognition using accelerometry. *Sci World J* 2014; 2014: 495391.
24. Anton D, Berges I, Bermúdez J, et al. A telerehabilitation system for the selection, evaluation and remote management of therapies. *Sensors (Basel)* 2018; 18: 1459.
25. Polinski JM, Barker T, Gagliano N, et al. Patients' satisfaction with and preference for telehealth visits. *J Gen Intern Med* 2016; 31: 269–275.
26. Isautier JM, Copp T, Ayre J, et al. People's experiences and satisfaction with telehealth during the COVID-19 pandemic in Australia: cross-sectional survey study. *J Med Internet Res* 2020; 22: e24531.
27. Navarro-Ortiz J, Romero-Diaz P, Sendra S, et al. A survey on 5G usage scenarios and traffic models. *IEEE Commun Surv Tutor* 2020; 22: 905–929.
28. Hoeschele T, Dietzel C, Kopp D, et al. Importance of Internet Exchange Point (IXP) infrastructure for 5G: estimating the impact of 5G use cases. *Telecommun Policy* 2021; 45: 102091.
29. Jr BB and Hall RW. Telemedicine: pediatric applications. *Pediatrics* 2015; 136: e293–e308.
30. Crico C, Renzi C, Graf N, et al. Mhealth and telemedicine apps: in search of a common regulation. *Ecancermedicalscience* 2018; 12: 853.