

Quality Control Analysis of Normal Breast Imaging using a Remote Ultrasound Robot

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Objective: To explore the quality control value of 5G remote ultrasound robot in normal breast imaging.

Methods: Fifty female volunteers from Xizang were selected to undergo routine breast examinations using 5G remote ultrasound robot (robot group) and on-site ultrasound (control group). Longitudinal and transverse continuous scanning methods were used to collect and save images respectively. The two groups of images were scored for breast imaging quality by five senior attending physicians or above using a blind method according to the Likert scale grading standard. The paired t-test was used to analyze the differences in breast imaging quality scores obtained by five physicians between the two examination methods and the age differences between the two groups of volunteers. The Kappa test was used to analyze the consistency of the image scoring results between the two groups. The χ^2 test was used to analyze the ethnic differences between the two groups of volunteers.

Results: There is no significant age difference between the two groups of volunteers ($t = -0.850$, $P = 0.101$, $P > 0.05$). There is no significant difference in the ethnic proportions between the two groups of volunteers ($P = 1.00$, $P > 0.05$). There was no statistically significant difference in the scores of the five physicians between the two groups of images ($P > 0.05$), Doctor A ($t = -1.647$, $P = 0.101$), Doctor B ($t = -0.943$, $P = 0.347$), Doctor C ($t = 0.582$, $P = 0.561$), Doctor D ($t = 0.040$, $P = 0.958$), Doctor E ($t = 0.144$, $P = 0.886$). The consistency of the scoring results of the five doctors on the two groups of images was good (Kappa = 0.789, 0.753, 0.807, 0.778, 0.823, $P < 0.001$).

Conclusion: The remote ultrasound robot has good consistency with the on-site ultrasound imaging quality. The remote ultrasound robot can be used for breast cancer screening in special environments such as high altitude and cold weather.

Key words: 5G remote ultrasound robot; Normal mammary gland; Ultrasound imaging; Image quality; Quality control

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Ultrasound is currently the preferred method for examining and diagnosing breast diseases and is a popular and indispensable imaging method for screening breast cancer in women in my country [1,2]. In recent years, communication technology has been continuously improved and telerobotics has developed rapidly, especially in the medical field. Teleultra-

sound robots can be effectively used in special areas such as the shortage of primary ultrasound doctors and lack of medical resources [3,4]. During the COVID-19 pandemic, a remote ultrasound robot based on the fifth generation mobile communication technology (5G) was used to evaluate critically ill infected patients in isolation wards, initially demonstrating its value in special

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scenarios [5,6]. In recent years, 5G remote ultrasound robots have also been expanded in the early diagnosis of trauma and emergencies in the abdomen, heart, fetus, lungs, musculoskeletal joints and other parts [7-9], but there are relatively few research reports on the application of 5G remote ultrasound robots in breast diseases. The population in the Xizang Plateau is dispersed, and due to the limitations of the natural environment, it is difficult to conduct screenings for female cancers in certain areas such as Ali and Naqu. In response to this urgent need, this study pioneers the use of a 5G remote ultrasound robot to explore the quality control of normal breast ultrasound imaging, aiming to lay a foundation for its application in breast screening.

Materials and Methods

Research subjects

We analyzed ultrasound imaging of 5G remote ultrasound robot breast examination in 50 female volunteers in Ali region of Xizang as the robot group, with an age range of 26 to 54 years and an average age of (36.2 ± 5.98) years. The control group consisted of participants who underwent on-site breast ultrasound examination during the same period, aged 26 to 54 years old, with an average age of (37.0 ± 5.17) years old. Inclusion criteria: No clear breast nodules were found by ultrasound examination. Exclusion criteria: incomplete data. This clinical study was approved by the Ethics Committee of the

General Hospital of the Chinese People's Liberation Army (KY2022-006), and the study subjects voluntarily signed the informed consent form.

Ultrasound instruments and examination methods

Robotic Group The MGIUS-R3 5G remote ultrasonic robot diagnostic instrument was used. The built-in ultrasonic instrument was a portable ultrasound instrument (Shenzhen Huasheng Medical, Clover60). The probe used was the L15-4 linear array probe with a frequency of 5.0-12.0 MHz and breast mode. The 5G remote ultrasound robot includes the patient side and the doctor side. The two ends are matched and connected through 5G communication technology. During the examination, a mobile vehicle equipped with a 5G remote ultrasound robot (patient end) was used to drive into various counties and districts in Ali, Xizang, to perform breast ultrasound examinations (Fig. 1).

Remote ultrasound robot examination method: The patient-side is located at an average altitude of 4700 m in the Ali region, where a local non-medical assistant assists the volunteers in positioning the patient. This assistant received training based on the requirements of this study, which primarily included familiarization with relevant precautions during the ultrasound examination and cooperation. The assistant helps the subject take the correct position, applies the coupling agent, and measures the amount used, while also being able to communicate accurately with the doctor during the examination. However, they do not participate in adjusting the equip-

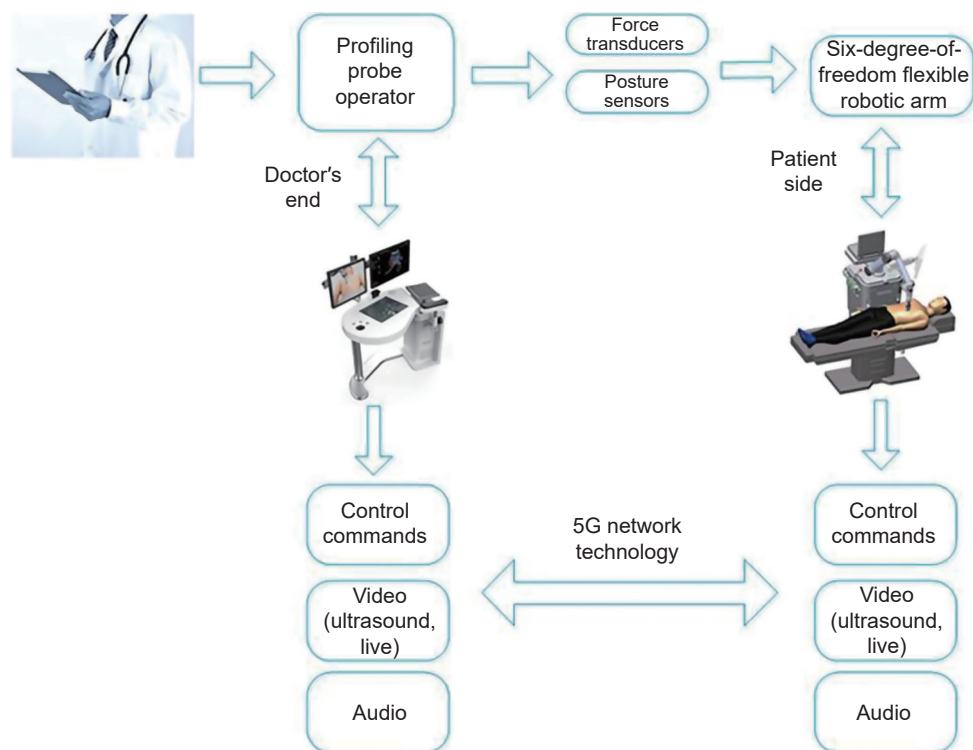


Figure 1 5G remote ultrasound robot application process.

ment, collecting images, or analyzing images. The medical end is located in Beijing, operated by doctors with over 10 years of experience in breast ultrasound and specifically trained in 5G remote ultrasound robot operation. They also have the experience of independently completing 30 cases of 5G remote ultrasound robot breast examinations, during which they can conduct real-time consultations with the examinee and provide guidance for cooperation during the examination. After the equipment is successfully matched and connected, select the high-frequency probe L15-4 breast condition and adjust the gain, dynamic range and focus. The subject is fully exposed to both breasts, and took supine or lateral positions as needed for remote ultrasound examination, covering their upper bodies as appropriate to keep warm and protect patient privacy. During the examination, both arms are raised to fully expose both breasts, and the patient-end probe of the remote ultrasound robot is placed in the breast area, and a continuous horizontal scan from top to bottom (transverse section) is performed first, followed by a continuous sagittal scan from the outside to the inside (longitudinal section). All scanned sections are superimposed to avoid omissions. Images are automatically stored in the device.

Control Group The same portable ultrasound diagnostic instrument (Clover60, Shenzhen Huasheng Medical) as that embedded in the 5G remote ultrasound robot was used, and the probe used was the L15-4 linear array probe with a frequency of 5.0-12.0 MHz and breast mode.

On-site Ultrasonic Inspection Methods: The volunteers' preparations before the examination were the same as those of the robot group. On-site ultrasound examinations by doctors with more than 10 years of experience in breast ultrasound. The ultrasound probe is placed in the breast area, and first a continuous horizontal scan from top to bottom (transverse section) is per-

formed, and then a continuous sagittal scan from outside to inside (longitudinal section) is performed. All scan sections are superimposed to ensure comprehensive breast scan, complete image display, and image storage.

Ultrasound image acquisition and evaluation

The ultrasound image acquisition points are all located at the 12 o'clock position, 1-2 cm from the nipple, with one image for each side of the left and right breast. A total of 100 normal baseline images of the breast are taken for each group, totaling 200 images between the two groups (Fig. 2).

According to the “Expert Consensus on Quality Control of Ultrasound Examination of Breast Diseases (2019 Edition)”, the quality control of basic imaging of normal breast ultrasound was carried out [10]. The basic images collected by the robot group and the control group were randomly coded and graded and quantified in a blind manner, and the scores of 5 senior attending experts or above were used as the final results.

The scoring criteria refer to the Likert scale grading criteria [11]: (a). 5 points: excellent, can be used for diagnosis, very satisfactory; (b). 4 points: good, can be used for diagnosis, satisfactory; (c). 3 points: some defects, does not affect diagnosis, average; (d). 2 points: poor, affects diagnosis, unsatisfactory; (e). 1 point: poor, cannot be used for diagnosis, unsatisfactory.

Statistical methods

SPSS 25.0 statistical software was used to analyze the data. The measurement data are expressed as mean $\pm$ standard deviation ($\bar{X} \pm S$), and the count data are expressed as examples (pieces). Five doctors compared the differences in image scoring results between the two groups and the age differences between the two groups of volunteers using a paired t-test, with $P < 0.05$ consid-

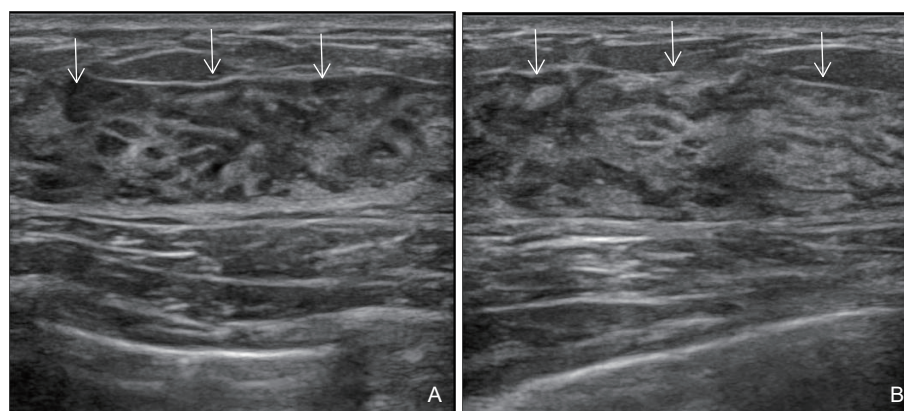


Figure 2 Ultrasound images of the robot group and the control group. (A) The 5G remote ultrasound robot shows the structural hierarchy of breast images, with the arrows indicating the glandular layer; (B) Live ultrasound shows the structural layers of the breast image, with the arrows indicating the glandular layer.

ered the difference statistically significant. The consistency of the image quality between the two groups was tested using the Kappa test. $Kappa \geq 0.75$ indicated good consistency between the two groups; $0.75 > Kappa \geq 0.4$ indicated fair consistency between the two groups; and $Kappa < 0.4$ indicated poor consistency between the two groups. The χ^2 test was used to compare the ethnic proportions of the two groups of volunteers, and the difference was considered statistically significant when $P < 0.05$.

Result

Basic situation

All the subjects in both groups were female, including Han and Tibetan people. There were 22 Han people and 28 Tibetan people in the robot group, and 24 Han people and 26 Tibetan people in the control group. The age of the robot group was 26~54 years old, and the average age was (36.2 ± 5.98) years. The age of the control group was 26~54 years, the mean age was (37.0 ± 5.17) years (Table 1).

Scoring results of ultrasound imaging in the two groups

Five senior physicians analyzed and scored the normal breast ultrasound images of the robot group and the control group. The specific results are shown in table 2. Paired t-test was used to analyze the imaging quality scores of the robot group and the control group of 5 doctors. The results showed that there was no statistically significant difference in the basic scores of normal breasts between the two groups ($P > 0.05$) (Table 2).

Each doctor scored ≥ 4 points for the two groups of images, which was considered a satisfactory diagnosis, and < 4 points for an unsatisfactory diagnosis. Kappa test was performed, and the results showed that the con-

sistency of the diagnosis results of the five doctors in the two groups was good ($Kappa = 0.789, 0.753, 0.807, 0.778, 0.823, P < 0.001$).

Discussion

Our country has vast territory and a large population, with uneven economic development across different regions, leading to a disparity in healthcare levels between urban and rural areas. For instance, in the Xizang Plateau region, the population is widely distributed, and awareness of breast cancer prevention and treatment is relatively weak. Additionally, medical resources are scattered and underdeveloped, with most medical facilities only able to conduct examinations through consultations, physical examinations, and limited medical equipment. The implementation of a hierarchical medical system is challenging, and patients with suspected diagnoses need to travel long distances to refer to higher-level hospitals, resulting in missed diagnoses and delayed treatment [12]. Based on the successful experience of 5G remote ultrasound robots in routine abdominal examinations in isolation wards and remote areas [13-14], in order to promote the widespread implementation of cervical and breast cancer screenings among women in the Ali region, this study explores the imaging quality control analysis of normal breast ultrasound using a 5G remote ultrasound robot.

5G remote ultrasound robot technology utilizes principles of internet information transmission, master-slave control, and human-computer interaction to achieve cross-regional sharing of medical resources. The ultrasound doctor controls the ultrasound probe mounted on the end of the patient-side robotic arm in real time by manipulating the contoured probe to perform ultrasound examination on the patient. During the examination, ultrasound doctors can communicate with patients

Table 1 Consistency of basic conditions between the robot group and the control group

Grouping	Number of cases	Age	Han chinese/tibetan (example)
Robot Group	50	36.2 ± 5.98	22/28
Control Group	50	37.0 ± 5.17	24/26

Note: There was no difference in age between the two groups ($t = -0.850, P = 0.101, P > 0.05$). No difference in ethnic proportion $P = 1.00, P > 0.05$.

Table 2 Normal breast ultrasound imaging quality scores in the robot group and the control group

Doctor	Robot group	Control group	t-value	p-value
Doctor A	4.31 ± 0.587	4.37 ± 0.556	-1.647	0.101
Doctor B	4.38 ± 0.515	4.39 ± 0.521	-0.943	0.347
Doctor C	4.37 ± 0.614	4.32 ± 0.601	0.582	0.561
Doctor D	4.35 ± 0.552	4.35 ± 0.524	0.040	0.958
Doctor E	4.37 ± 0.497	4.37 ± 0.483	0.144	0.886

Note: $P < 0.05$ the difference is statistically significant.

through a high-quality audio and video system, adjust the parameters of the ultrasound equipment at the patient's end in real time, and obtain real-time ultrasound images for medical diagnosis. This can effectively alleviate the long-standing issues in the Xizang region of having large imaging equipment that cannot be transported, the inconvenience caused by special geographical environments when operating imaging technology, and the problem of not having relevant specialized doctors who know how to use the equipment.

Through the quality analysis of breast ultrasound imaging by 5G remote ultrasound robot, the feasibility of breast ultrasound examination by remote ultrasound robot is clarified. It adopts six-free arm scanning, the probe runs flexibly without dead angle, the running track simulates the probe held by wrist in real time, and the probe running track operated by doctor during on-site examination is fitted through the scanning of robot arm probe. Ultrasonic imaging can cover the examined organ and form sectional image. The probe of 5G remote ultrasound robot adopts 3 Newton (N), which is equivalent to the force felt when holding an object with a mass of 300 g (about 3 eggs) by hand. Because breast is different from other organs, if the probe pressure is too small during inspection, it is easy to cause the problem that the probe is not closely attached to the skin and the scanning is not comprehensive, if the pressure is too large, it will cause the examinee to feel compression. The force of 3N is not easy to make the patient feel uncomfortable during the examination, and the problems of incomplete scanning and unclear ultrasound image display are overcome. Through the evaluation and comparative analysis of imaging quality by senior ultrasound doctors, the remote ultrasound robot has been able to determine the overall echo uniformity of the breast and the imaging quality of the skin layer, subcutaneous fat, glandular layer, retromammary space, and chest wall muscle layer, thus demonstrating the application value of the 5G remote ultrasound robot in breast screening.

Since the breast is a superficial organ with a large range of motion, many ultrasound doctors in clinical practice use the traditional radial scanning along the nipple direction combined with parallel movement scanning. In this study, both the remote ultrasound robot group and the control group used a combination of continuous horizontal scanning from top to bottom (transverse section) and continuous sagittal scanning from outside to inside (longitudinal section). The image quality scores obtained were consistent and can be used for the diagnosis of breast diseases. Clinically, breast morphology and texture vary greatly among women of different ages and nationalities. There is no difference in

imaging quality between breast scanning methods using remote ultrasound robots and on-site ultrasound. Remote ultrasound robots are easy to train and master, and overlapping scanning can avoid missed diagnoses.

The quality of ultrasound imaging determines the standardization of ultrasound examinations and the accuracy of results. The results of this study showed that the imaging quality of the two groups was consistent. Five senior attending physicians or above scored the normal breast ultrasound images of the two groups, and the results showed no difference. This shows that there is no significant difference in the normal breast imaging quality between the 5G remote ultrasound robot and on-site ultrasound. It can be applied to normal breast examinations with relatively reliable results.

There are also the following deficiencies in this study. The 50 volunteers included in the study only included Han nationality and Tibetan nationality, while the morphology, size and texture of female glands of different nationalities were different. In the later stage of this study, more volunteers from different regions and races were planned to be included to expand the sample size and reduce bias.

In summary, the 5G remote ultrasound robot is a promising imaging method for breast cancer screening in special environments such as high altitude and cold weather. The evaluation of its imaging quality control in this study showed that the remote ultrasound robot has good consistency with the on-site ultrasound imaging quality, thus confirming the feasibility of the remote ultrasound robot in breast disease screening.

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Authors' Contributions

Faqin Lv and Yutong Ma conceived of and designed the study; Yutong Ma drafted the manuscript; Yingying Chen, Renqing Jiancan and Xiuzhu Ma performed statistical design and analysis; Yun Zhang, Xiaochu Dang and Xuejuan Wang performed the research; Zhanlei Zhang and Faqin Lv acquired and interpreted of the data for the work. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

Data Availability

All data generated or analysed during this study are included in this

published article [and its supplementary information files].

Declarations

Ethics approval and consent to participate

This clinical study was approved by the Ethics Committee of the General Hospital of the Chinese People's Liberation Army (KY2022-006).

Consent for publication

Not applicable.

Conflict of interest

The authors have no conflict of interest to declare.

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