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REVIEW ARTICLE

Development of 5G-based Remote Ultrasound Education: Current Status and Future Trends

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Abstract: The rapid advancement of 5G technology has opened new possibilities for remote ultrasound education, offering the potential to enhance training, real-time consultation, and quality control for primary ultrasound doctors. The 5G remote ultrasound education has the potential to revolutionize the way primary ultrasound doctors are trained and supported, ultimately leading to improved patient care and outcomes. By understanding the current status and development trends of this cutting-edge educational approach, the medical community can better prepare for and contribute to its ongoing evolution. Looking towards the future, the development trends in 5G remote ultrasound education are expected to revolve around continuous improvement and innovation in educational methods and technologies. This includes the exploration of artificial intelligence and machine learning applications, the expansion of telemedicine and telementoring programs, and the development of personalized learning plans tailored to individual learners' needs. This article aims to offer an overview of the current status and applications of 5G remote ultrasound education, including the development of theoretical courses and network construction within our institutes, and to discuss future trends in this field.

Key words: 5G; Remote ultrasound education; Ultrasound training; Telemedicine

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The rapid development of 5G-based transmission technology has significantly impacted on various industries, while education is no exception [1]. The implementation of 5G technology has brought unprecedented changes and opportunities for medical education [2]. The use of 5G remote ultrasound education has become a new teaching method which has been increasingly used [3-5].

The current applications and advantages of 5G remote ultrasound education include in following aspects [3,5-7]: (1) Enhanced connectivity: 5G technology offers faster speeds, lower latency, and more reliable connections, making it possible for ultrasound educators to deliver real-time, high-quality training to students, regardless of their location. This has made remote ultrasound education more accessible and efficient. (2) Real-time demonstrations: the improved connectivity provided by 5G networks enables real-time demonstrations of ultrasound techniques, allowing students to observe and learn from experts as they perform ultrasound examinations. This interactive learning experience is crucial in developing the skills needed to become proficient in ultrasound diagnostics. (3) Virtual simulation training: with the integration of 5G technology, virtual simulation training has become more realistic and immersive. Students can now practice ultrasound techniques in a simulated environment, which helps improve their skills and confidence before

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performing examinations on actual patients. (4) Collaboration and peer learning: 5G has facilitated collaborative learning experiences, allowing students to work together on case studies, share their findings, and discuss their interpretations in real-time at clinical setting. This promotes a deeper understanding of ultrasound concepts and fosters a strong sense of teamwork among students. (5) Access to advanced educational resources: 5G technology has made it possible for educational institutions to offer advanced resources, such as high-quality video lectures, virtual labs, and simulations, to students in remote locations. This ensures that students have equal access to high-quality education and clinical training, regardless of their geographical location.

At the same time, 5G remote ultrasound education faces some challenges [3,5-7] as follows: (1) Technical difficulties: although the development of 5G technology has facilitated remote ultrasound education, practical applications may still face technical challenges, such as network instability and device compatibility. (2) Information security and privacy protection: remote ultrasound education involves with patient data and privacy, so it is necessary to strengthen information security and privacy protection measures to prevent information leaks and misuse. (3) Educational resource allocation: 5G remote ultrasound education may exacerbate the issue of unequal distribution of educational resources, particularly in developing countries and underdeveloped regions. (4) Certification and qualifications: remote ultrasound education may face challenges related to certification and qualification recognition, requiring the establishment of corresponding standards and systems to ensure the quality of education.

Addressing the urgent problem of overcoming challenges and leveraging the benefits of 5G remote technology, along with the close integration of ultrasound medical theory and practice, to efficiently train primary ultrasound doctors and achieve real-time consultation and regular quality control, in order to meet the needs of the majority of primary patients, can be accomplished by implementing some strategies. This article aims to offer an overview of the current status and applications of 5G remote ultrasound education, including the development of theoretical courses and network construction within our department, and to discuss future trends in this field.

5G Remote Ultrasound Education: Developing Theoretical Courses

Leveraging the National Telemedicine and Internet Medicine Center platform, we consolidate top-notch ultrasound medical teaching resources to develop and refine a comprehensive set of 5G-enabled ultrasound residency training video courses at China-Japan Friendship Hospital. With the backing of the National Telemedicine and Internet Medicine Center in supplying venues and remote technical support, courses are conducted concurrently in-person and online. Students can opt for their preferred learning approach according to their individual requirements. The courses will be recorded and accessible on the National Telemedicine Center's online platform, enabling doctors with verified identities to review the material at their convenience.

Capitalizing on the subject expertise of various hospitals in Beijing, instructors are assigned to different ultrasound sub-specialty groups. For instance, in the “Ultrasound Assessment of Neonatal Health Status” course series, experts from Beijing Chaoyang Hospital and Beijing Children's Hospital teach segments on cranial and pulmonary aspects. Meanwhile, specialists from Fuwai Hospital and Anzhen Hospital instruct courses on cardiac aspects, and professionals from Jishuitan Hospital cover topics related to hip joint aspects.

Courses are categorized into basic, advanced, and specialized levels according to their content. For instance, the “Ultrasound Evaluation of Thyroid Nodules” course series encompasses basic courses such as “Standardized Thyroid Ultrasound Scanning” and “Learning ACR Standardized Features of Thyroid Nodules.” It also includes advanced courses like “The Role of Ultrasound in the Comprehensive Management of Thyroid Nodules” and “Ultrasound Evaluation of Postoperative Metastasis and Recurrence of Thyroid Cancer”, as well as specialized courses such as “The Application of AI-based Thyroid Nodule Ultrasound-Assisted Diagnosis System in Clinical Practice.” Learners can select courses tailored to their background and requirements.

A robust assessment and evaluation system is established for each course, incorporating diverse elements that consider the needs of both instructors and students. A two-way evaluation system is implemented, where students evaluate the lecture content delivered by instructors in terms of knowledge, engagement, and organization. Simultaneously, student assessments consist of written tests, image interpretation, and hands-on practical exercises in various formats. The courses undergo continuous optimization based on the outcomes of these assessments and evaluations (Fig. 1).

Using the “Resident Physician Clinical Research Design and Article Writing Ability Improvement Series Course” as an example, this course series invites renowned experts and scholars from the field of scientific research across the country to teach, ensuring the highest level of professionalism and organization. Simultaneously, we conducted a survey to assess the learning outcomes of this course. We selected 44 students who participated in the training course from June 7 to December 12, 2019, as research subjects. Based on the students' learning methods, they were divided into three groups: Group A for remote learning (14 people), Group B for on-site learning (16 people), and Group C for a combination of remote and on-site learning (14 people). Upon course completion, a questionnaire survey evaluated students' learning outcomes and satisfaction levels. The survey results revealed that students from all three groups felt they had gained knowledge, and their research capabilities had improved, with 88.6% (39/44) of the students considering their gains significant or relatively substantial. There was no statistically significant difference in the satisfaction levels of the three groups concerning course content, instructor quality, and course organization (all $P > 0.05$). Consequently, in learning resident physician research courses, the teaching model based on the National Telemedicine and Internet Medicine Center can achieve better learning outcomes.

China-Japan Friendship Hospital Ultrasound Department Simulation Exam Clinical Thinking Assessment Station Score Sheet

Student's Name: Exam Date:

Assessment Items: Abdominal/Cardiovascular/Superficial/Obstetrics and Gynecology

Assessment Content	Evaluation Criteria	Score		Personal Score
1. Clinical Data Collection	(1) Describe basic patient information (gender, age, etc.); (2) Describe medical history; (3) Verify examination date, examination site, and examination method, etc.	Deduct 1 point for each omission or incorrect description.	10	
2. Ultrasound Imaging Description	(1) Comprehensive observation of image information; (2) Describe important positive and negative signs; (3) Objective description, strong logic, rigorous thinking, concise language, and correct use of professional terminology; (4) Analysis process effectively combines clinical data.	(1) Deduct 1-5 points for incomplete observation of image information; (2) Deduct 3-5 points for each important positive and negative sign not described; (3) Deduct 1-10 points as appropriate for subjective description, poor language logic, unrigorous thinking, and incorrect use of professional terminology; (4) Deduct 1-5 points for not combining clinical data in the analysis process.	35	
3. Ultrasound Diagnosis and Differential Diagnosis	(1) Reasonable diagnostic basis and correct diagnostic conclusion; (2) Provide at least 2 differential diagnoses and describe the basis for differentiation; (3) If the diagnosis is unclear, describe the primary and secondary suspected diagnoses and provide a plan for further examinations.	(1) Reasonable diagnostic basis and correct diagnostic conclusion; (2) Provide at least 2 differential diagnoses and describe the basis for differentiation; (3) If the diagnosis is unclear, describe the primary and secondary suspected diagnoses and provide a plan for further examinations.	35	
4. Answer Questions	The examiner will randomly ask 2 related questions based on the case and the student's personal situation.	Deduct 10 points for incorrect answers; Deduct 1-5 points for incomplete answers.	20	
Total			100	

Examiner's Evaluation:

Examiner's Signature:

Note: The minimum score for this station is 1 point. An initial score of 70 or above is considered passing.

Teacher Evaluation Survey Questionnaire - For Students

1. What is the name of the teacher in charge? What subject do they teach? (Fill in the blank)
____
2. Do you think this teacher cares about students? (Single choice) Yes No
3. Do you think this teacher fully embodies medical ethics and teacher's ethics? (Single choice) Excellent, fully reflects a good work style Good, plays a certain exemplary role Acceptable, basically meets the requirements Poor, some violations in words and deeds
4. Are there any bad behaviors in this teacher's class, such as smoking, answering phone calls, being late, leaving early, or not attending class without a reason? (Single choice) Never Occasionally Sometimes Often
5. How do you think this teacher's mastery of the subject they teach? (Single choice) Very familiar Average Unfamiliar
6. Is the teacher's language expression fluent? (Single choice) Fluent language expression Average language expression Inarticulate language expression, dialect, understanding ambiguity
7. Is the teacher's logic clear? (Single choice) Clear logic, well-organized, distinct hierarchy Acceptable logic, can explain the problem Average logic, can understand after class review Poor logic, need self-strengthening learning after class
8. Does the teacher assign homework to consolidate knowledge after class? (Single choice) Often assigns homework Rarely assigns homework Seldom assigns homework Doesn't assign homework Other__
9. Are you satisfied with the teacher's homework assignment and grading? (Single choice) Very satisfied Satisfied Average Dissatisfied Very dissatisfied
10. Apart from homework, do you actively review after class? (Single choice) Yes No
11. If there are questions related to the course after class, how do you communicate with the teacher? (Single choice) Ask questions and get answers in the next class Through email, WeChat, or other instant communication tools Rarely find problems, not much communication
12. Does the teacher prepare for each class with focus and specificity? (Single choice) Well-organized course, suitable for personal learning Simple teaching plan, weak content focus Teaching straight from the book
13. What is the main focus of the teacher's classroom teaching? (Single choice) Teaching knowledge points A lot of practice Combination of knowledge points and practice
14. Does the teacher pay the same attention to you as other students? (Single choice) Very attentive Treats everyone equally Not very attentive Doesn't care
15. What are the teaching styles of this teacher during class? (Multiple choice) Very humorous Very patient Frequent interaction Boring and uninteresting Not attractive to me at all
16. Are you interested in this teacher's classroom teaching? (Single choice) Very interested Average Not interested
17. What are the common teaching methods used by this teacher? (Multiple choice) Multimedia PPT Using teaching charts, models, or other tools Writing on the blackboard
18. How much have you gained from the current course? (Single choice) A lot, meeting practical operation requirements Quite a bit, meeting exam requirements Average, generally meeting examination requirements A little, popular science nature Very little, not much different from before learning
19. What suggestions do you have for this course? (Fill in the blank)

Figure 1 The two-way assessment and evaluation tables for a course.

The remote teaching model based on the National Telemedicine and Internet Medicine Center can effectively and scientifically enhance the flow of teaching information, fully utilize the collective benefits of educational resources, and achieve the rational distribution of medical teaching resources. It can transcend time and space constraints, enabling the synchronous transmission of information and sharing of teaching resources, while considering the unique circumstances of each student and maximizing the efficiency of educational resources. Students can engage in self-directed learning during fragmented time, which to some extent resolves the conflict between scientific research training time and clinical work time. Simultaneously, students provide feedback on the learning content, laying the foundation for further course optimization. Currently, the construction of the ultrasound theoretical courses has been initially completed, encompassing 80 basic courses, 50 advanced courses, and 50 specialized courses.

5G Remote Ultrasound Education: Building the Network Infrastructure

Ultrasound medicine is a discipline that emphasizes both theory and practice. Relying on the National Telemedicine and Internet Medicine Center, we take full advantage of the technical capabilities of tertiary hospitals and construct 5G and AI-integrated remote laboratories within and beyond the hospitals in phases. Depending on the distinct medical service targets, we implement a modular construction approach for 5G+AI medical practice. Our goal is to explore scalable and replicable remote diagnosis and treatment models, ultimately transcending regional boundaries of ultrasound resources, diminishing the disparities in diagnostic and treatment capabilities among hospitals, and balancing medical resources [3,4] (Fig. 2).

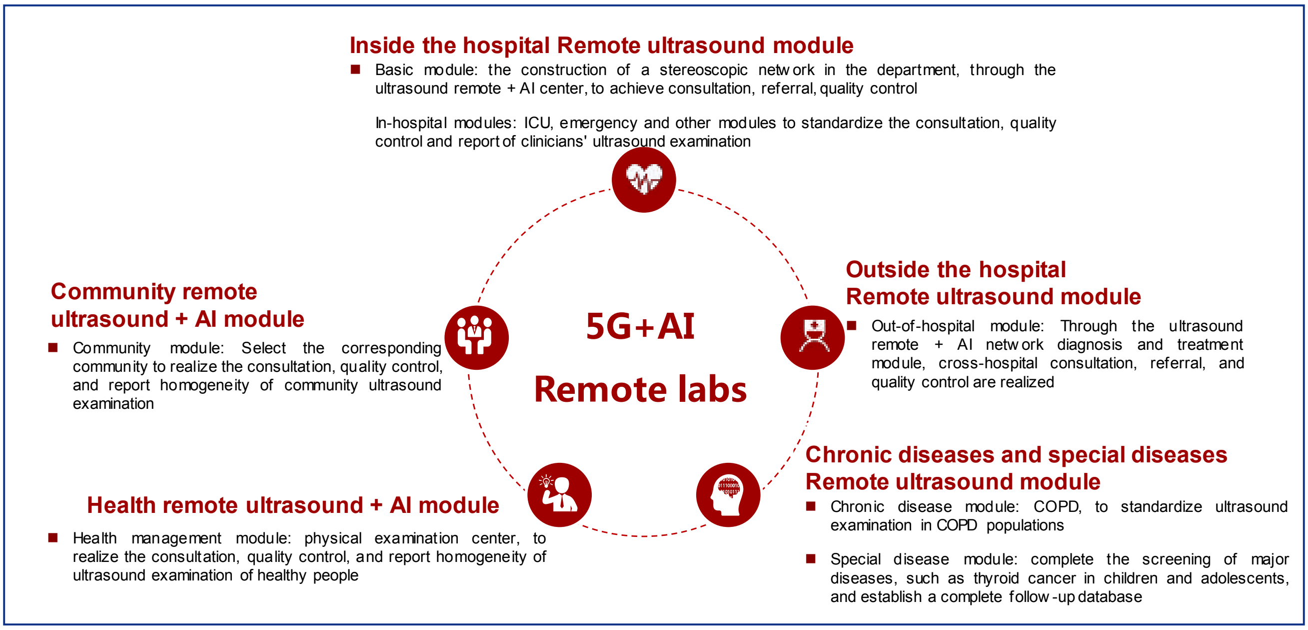

Figure 2 The construction of 5G and AI-integrated remote laboratories within and beyond the hospitals in phases.

Utilizing the National Telemedicine and Internet Medicine Center as the 5G terminal, a three-tier network architecture is established for ultrasound remote consultations and the storage and transmission of ultrasound images, reports, and other data. Different functional permissions are set for each level [6-8].

The tertiary (top-level) network, which includes the Department of Ultrasound at the China-Japan Friendship Hospital, serves as the regional remote consultation center for ultrasound. It establishes a 5G-based full-function network center, a network of clinical ultrasound equipment and workstations, and sets up a storage database. The main responsibilities of the tertiary institutions include: (1) Handling image transmission and consultation tasks from primary and secondary institutions; (2) Collecting, storing, and organizing ultrasound images and report data from secondary institutions for further analysis; (3) Collaborating with other tertiary centers to analyze difficult ultrasound cases, conducting joint consultations, and sharing or dividing project data statistics and analysis work; (4) Utilizing AI imaging software and equipment to interact with primary and secondary institutions, applying human intervention and correction to screen AI diagnostic results, which are then statistically analyzed and stored to improve and test AI software algorithms and intelligent diagnostic accuracy [9]; (5) Continuously upgrading software and AI artificial image diagnosis for primary and secondary institutions; (6) Providing on-site training, continuing education, and guidance for relevant project personnel from primary and secondary institutions.

The tertiary institutions serve as the regional remote consultation center and have full access to the network. They play a crucial role in providing remote consultations, analyzing difficult cases, and working with other tertiary centers to share data and insights. Additionally, they are responsible for upgrading AI software algorithms and intelligent diagnostic accuracy, as well as providing training and guidance for personnel from primary and secondary institutions.

The secondary network encompasses the equipment outside the ultrasound department in the hospital and other departments' ultrasound equipment in secondary hospitals, primarily responsible for ultrasound examinations in wards. As a secondary medical center, its main responsibilities include: 1) Project implementation: responsible for promoting and implementing the project, ensuring the smooth progress of various tasks. 2) Bridging role: as an intermediate-level medical institution, the secondary medical center must maintain close communication and collaboration with higher-level tertiary institutions and lower-level primary institutions.

3) Monitoring 5G facilities and transmission effects: continuously monitor the operation of 5G network facilities to ensure optimal transmission effects that support remote consultations and the collection and uploading of images and data. 4) Maintaining smooth communication with primary and tertiary centers: ensuring seamless communication with primary and tertiary centers for consultations as an intermediate-level medical institution. 5) Reviewing and submitting primary-level images and data: ensuring the accuracy and completeness of the information by reviewing the images and data submitted by primary-level institutions.

At the secondary level, institutions not only perform ultrasound examinations but also play a crucial bridging role between primary and tertiary institutions. They have broader access to the network, allowing them to monitor the 5G facilities and transmission effects, and communicate with corresponding tertiary institutions to ensure smooth consultations. Secondary institutions are also responsible for reviewing and submitting primary-level images and data.

Primary institutions, situated at the grassroots level, form the foundation for data provision throughout the entire project, emphasizing the significance of quality control. These institutions heavily rely on remote consultations and AI support, making the stability of remote consultations and case data transmission essential. The primary network is designed for ultrasound equipment operators working at grassroots medical consortium hospitals (or community medical centers). Their primary responsibilities include collecting and transmitting ultrasound image data, such as patient basic information, past medical records, ultrasound images, ultrasound reports, and other radiological data. Primary-level operators should undergo professional training to conduct standardized ultrasound scanning, image uploading, storage, daily maintenance of 5G equipment, and proficient operation of AI software. At the primary level, the main focus is on performing ultrasound examinations and uploading pertinent images, reports, and other data. Primary institutions have limited access to the network and can request remote consultations from higher-level institutions.

The network facilitates data transmission and management, with the central ultrasound system server storing all ultrasound data and utilizing the 5G network for transmission. The doctor reporting system in the remote ultrasound system features standard ultrasound diagnostic templates, and the system provides automatic analysis, measurement, and diagnostic suggestions or results, with data autonomously saved. System permission management grants and manages the authorization and administration of diagnostic report writing, encryption, modification, review, uploading, browsing, and downloading permissions [10].

By implementing this three-tier network architecture, the system effectively capitalizes on the advantages of 5G technology and artificial intelligence to enhance the efficiency and quality of ultrasound examinations and remote consultations, ultimately improving the overall level of medical services. Based on the three-tier network architecture, a phased construction of 5G and AI-integrated remote laboratories within and outside the hospitals is carried out (Fig. 3).

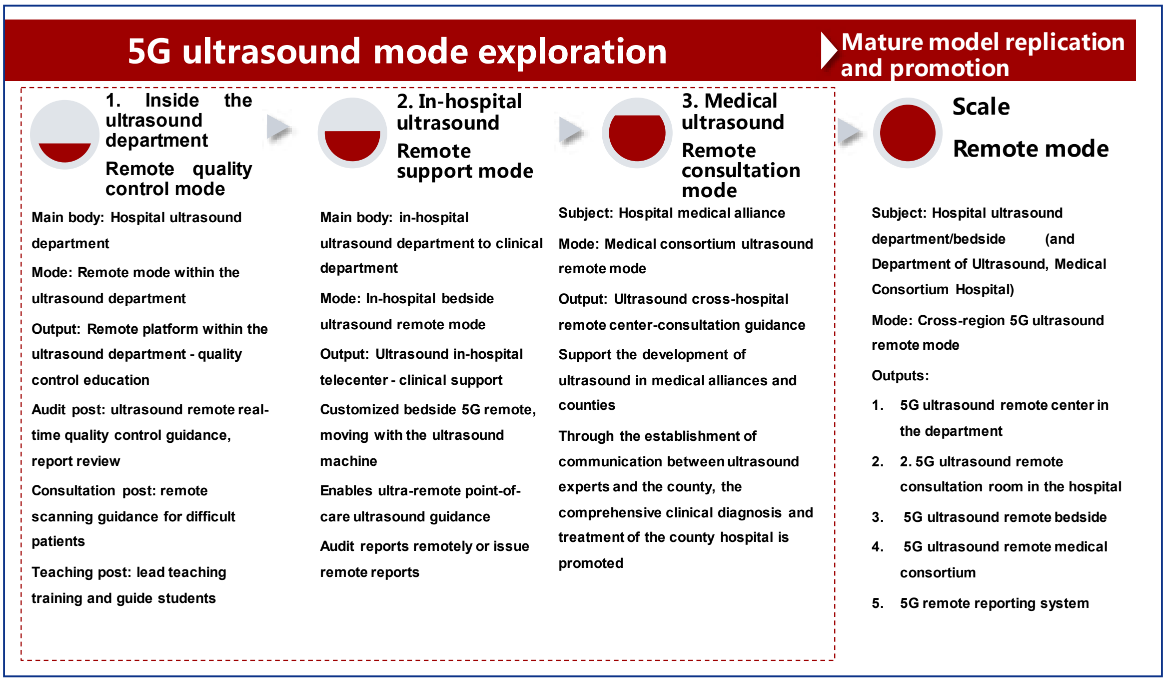

Figure 3 The phased construction of 5G and AI-integrated remote laboratories within and outside the hospitals.

Phase 1: Construction of the remote consultation network within the Ultrasound Department. This phase achieves interconnectivity among ultrasound equipment within the department, establishes primary, secondary, and tertiary consultation posts, and conducts monthly quality control of consultation cases, including basic quality control (smooth and timely image transmission) and deep quality control (accuracy of consultation results).

Phase 2: Construction of the remote consultation network within the hospital. This phase achieves interconnectivity between the ultrasound department and other departments' ultrasound equipment within the hospital (including ICU, emergency departments, etc.), using the 5G network to transmit ultrasound images and facilitating remote consultations for difficult cases. It also follows a graded consultation system and quality control system [11].

Phase 3: Grassroots coverage of the remote ultrasound consultation network. This phase achieves grassroots coverage of the remote ultrasound consultation network centered around the ultrasound department at the China-Japan Friendship Hospital. Grassroots hospitals standardize ultrasound image collection and use AI assistance for basic diagnosis [9]. The 5G network is utilized for standardized image transmission, enabling ultrasound report reviews and remote consultations for difficult cases. This phase also follows a graded consultation system and quality control system.

Currently, we have completed the construction of laboratories for the first and second phases. Through theoretical courses and remote network construction, we have established an “Internet+” ultrasound theory and practice teaching base to meet the needs of specialized education and retraining for ultrasound doctors at different levels in the capital. Simultaneously, we rely on the medical consortium to bring high-quality resources to the grassroots level, improving the overall ultrasound diagnosis and treatment level in the consortium's coverage area.

The Future Trends in 5G Remote Ultrasound Education

The 5G remote ultrasound education presents numerous development trends as following [8,12,13]: 1) Expanding access: as 5G networks continue to grow, remote ultrasound education will gain popularity, reaching a wider audience, including students in rural or underprivileged areas. This will help democratize access to high-quality ultrasound education. 2) AI integration: incorporating AI in remote ultrasound education enables personalized learning experiences. AI-driven systems can analyze students' performance and adapt educational content based on their individual needs, ultimately enhancing learning outcomes. 3) Strengthened security and privacy: with advancements in 5G technology, more robust security and privacy measures will be implemented for remote ultrasound education. This is crucial for safeguarding sensitive patient information and ensuring the integrity of online learning platforms. 4) Ongoing innovation: as 5G technology evolves, novel and innovative applications for remote ultrasound education will emerge. This will result in more engaging, interactive, and immersive learning experiences, further revolutionizing the ultrasound education landscape [1,7,14].

In conclusion, 5G remote ultrasound education holds tremendous potential for development and market growth. As 5G technology becomes more widespread and advanced, remote ultrasound education will become increasingly accessible and effective, providing students with a more personalized and engaging learning experience. The future of 5G remote ultrasound education is bright, with its potential to greatly influence medical education and healthcare worldwide. By addressing the challenges and capitalizing on the opportunities presented by 5G, remote ultrasound education has the capacity to revolutionize medical education and healthcare services on a global scale.

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Conflict of Interest

All authors declare that they have no conflicts of interest related to this review article.

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