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Patient Acceptability of Automated Robotic Ultrasound by Patient Profile

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Abstract

Robotic ultrasound (US) has emerged as a promising solution to enhance the accuracy, consistency, and accessibility of US examinations. Although many studies have proposed various technologies toward full automation, patient acceptance of the robotic US system has not been discussed. This study explored the patient's acceptability of robotic US through a questionnaire survey. The 480 participants were asked about their willingness to use a medical facility that offers robotic US examinations. The results showed that the score was 3.61 out of 6, slightly above the average of 3.5. As the reasons for wanting to undergo the robotic US examination, many participants pointed to "time" and "cost". The most common reason for not wanting to use it was "vague anxiety" that patients feel somewhat anxious and "object anxiety" such as a fear of danger due to malfunction. These negative reasons were relatively low among participants who had found diseases via US examinations and among those who already had experience using robots in medical and nursing care fields. This suggests that patients need to increase their knowledge and experience of US examination and robotics to increase their willingness to use automated robotic US.

Keywords: robotic ultrasound; acceptability; autonomy

1. Introduction

Ultrasound (US) imaging is a widely used, non-invasive diagnostic tool in medicine that provides real-time imaging of internal organs, soft tissues, and blood flow. US requires trained sonographers to manipulate a probe and interpret the images, which introduces variability and dependency on the expertise. Additionally, performing US can be physically demanding for clinicians, leading to work-related musculoskeletal disorders [1–4]. With advances in robotics, artificial intelligence (AI), and medical imaging, robotic US has emerged as a promising solution to enhance the accuracy, consistency, and accessibility of US examinations. Robotic US systems typically consist of robotic arms equipped with US probes, force sensors, and AI-driven algorithms for image processing and decision-making. The system integration might overcome the operator-dependent problem and the work-related musculoskeletal disorder by means of either a teleoperated, collaborative assisting, or even autonomous system.

A previous review paper [5] suggested classifying the level of autonomy (LORA) [6] of robotic US as a teleoperated system, a collaborative assistance system, or an autonomous system. Toward fully autonomous robotic US, many studies have proposed various applications targeting the abdomen, fetus, breast, lung, thyroid and so on. Autonomous systems

Check for updates

Academic Editor: Ken Masamune

Received: 29 December 2025
Revised: 31 January 2026
Accepted: 5 February 2026
Published: 7 February 2026

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in the field of robotic US can be the systems performing the control and movement of the robot to acquire US images for diagnostic or intervention tasks. This requires scan path planning, contact force control to ensure safety, and position optimization to search for the target cross-section while avoiding shadows. The scan path planning was developed based on the registration between the MRI/CT atlas and current patient body [7,8] or the shape and landmark of the body surface captured by RGB-D camera [9–11]. The safe contact was achieved based on the force feedback control of the probe position [11–14] or the unique passive mechanism for holding the probe [15–17]. The position optimization was performed based on the visual servo with real-time US image feedback [18–20].

Although various technologies toward autonomous US image acquisition have been developed, patient acceptance of the autonomous robotic US system has not been discussed in depth. There have been many reports on the acceptability of social robots. This review paper [21] summarized the research on social robot acceptance over the past decade and identified what factors influence acceptance. The most common area of research was in the healthcare field (60.5%), especially research related to support for the elderly (32.6%). Other areas of research included education (23.3%) and entertainment (10.5%). In terms of acceptability trends, 67.4% of the studies identified "positive acceptance"; 11.6% of the studies showed "ambiguous reactions," with some factors hindering acceptance. Humanoid robots such as NAO (23.26%), Pepper (11.63%), and SCITOS (16.28%) were frequently used to assess acceptability. The paper mentioned that the factors influencing acceptability include the appearance and behavior of the robot, the age and experience of the user, and social influences such as concerns that the robot will take occupations. Focusing on the research on evaluating the acceptability of robots used in the healthcare field, this study [22] reports on an experimental pilot study conducted to evaluate the acceptability of nursing assistant robot. The robot was developed to assist nurses with functions such as walking assistance, acquisition and delivery of goods, and patient observation. The usefulness and ease of use of the system in a simulated environment was evaluated for nursing students, not its acceptability to patients. The acceptability of robotic technology in neurorehabilitation was also investigated [23]. In the experiment, seven questionnaire items (comfort, pain, fatigue, enjoyment, benefit, desire to continue, and recommendation to others) were evaluated. The result showed that "comfort," "enjoyment," and "desire to continue" rated particularly highly and patients tended to accept the robotic rehabilitation favorably and were willing to continue using it. A technology acceptance model for the acceptability of upper limb rehabilitation exoskeletons was proposed to promote the use of the exoskeleton for upper limb rehabilitation [24]. This study provides detailed analysis of the acceptability of exoskeletal technology from the therapist's perspective and presents findings that provide a foundation for future implementation strategies. Patient acceptance of medical service robots was also studied [25]. The robot was designed for public service, providing patient guidance and consultation. The study examined how four aspects of anthropomorphism (appearance, voice, behavior, and personality) affect patients' expectations, empathy, interaction experiences, and emotions.

Although the acceptance of several social robots in the healthcare field was investigated, there have been no studies focusing on the acceptability of autonomous robotic systems manipulating medical equipment such as the US probe. The purpose of this study is to quantify the current level of patient acceptance of the autonomous robotic US system by conducting a questionnaire survey on patient acceptance of the system in Japan. To our knowledge, this is the first study to evaluate the patient acceptability of the automated robotic US.

2. Materials and Methods

2.1. Questionnaire Preparation

First, we asked for the profiles of survey participants including gender (Q1), age (Q2), medical history (Q3), sufficiency of surrounding medical facilities (Q4), knowledge and experience in the use of medical and nursing care robots (Q5), and occupations (Q7), as shown in Table 1. Regarding medical history (Q3), we asked if any diseases and lesions (polyps, tumors, stones, etc.) were found and treated, if any disease or lesion was found and under follow-up, or if nothing was found. The questions on the sufficiency of surrounding medical facilities (Q4) asked whether they or their family feel that it is difficult to get medical checkups, daily medical examinations, etc., at nearby medical facilities. The question on the knowledge and experience in the use of medical and nursing care robots (Q5) asked whether the participants "are using or have used it", "have never used it but know of it", or "have never used it and don't know of it at all". Regarding the occupation (Q6), we asked whether the participants had a medical (doctor, nurse and clinical technologist) or non-medical job.

Next, after we showed a one-minute demo video regarding the automated robotic abdominal US system that was developed in a previous study [26] (see Figure 1), the participants were asked several questions as shown in Table 2. Note that Supplemental Video S1 shows the demo with our robotic abdominal US system. The robotic US system performed a fully automated scan along the subcostal boundary, sequentially visualizing the liver, gallbladder, and kidney. The scanning path tailored to individual body shapes was estimated using an RGB-D camera. During the scanning, the contact force between the probe and body surface was maintained safely. The probe pose was automatically adjusted based on the quality of the visualized images. Also, in the demo, only a patient is in the room, with no medical staff nearby. First, the participants were asked questions regarding their willingness to undergo the robotic US examination (Q7). The willingness was rated on a six-point scale in order to elicit a clear and definitive assessment of the willingness. Participants who answered that they wanted to use the examination were asked to select the reasons why they wanted to use it in terms of accuracy, time, cost, and interpersonal anxiety (Q8). The "accuracy" is that the examination can be performed more accurately than people do. The "time" is that the examination can be done faster than by people and the waiting time is shorter. The "cost" is that the cost of the examination may be less than if people perform it. The "interpersonal anxiety" is that there are fewer opportunities for people to see or touch the patient's body. Participants who answered that they did not want to use it were asked to select the reasons why they did not want to use it (Q9). We also asked about the reasons for this in terms of accuracy, time, cost, object anxiety and vague anxiety. The meanings of "accuracy", "time" and "cost" are the same as in Q8. The "object anxiety" is a fear of danger due to malfunction, etc. The "vague anxiety" refers to a somewhat anxious feeling. After that, the participants were asked questions regarding their willingness to undergo a robotic US examination for the scanning areas in the abdomen, neck, fetus and breast, respectively (Q10). Only female participants were asked about willingness regarding fetus and breast examinations. The willingness was rated on a seven-point scale to allow participants to express neutrality/ambivalence toward individual areas without forcing direction.

Finally, we asked what safety measures would make them feel safer during the robotic US examination (Q11). Seven options were presented in terms of the risk assessment and measures, operation of equipment, emergency measures, training of the operator, information, and appropriate allocation of staff. The option "risk assessment and measures" is to identify what risks are present in advance and take proper measures. The option "operation of equipment" shows the examination is properly checked by the person in

charge, such as whether the case is unsuitable for examination by robot or not. The option "emergency measures" is to prepare a button to stop the robot movement in case of emergency. The option "training of operators" means ensuring that operators have sufficient knowledge. The option "information" is to explain the examination performed by the robot and the safety measures taken. The option "appropriate allocation of staff" refers to the appropriate staffing to operate and control the robot. The option "other" is the option for cases that do not fit the above.

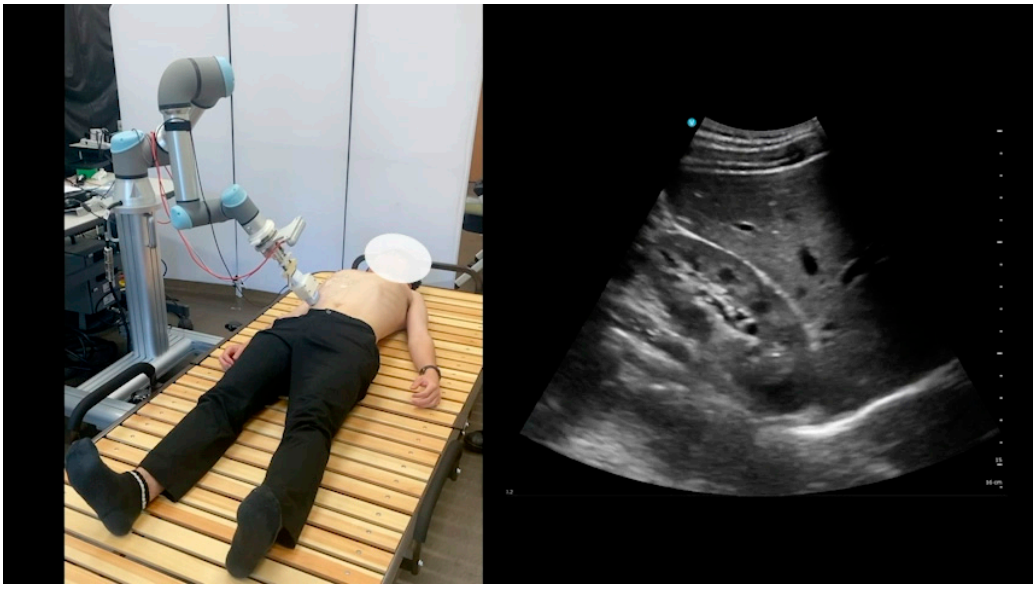


Figure 1. Automated robotic abdominal ultrasound system used for the survey.

Table 1. Question list regarding patients' profiles.

No.	Questions	Answers
Q1	What is your gender	Male Female No answer
Q2	What is your age	18–79
Q3	Has the disease been found or has there been a finding that follow-up is required?	Disease found and treated In follow-up Nothing found
Q4	Do you feel that you or your family members have recently experienced difficulty in accessing medical checkups, daily medical examinations, etc. at nearby medical facilities?	Not at all Rarely Somewhat Often
Q5	Are you aware of any examples of the use of robots in medical or nursing care field (e.g., communication robot, surgical robot)?	I am using or have used it I have never used but know it I have never used and don't know it
Q6	What is your occupation	Doctor Nurse Medical technologist None of the above

Table 2. Question list regarding willingness to use robotic US.

No.	Questions	Answers
Q7	Would you be willing to use a medical facility that offers this type of robotic ultrasound?	6: Very much want 5: Want 4: Somewhat want 3: Prefer not if possible 2: Don't want 1: Absolutely don't want
Q8	Select the reasons that apply to why you want to use [MA]	(Accuracy) Because I think it can be done more accurately than a person can do it. (Time) Because the examination can be done faster than by a person and the waiting time is shorter. (Cost) Because the cost of the examination may be less than if a person was to perform it. (Interpersonal anxiety) Because there are fewer opportunities for people to see or touch my body. (Other)
Q9	Select the reasons that apply to why you don't want to use [MA]	(Accuracy) Because it's more accurate if a person does it. (Time) Because it may take longer than a person would do it and the waiting time would be longer. (Cost) Because the cost of the examination may be higher than if it were done by a person. (Object anxiety) Because there is a fear of danger due to malfunction, etc. (Vague anxiety) Because I feel somewhat anxious. (Other)
Q10	Would you be willing to use the examination for each examination area (abdomen/neck/fetus/breast)	7: Very much want 6: Want 5: Somewhat want 4: It depends 3: Prefer not if possible 2: Don't want 1: Absolutely don't want
Q11	What safety measures would make you feel safer during the robotic ultrasound examination? Please select up to three that you think are particularly important [MA]	(Risk assessment and measure) Identification of what risks exist in advance and take proper measures. (Operation of equipment) Confirmation by the person in charge before the examination as to whether the case is unsuitable for the robotic examination. (Emergency measure) Button to stop robot movement in case of emergency. (Training of operator) Operator such as sonographer must have sufficient knowledge. (Information) Explanation of the examination performed by the robot and safety measures taken. (Appropriate allocation of staffs) Appropriate staffing to operate and control the robot (Other)

2.2. Data Collection

We performed a web questionnaire survey with a survey company that has a questionnaire system and a large-scale respondent database. The study subjects were Japanese males and females aged 18 to 79 years who had undergone at least three US examinations of the abdomen or neck. The number of responses obtained was 360 patients with at least three previous abdominal examinations and 120 patients with at least three previous neck examinations. The reason for separating those with abdominal and neck US experiences is that the scanning areas are markedly different, and we assumed that this would change their impression of the examination. The study period was from 20 December 2024 to 23 De-

cember 2024. This survey was conducted with the approval of the Ethics Review Committee of the National Institute of Advanced Industrial Science and Technology (No. 2024-577).

3. Results

3.1. Profiles of Survey Participants

The results of the profiles of participants are shown in Table 3. First, we focus on the profile of participants who underwent abdominal US (see Figure 2). The number of participants by gender was 208 males (57.8%) and 150 females (41.7%), and 2 did not respond (0.6%), indicating a slightly higher percentage of male participants (see Figure 2a). Regarding the age of participants, about half of the participants were between 60 and 79 years old, with 16.1% between 60 and 65 years old and 14.7% between 65 and 70 years old (see Figure 2b). Meanwhile, 36.4% of the participants were also from the working age group between 40 and 60 years old and 12.2% were from the younger age group between 18 and 40 years old. The medical history showed that approximately 40% of the respondents were treated or followed up based on some disease or lesion by abdominal US (see Figure 2c). Regarding the accessibility of medical facilities, most of the participants were in a situation where they were more likely to seek medical facilities (see Figure 2d); 55.8% of all participants had no experience or knowledge of the use of robots in medical and nursing care fields (see Figure 2e).

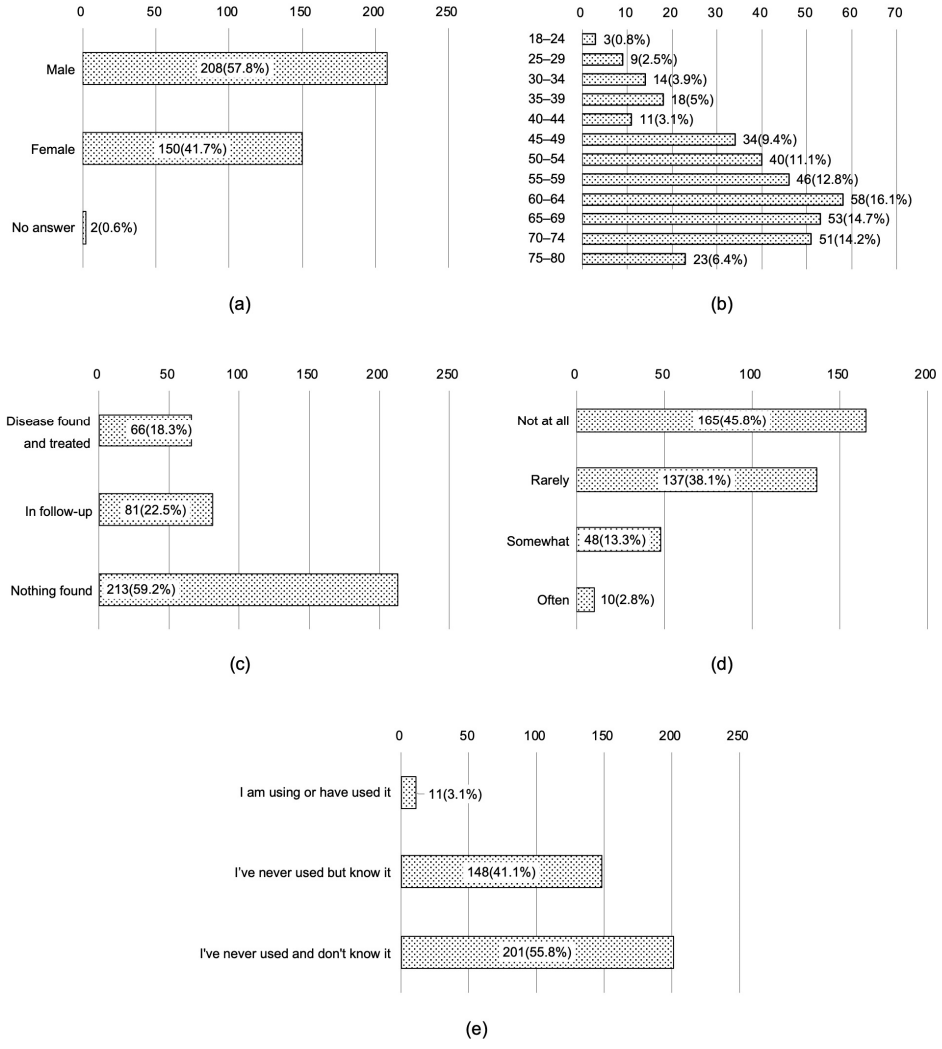


Figure 2. Profiles of patients with abdominal US experiences: (**a**) gender, (**b**) age, (**c**) medical record, (**d**) accessibility of medical facility, and (**e**) knowledge and experience of the use of robots.

Next, we focus on the profile of participants who underwent neck US (see Figure 3). The ratio of male to female was almost equal, with 63 males (52.5%) and 57 females (47.5%) (see Figure 3a). In total, 14.2% of participants were between 60 and 65 years old, and 6.7% were between 65 and 70 years old (see Figure 3b). In total, 40% of participants were between 60 and 79 years old, but 36.7% also came from the working age group between 40 and 60 years old and 23.3% from the younger group between 18 and 40 years old. The medical history showed that the majority of participants were treated or followed up based on some disease or lesion by neck US (see Figure 3c). Regarding the accessibility of medical facilities, most of the participants were in the situation where they were more likely to seek medical facilities (see Figure 3d). While 45.8% of all participants indicated that they had never used but knew about the use of robots in medical and nursing care fields, 39.2% had neither experience nor knowledge of the use of robots (see Figure 3e).

Regarding the occupation (see Figure 4), some participants were doctors (3.5%), nurses (5%), and clinical technologists (0.6%), but most were in non-medical occupations (90.8%).

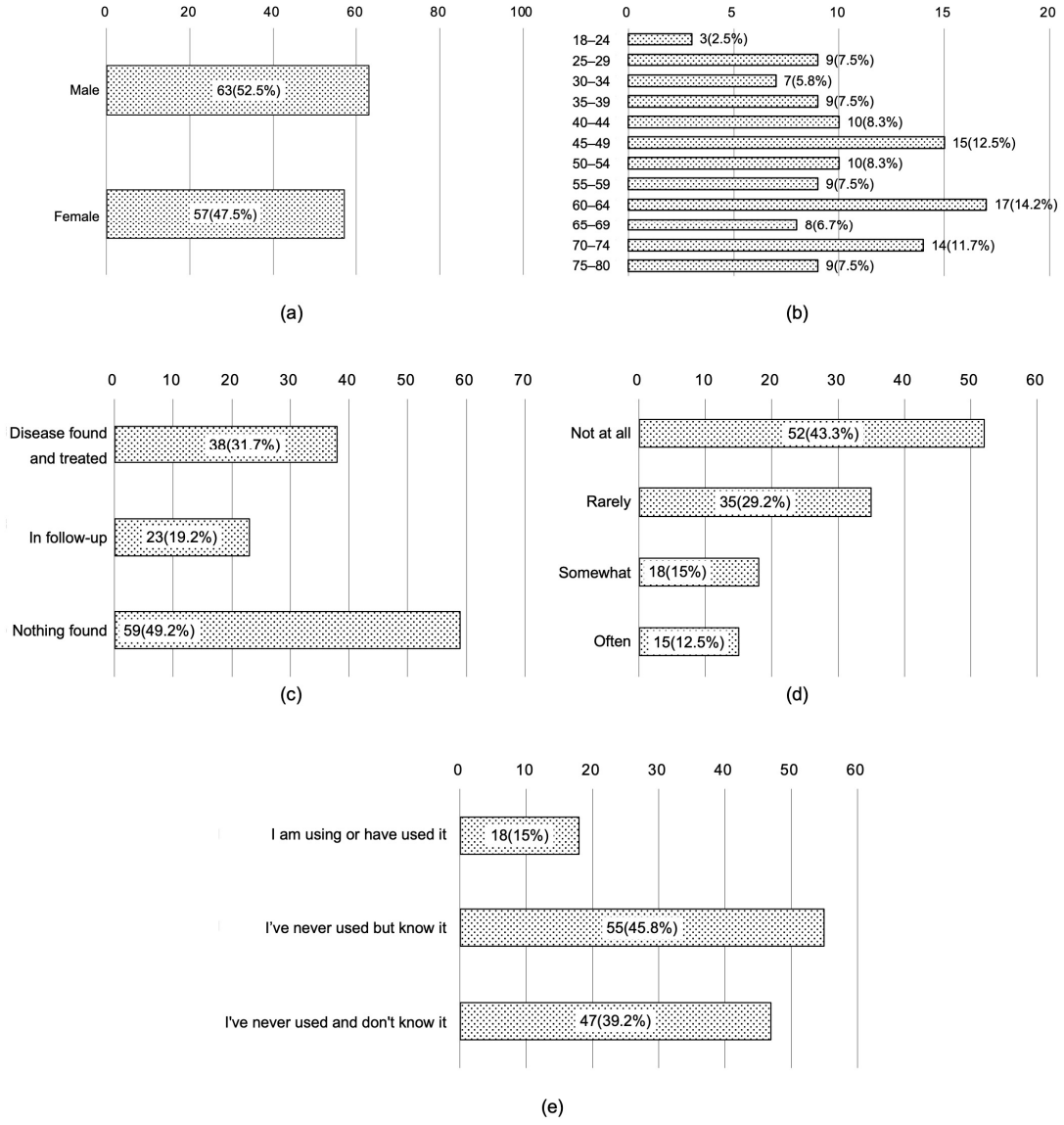


Figure 3. Profiles of patients with neck US experiences: (**a**) gender, (**b**) age, (**c**) medical record, (**d**) accessibility of medical facility, and (**e**) knowledge and experience of the use of robots.

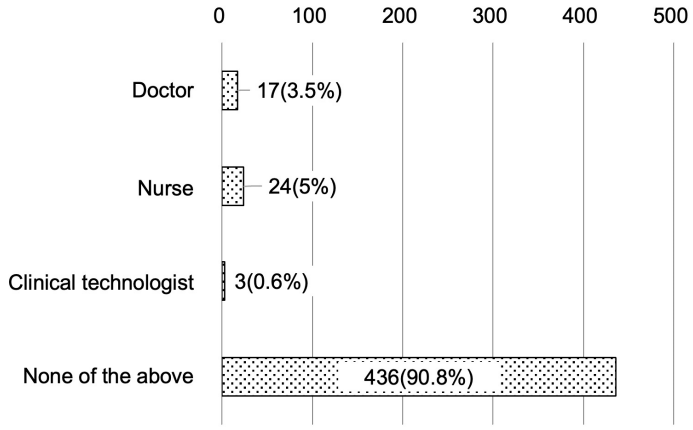


Figure 4. Occupations of patients.

Table 3. Results for patients' profiles.

	Options	Counts	%
Q1	Male	271	56.5
	Female	207	43.1
	No answer	2	0.4
Q2	Average	56.49	unit: years old
	Min	20.00	
	Max	78.00	
Q3	Disease found and treated	104	21.7
	In follow-up	104	21.7
	Nothing found	272	56.7
Q4	Not at all	217	45.2
	Rarely	172	35.8
	Somewhat	66	13.8
	Often	25	5.2
Q5	I am using or have used it	29	6.0
	I have never used but know it	203	42.3
	I have never used and don't know it	248	51.7
Q6	Doctor	17	3.5
	Nurse	24	5.0
	Clinical technologist	3	0.6
	None of the above	436	90.8

3.2. Willingness to Undergo Robotic Ultrasound Examination

The results of the willingness to undergo robotic US examination are summarized in Table 4 and Figures 5 and 6. The scored willingness was analyzed from the participants' profiles. The statistical analysis was performed with the Mann–Whitney U test. The participants who had experienced abdominal US gave a 6-point rating of 3.58 for their willingness to undergo the robotic US examination, above the mean of 3.50 (see Figure 5). The participants who had experienced neck US were also at 3.73, 0.15 points higher than the participants with abdominal US experience, but there was no statistical difference ($p = 0.351$). By gender (see Figure 6a), the male participants were 0.2 points more likely to willing to use the robotic US ($p = 0.048$). By age (see Figure 6b), the willingness to use the robotic US was 3.86, about 0.3 points higher among younger participants aged "18 to 40," and higher than among participants older than the young age group ($p = 0.032$). The participants who had previously found a disease or lesion that required medical treatment were more likely to be willing to undergo the robotic US examination, especially those who had found a disease

or lesion that required medical treatment, while those who had never found such a disease or lesion were less likely to be willing to undergo the robotic US (see Figure 6c). There was a significant difference between the participants who required medical treatment and who had never found the disease ($p = 0.000$). Participants who considered the sufficiency of medical facilities to be low tended to have higher willingness to use it (see Figure 6d). The participants who had experience with the use of a nursing or medical robot showed a very high willingness to use it and scored 5.07 (see Figure 6e). There was a significant difference between experienced participants and inexperienced participants ($p = 0.000$). By occupation, although the population was small, the doctors had very high willingness at 4.35, while the three clinical technologists all indicated that they would not want to use it if they could (see Figure 6f). There was no statistically significant difference between medical professionals (doctors, nurses, and clinical technologists combined) and non-medical respondents ($p = 0.063$), although medical professionals tended to show slightly higher acceptance.

The selected reasons for willingness to use the robotic US examination were analyzed based on the participants' profiles as shown in Table 5. Those with abdominal US experience were more likely to say it was because it may take less time (59.3%) and may be less expensive (38.2%) to perform the examination. Those with neck US experience, likewise, were more likely to say that it may take less time (52.2%), followed by saying that it is more accurate than a person performing it (47.8%), a trend not dissimilar to that in abdominal US. By gender, fewer male participants selected "Because there are fewer opportunities for people to see or touch my body" (14.0%) than female participants, while fewer female participants chose "because the cost of the examination may be less than if a person were to perform it" (21.6%). By age, a slightly higher percentage of younger participants in the "18–40" age group selected "because there are fewer opportunities for people to see or touch my body". By occupation, although the population was small, doctors were the most likely to respond, "because the examination can be done faster than by a person" (92.9%). Another unique feature of the survey was that doctors gave a high rating for accuracy. A higher percentage of the participants who had US examination and found a disease or lesion requiring follow-up care selected "because the cost of the examination may be less than if a person were to perform it" than the others. In addition, among those who had a disease or lesion that required medical treatment, the proportion of "because there are fewer opportunities for people to see or touch my body" was about 10 points higher than that of the other participants. The participants who indicated that they had difficulty accessing medical facilities, although the sample size was small, were more likely to answer, "because the cost of the examination may be less than if a person were to perform it." In the group that had experience using robots, many participants answered, "because I think it's more accurate if a person does it".

The selected reasons for not wanting to use the robotic US examination were analyzed based on the participants' profiles as shown in Table 6. Many participants did not want to use it "because I feel somewhat anxious" (45.3%), followed by "because there is a fear of danger due to malfunction, etc." (36.0%). Regarding those with abdominal US experience, a large proportion of the group answered, "because it is more accurate if it is done by a person". No significant differences in the trends were observed between male and female. By age group, a higher percentage of younger participants (18–40 years old) chose "because the cost of the examination may be higher than if it were done by a person." By occupation, although the population was small, nurses and clinical technologists were more likely to answer, "because the cost of the examination may be higher than if it were done by a person". Among the participants whose US examinations led to the finding of diseases or lesions requiring follow-up care, a high percentage answered, "because there is a fear of

danger due to malfunction, etc.". In addition, a higher percentage of the participants who found a disease or lesion that required medical treatment answered, "because I think it's more accurate if a person does it" and "because I feel somewhat anxious". Although the sample size was small, a higher percentage of participants who had difficulty accessing medical facilities were more likely to respond, "because I feel somewhat anxious".

The analysis of trends in willingness to use robotic US by each examination area showed that the participants were willing to undergo the examination for the abdomen and carotid artery, while they were less willing to undergo the examination for the fetus and breast. For the fetus, the result was 3.86, below the average of 4, and the willingness was particularly low.

The results of the safety measures are shown in Table 7. Emergency measures (54.4%) and risk assessment and measures (46.7%) were the most common answers. Providing information was given relatively low priority (19.2%). There were no significant differences by gender of participants. The emergency measures were rated higher for those aged 60 to 79, and risk assessment was rated higher for those aged 18 to 40. By occupation, the risk assessment was rated highly by doctors, the emergency measures by nurses, and the training for operators by clinical technologists. On the other hand, non-medical professionals rated the risk assessment, the equipment operation, and the emergency preparedness highly. The participants who had never had a lesion or disease found by US examination were more likely than those who had a lesion or disease undergoing treatment or follow-up to emphasize emergency measures. The participants with relatively low sufficiency of surrounding medical facilities were more likely to request adequate staffing in addition to the items emphasized by other respondents, such as risk assessment. Participants who had experience using the robot pointed out, in particular, the importance of emergency measures. Many participants who had no experience using the robot wanted the equipment to be operated properly.

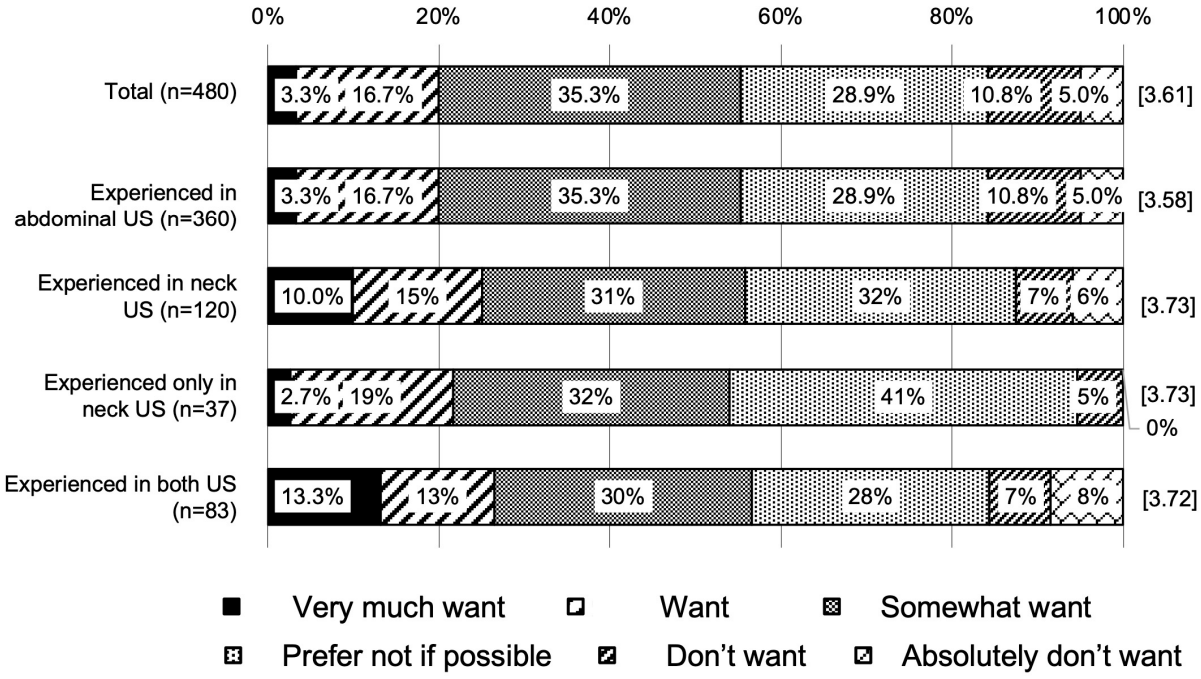


Figure 5. The willingness to use the medical facility that performs the robotic US examination by abdominal and neck US experiences.

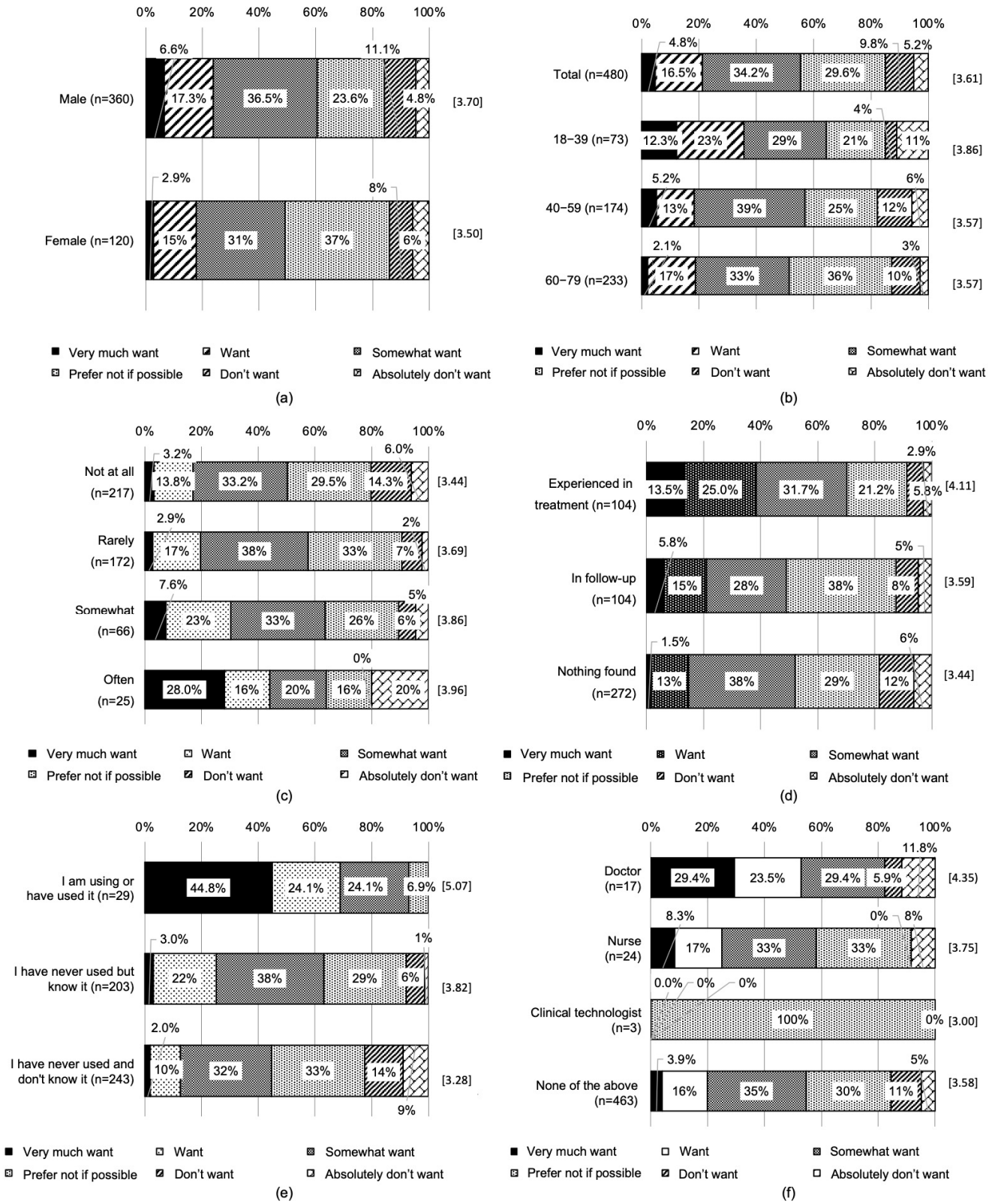


Figure 6. The willingness to use the medical facility that performs the robotic US examination by (**a**) gender, (**b**) age, (**c**) medical record, (**d**) accessibility of medical facility, (**e**) knowledge and experience of the use of robots and (**f**) occupation.

Table 4. Results of willingness to use robotic ultrasound.

	Options	Counts	%
Q7	6: Very much want	24	5.0
	5: Want	78	16.3
	4: Somewhat want	164	34.2
	3: Prefer not if possible	142	29.6
	2: Don't want	47	9.8
	1: Absolutely don't want	25	5.2
Q8	(Accuracy) Because I think it can be done more accurately than a person can do it.	101	38.0
	(Time) Because the examination can be done faster than by a person and the waiting time is shorter.	153	57.5
	(Cost) Because the cost of the examination may be less than if a person were to perform it.	105	39.5
	(Interpersonal anxiety) Because there are fewer opportunities for people to see or touch my body.	55	20.7
	(Other)	4	1.5
Q9	(Accuracy) Because it's more accurate if a person does it.	66	30.8
	(Time) Because it may take longer than a person would do it and the waiting time would be longer.	21	9.8
	(Cost) Because the cost of the examination may be higher than if it were done by a person.	41	19.2
	(Object anxiety) Because there is a fear of danger due to malfunction, etc.	77	36.0
	(Vague anxiety) Because I feel somewhat anxious.	97	45.3
	(Other)	9	4.2
Q10	Abdomen	104	21.7
	7: Very much want	51	10.6
	6: Want	98	20.4
	5: Somewhat want	121	25.2
	4: It depends	75	15.6
	3: Prefer not if possible	81	16.9
	2: Don't want	37	7.7
	1: Absolutely don't want	17	3.5
	Neck		
	7: Very much want	44	9.2
	6: Want	92	19.2
	5: Somewhat want	104	21.7
	4: It depends	100	20.8
	3: Prefer not if possible	80	16.7
	2: Don't want	40	8.3
	1: Absolutely don't want	20	4.2
	Fetus		
	7: Very much want	24	5.0
	6: Want	61	12.7
	5: Somewhat want	79	16.5
	4: It depends	133	27.7
	3: Prefer not if possible	82	17.1
	2: Don't want	57	11.9
	1: Absolutely don't want	44	9.2
	Breast		
	7: Very much want	26	5.4
	6: Want	62	12.9
	5: Somewhat want	78	16.3
	4: It depends	134	27.9
	3: Prefer not if possible	84	17.5
	2: Don't want	59	12.3
	1: Absolutely don't want	37	7.7

Table 4. *Cont.*

	Options	Counts	%
Q11	(Risk assessment and measure) Identification of what risks exist in advance and take proper measures.	224	46.7
	(Operation of equipment) Confirmation by the person in charge before the examination as to whether the case is unsuitable for the robotic examination.	194	40.4
	(Emergency measure) Button to stop robot movement in case of emergency.	261	54.4
	(Training of operator) Operator such as sonographer must have sufficient knowledge.	196	40.8
	(Information) Explanation of the examination performed by the robot and safety measures taken.	92	19.2
	(Appropriate allocation of staffs) Appropriate staffing to operate and control the robot	119	24.8
	(Other)	6	1.3

Table 5. Analysis of reasons for wanting to use robotic ultrasound.

	Accuracy	Time	Cost	Interpersonal Anxiety	Other
Total (n = 266)	38.0	57.5	39.5	20.7	1.9
Experience					
Abdomen (n = 199)	34.7	59.3	38.2	17.1	1.5
Neck (n = 67)	47.8	52.2	43.3	31.3	1.5
Gender					
Male (n = 164)	41.5	57.9	50.6	14.0	1.8
Female (n = 102)	32.4	56.9	21.6	31.4	1.0
Age					
18–39 (n = 47)	38.3	63.8	38.3	36.2	2.1
40–59 (n = 99)	28.3	52.5	43.4	19.2	3.0
60–79 (n = 120)	45.8	59.2	36.7	15.8	0.8
Occupation					
Doctor (n = 14)	64.3	92.9	64.3	35.7	0.0
Nurse (n = 14)	28.6	50.0	50.0	14.3	0.0
Technologist (n = 0)	0.0	0.0	0.0	0.0	0.0
None of the above (n = 238)	37.0	55.9	37.4	20.2	1.7
Medical record					
Disease found and treated (n = 73)	43.8	57.5	34.2	30.1	1.4
In follow-up (n = 51)	37.3	60.8	47.1	19.6	0.0
Nothing was found (n = 142)	35.2	56.3	39.4	16.2	2.1
Sufficiency of medical institution					
Not at all (n = 109)	38.5	56.0	33.9	16.5	1.8
Rarely (n = 99)	32.3	52.5	40.4	16.2	2.0
Somewhat (n = 42)	42.9	66.7	42.9	26.2	0.0
Often (n = 18)	56.3	75.0	62.5	62.5	0.0
Experience and knowledge of robot					
I am using or have used it (n = 27)	74.1	66.7	51.9	25.9	0.0
I have never used it but know it (n = 128)	39.1	53.9	39.1	23.4	1.6
I have never used it and do not know it (n = 111)	27.9	59.5	36.9	16.2	1.8

Table 6. Analysis of reasons for not wanting to use robotic ultrasound.

	Accuracy	Time	Cost	Object Anxiety	Vague Anxiety	Other
Total (n = 214)	30.8	9.8	19.2	36.0	45.3	4.2
Experience						
Abdomen (n = 161)	32.3	9.3	18.0	37.9	44.7	3.1
Neck (n = 53)	26.4	11.3	22.6	30.2	47.2	7.5
Gender						
Male (n = 107)	33.6	9.3	18.7	37.4	43.9	5.6
Female (n = 105)	28.6	9.5	20.0	35.2	46.7	2.9
Age						
18–39 (n = 26)	26.9	11.5	34.6	26.9	46.2	0.0
40–59 (n = 75)	30.7	12.0	18.7	25.3	46.7	5.3
60–79 (n = 113)	31.9	8.0	15.9	45.1	44.2	4.4
Occupation						
Doctor (n = 3)	33.3	33.3	33.3	33.3	100.0	0.0
Nurse (n = 10)	0.0	0.0	50.0	30.0	40.0	0.0
Technologist (n = 3)	0.0	0.0	66.7	0.0	33.3	0.0
None of the above (n = 198)	32.8	10.1	16.7	36.9	44.9	4.5
Medical record						
Disease found and treated (n = 73)	38.7	9.7	16.1	29.0	54.8	3.2
In follow-up (n = 51)	32.1	15.1	26.4	45.3	32.1	1.9
Nothing was found (n = 142)	28.5	7.7	16.9	33.8	48.5	5.4
Sufficiency of medical institution						
Not at all (n = 108)	31.5	9.3	13.9	37.0	39.8	3.7
Rarely (n = 73)	30.1	9.6	26.0	38.4	43.8	4.1
Somewhat (n = 24)	33.3	12.5	20.8	20.8	62.5	0.0
Often (n = 9)	22.2	11.1	22.2	44.4	77.8	22.2
Experience and knowledge of robot						
I am using or have used it (n = 2)	50.0	0.0	0.0	0.0	0.0	50.0
I have never used it but know it (n = 75)	33.3	10.7	26.7	33.3	40.0	6.7
I have never used it and do not know it (n = 137)	29.2	9.5	15.3	38.0	48.9	2.2

Table 7. Analysis of safety measures by patients' profile.

	Risk Assessment and Measures	Operation of Equipment	Emergency Measures	Training of Operator	Information	Appropriate Allocation of Staff	Other
Total (n = 480)	46.7	40.4	54.4	40.8	19.2	24.8	1.3
Experience							
Abdomen (n = 360)	47.8	41.1	55.8	41.9	17.8	24.7	1.1
Neck (n = 120)	43.3	38.3	50.0	37.5	23.3	25.0	1.7
Gender							
Male (n = 271)	45.8	39.5	55.7	39.1	19.6	24.4	1.5
Female (n = 207)	48.3	41.5	52.7	43.5	18.4	25.6	1.0
Age							
18–39 (n = 73)	52.1	45.2	45.2	39.7	20.5	20.5	1.4
40–59 (n = 174)	43.7	37.4	45.4	35.6	22.4	22.4	1.1
60–79 (n = 233)	47.2	41.2	63.5	45.5	15.9	27.9	1.7
Occupation							
Doctor (n = 17)	50.0	33.3	16.7	16.7	0.0	33.3	0.0
Nurse (n = 24)	44.4	38.9	61.1	33.3	16.7	22.2	0.0
Technologist (n = 3)	42.9	33.3	33.3	52.4	33.3	23.8	0.0
None of the above (n = 436)	63.0	63.0	51.9	37.0	18.5	14.8	0.0

Table 7. *Cont.*

	Risk Assessment and Measures	Operation of Equipment	Emergency Measures	Training of Operator	Information	Appropriate Allocation of Staff	Other
Medical record							
Disease found and treated (n = 104)	38.1	47.6	28.6	42.9	9.5	19.0	0.0
In follow-up (n = 104)	36.7	36.7	42.9	26.5	24.5	24.5	2.0
Nothing was found (n = 272)	44.0	38.0	54.0	40.0	26.0	24.0	0.0
Sufficiency of medical institution							
Not at all (n = 217)	52.7	32.7	47.3	36.4	23.6	20.0	1.8
Rarely (n = 172)	46.7	40.0	60.0	45.3	17.3	24.0	1.3
Somewhat (n = 68)	36.1	41.0	65.6	44.3	13.1	31.1	3.3
Often (n = 25)	56.9	41.5	55.4	44.6	13.8	33.8	1.5
Experience and knowledge of robot							
I am using or have used it (n = 29)	50.0	43.8	84.4	50.0	21.9	18.8	0.0
I have never used it but know it (n = 203)	47.1	47.1	52.9	23.5	23.5	17.6	0.0
I have never used it and do not know it (n = 248)	33.3	50.0	37.5	20.8	25.0	8.3	0.0

4. Discussion

The 480 participants with at least three previous abdominal and neck US examinations were asked about their willingness to use the medical facility that offers robotic US examinations shown in the demo video, scoring 3.61 out of 6, slightly above the average of 3.5. Those who had experience with neck US were slightly more willing to use it than those who had experience with abdominal US. As for the reasons for wanting to undergo the robotic examination, many pointed to "(Time) because the examination can be done faster than by a person and the waiting time is shorter" and "(Cost) because the cost of the examination may be less than if a person were to perform it". The most common reason for not wanting to use it was "(Vague anxiety) because I feel somehow anxious," followed by "(Object anxiety) because there is a fear of danger due to malfunction, etc." These negative reasons were relatively low among participants who had found lesions or diseases in previous US examinations and among those who already had experience using robots in medical and nursing care fields. This suggests that increased knowledge and experience of ultrasonography and robots is necessary to increase the willingness to use robots. Regarding the "Vague anxiety", further investigation is needed to determine whether this anxiety stems from distrust of automation or from general concerns about medical safety. This can be inferred from multiple perspectives, including the opacity of robot control, motion legibility near the body, the weaker connection with humans, and the ambiguity of accountability. Although the sample size of clinical technologists is really small, their impression of the robotic US was negative. There may be several potential reasons derived from their expertise. They understand that the procedure of the US scan is difficult and may be negative toward the robotic automation. In addition, there may be some concern that robots might take their jobs. Meanwhile, this sample size is too small to make generalized conclusions. An acceptability assessment for clinical technologists needs to be conducted in the future. On the other hand, participants hoped to use the robot primarily to save "time" and "costs". However, many of the robots currently being proposed may take longer than humans do. This is because there are limitations on operating speed from the perspective of patient safety, and it may be necessary to determine an acceptable operating speed. Since such robots have not yet been commercialized, it is

difficult to discuss costs at this stage. Nevertheless, it is expected that introducing these robots will significantly reduce clinical laboratory technician labor costs and substantially increase the number of tests performed per day.

As safety measures necessary for the use of medical robots, many participants mentioned "(Emergency measures) button to stop robot movement in case of emergency", as well as "(Risk assessment and measures) identification of what risks exist in advance and taking proper measures." This indicates that many participants thought it was important to take appropriate actions in case of an emergency and to conduct risk assessments to enable such actions. Although most robots have an emergency stop button, who should have the emergency stop button in the autonomous medical robot needs further consideration. Automatic detection of overloads and abnormal contact may also be essential. Standards for collaborative robots (e.g., ISO/TS 15066:2016 [27]) and risk management of medical devices (e.g., ISO 14971:2019 [28]) may be helpful. For example, we should adopt a layered stop hierarchy to balance patient safety, device protection, and workflow continuity: (1) soft pause (non-safety)—a software "hold" for workflow control (not a safety function). (2) Monitored standstill—a safety-rated stop with drives energized while standstill is monitored. This enables rapid, supervised resumption once hazards are cleared and is well-suited to contact procedures. (3) Emergency stop, Category 1—controlled deceleration to a stop, then power removal. In patient contact, Cat. 1 is generally preferred because it permits a brief, controlled retraction to a safe pose before de-energizing, helping avoid secondary harm (e.g., pinching or residual load). (4) Emergency stop, Category 0—immediate power removal (uncontrolled stop). Reserved for conditions where instantaneous de-energization is paramount (e.g., electrical/fire hazards). Standards emphasize that an E-stop must override all other functions, stop hazardous motion as quickly as practicable without creating other hazards, and not restart on reset—criteria that guide the Cat. 0 vs. Cat. 1 choice.

In order to address the concerns of patients when US examinations are performed by robots in the future, it is first necessary to make sure that they understand US examinations and the medical services provided by robots. In particular, since the results for the doctors have been very positive for robotic US, one useful approach is to increase the experience of doctors and other healthcare professionals with the use of robotic US by making them fully aware of its safety and usefulness. It is also necessary to implement appropriate safety measures based on risk assessment. Furthermore, in order to increase the acceptance of robotic US, it may be useful to demonstrate that appropriately timed US examination leads to early detection of lesions and diseases, while promoting that (1) there is no waiting time, (2) the cost is low, and (3) a certain level of accuracy is guaranteed.

A limitation of this study is that it investigates the acceptability for only Japanese patients. Because Japan is a small country, many of its citizens have relatively easy access to medical facilities compared to countries with large land areas such as the United States and China. Therefore, Japanese people may not recognize the need for robotic telemedicine yet. In fact, in the profile survey of the participants, fewer participants complained about accessibility to medical facilities. Different results might be obtained if the same questionnaire surveys were conducted in areas with fewer medical resources. Additionally, this study focused on the patient acceptability of the automated robotic US system, but the acceptability of other stakeholders such as doctors, nurses and clinical technologists needs to be further evaluated.

Another limitation is that this survey was web-based. Unlike face-to-face or phone surveys, respondents cannot ask for clarification if a question is unclear. Misinterpretation of questions may lead to inaccurate responses. Some respondents may provide random or dishonest answers to finish quickly. The impression of the robot is also expected to be different between the demo video and the actual system. In this study, the video of the

robot's movements presented was only one pattern seen from an overhead view. Providing various scenarios such as successful cases and potential failure cases may standardize participants' impressions and help avoid bias. Presenting the patient's field of view during the actual examination using a glasses-type camera, etc., may provide a more realistic view. Ideally, patients should undergo the actual robotic US examination, and their acceptance should be assessed.

5. Conclusions

This study explored the patient's acceptability of the automated robotic US with the web-based questionnaire survey. The 480 participants with at least three previous abdominal and neck US examinations were asked about their willingness to use the medical facility that offers robotic US examinations. The results showed that the score was 3.61 out of 6, slightly above the average of 3.5. As to the reasons for wanting to undergo the robotic examination, many participants pointed to "time" and "cost". The most common reason for not wanting to use it was "vague anxiety" that patients feel somewhat anxious and "object anxiety" such as a fear of danger due to malfunction. These negative reasons were relatively low among participants who had found lesions or diseases in previous US examinations and among those who already had experience using robots in medical and nursing care fields. This suggests that increased knowledge and experience of ultrasonography and robots are necessary for patients to increase their willingness to use robots. Our research will contribute to the available knowledge on developing autonomous robotic ultrasound. Furthermore, the study provides stakeholders with some insights that could benefit the future rollout and adoption of medical robots.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/robotics15020037/s1, Video S1: Demonstration of the automated abdominal robotic ultrasound.

Author Contributions: Conceptualization, R.T. and K.Y.; methodology, R.T.; software, R.T.; validation, R.T.; formal analysis, R.T.; investigation, R.T. and K.Y.; resources, R.T. and K.Y.; writing, R.T.; supervision, K.Y.; funding acquisition, R.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research is supported in part by JST FOREST Program under Grant JPMJFR215A.

Institutional Review Board Statement: This survey was conducted with the approval of the Ethics Review Committee of the National Institute of Advanced Industrial Science and Technology (No. 2024-577).

Data Availability Statement: The data set used in this study is available from the corresponding author upon reasonable request.

Acknowledgments: During the preparation of this manuscript/study, the authors used ChatGPT 5.2 for the purposes of refining the text. The authors have reviewed and edited the output and take full responsibility for the content of this publication.

Conflicts of Interest: The authors declare no conflicts of interest.

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