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● *Original Contribution*

TELES-OPERATED ECHOCARDIOGRAPHY USING A ROBOTIC ARM AND AN INTERNET CONNECTION

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Abstract—The objective was to design and validate a method of tele-operated echocardiography. The method was tested in a hospital facility with an expert sonographer located in a room 10 m away from the patient. An ultrasound probe, fixed to a motorized probe holder, was located on the patient by a non-sonographer and was remotely controlled by the expert sonographer via an Internet connection. Scans were performed on 41 cardiac patients. The quality of the cardiac views obtained using tele-echocardiography was lower than that of reference echocardiography, but generated similar measurements in 93%–100% of the cases. Bland–Altman plots and statistical comparison of tele- and reference echocardiography measures revealed no differences ($p > 0.05$). Of the 71 valve leaks or aortic stenoses present, 61 (86%) were detected using tele-echocardiography. These results indicate that tele-echocardiography provided reliable diagnoses and acceptable measurements in 86% and 93% of cases, respectively, with no false-positive diagnoses being reported. (E-mail: arbeille@med.univ-tours.fr) © 2014 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Ultrasound, Echocardiography, Telemedicine, Cardiac, Robotic arm.**

INTRODUCTION

In both hospital and private practice settings, ultrasound is typically the first diagnostic imaging modality used; therefore, there is a need to have access to this technique. Presently, there is a lack of trained sonographers, with many specializing in only one type of imaging (*e.g.*, cardiac, vascular, digestive, obstetrics). The probability that sonographers specialized in all types of imaging are available at all times is exceptionally low, especially in small or remote medical centers. The use of robotic tele-operated ultrasound imaging may provide a solution to this shortage of trained sonographers.

Several methods have been proposed for echographic examinations where the patient is in a remote location or otherwise separated from the trained sonographer. Neonatal echography has been performed by a non-sonographer operator who was directed through verbal instruction by an expert sonographer (Awadallah et al. 2006; Otto et al. 2012; Randolph et al. 1999). In this method, the trained sonographer expert monitored the exam in real time, providing direction to the operator and medical interpretations of the images obtained. A similar procedure, called "remote guidance," was tested in space between the International Space Station and the Ground Space Research Center. The astronauts, minimally trained to work on themselves, were able to obtain apical four-chamber cardiac views (Hamilton et al. 2011).

Using voice remote guidance, the non-sonographer operator requires a long time to find appropriate views and needs to be guided continuously until the image is obtained. In addition, it is difficult for this non-sonographer operator to maintain appropriate views for several minutes while activating various ultrasound functions like color and pulsed wave Doppler. The use of this method requires that the operator be trained in ultrasound function and acquisition of images in the appropriate acoustic windows. Even with training, finding the correct position for certain diagnoses in some patients can depend on the degree of rotation or tilt of the ultrasound probe. Verbal remote guidance does not provide enough input from the expert sonographer to confidently provide initial diagnoses of patients unless the operator has been extensively

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trained. To date, no studies have used this method for echocardiography and the remote diagnosis of cardiac patients.

Tele-echocardiography has been used to send 3-D images of the heart to an expert center for analysis by a trained sonographer (Kratochwil et al. 2000; Masuda et al. 2001). The transfer of the 3-D image allows the trained sonographer to select the appropriate 2-D image for analysis. However, current 3-D/4-D ultrasound systems are rather heavy and expensive and would, therefore, be rarely available in small or isolated medical centers.

To facilitate tele-operated ultrasound, we designed a robotic arm that held an ultrasound probe that was placed on the patient by a non-sonographer operator and tele-operated by a trained sonographer in an expert center located away from the patient (Vieyres et al. 2003). The robotic arm was capable of producing precise rotation and tilt movements of the ultrasound probe, but not translation of this probe on the skin surface. If needed, translation had to be performed manually by the non-sonographer operator with vocal assistance from the expert through video conference communication. This system was validated several years ago for abdominal and fetal echography (Arbeille et al. 2007) and is presently in routine use in three small medical centers located in cities with populations of fewer than 5000 inhabitants.

The absence of tele-operated translation requires the active participation of the non-sonographer operator to move the robotic arm right, left, up and down according to the instruction of the expert. Although translational movements made by the non-sonographer were not accurate, these movements were acceptable for abdominal (gall bladder, portal vein, pancreas, kidney) and fetal (head, abdomen, femur) applications, as the acoustic windows for these scans are quite large. In contrast, the acoustic windows to image the heart (long-axis, short-axis or apical views) are very narrow. For echocardiography, the expert sonographer needs to translate the probe on the patient's skin to accurately locate the middle of the acoustic window. Once the middle is located, the expert then orients the probe (rotation, tilt) to obtain appropriate long-axis, short-axis or apical four-chamber views.

The objective of the current project was to develop a motorized probe holder capable of translation, rotation and tilting movement of the probe as required by the expert sonographer for the successful completion of tele-echocardiography. Similar to previous work with fetal and abdominal echography (Arbeille et al. 2007), only non-sonographers were present with the patient, and the trained sonographer operated the motorized probe holder from a different location. A conventional Internet link was used for video and data transfer between the two sites. It was hypothesized that the motorized probe holder would allow for the visualization and evaluation of the four cardiac chambers, measures of aortic flow velocity and the detection of any mitral, tricuspid or aortic valve leaks or aortic stenosis.

METHODS

The motorized probe holder consisted of two motorized supports and a mechanical arm. The robotic arm (Vieyres et al. 2003) held the ultrasound echo probe and oriented it (tilt, spin and rotation) around the contact point on the skin. The robotic arm was also fixed to a motorized plate, which allowed for translational movements on the patient's skin (Melody, AdEchoTech, Paris, France). The robotic arm and translational plate were affixed to a second mechanical arm that the non-sonographer used to position the probe on the patient (ITD, Munich, Germany) (Fig. 1b).

System design of the motorized probe holder

The robotic arm, which had been designed and tested on abdominal and fetal organs several years earlier (Arbeille et al. 2007; Vieyres et al. 2003), was able to use any commercially available ultrasound probe. The probe was affixed to a flat piece of plastic that could move the probe though tilt ($\pm$40°), rotation ($\pm$180°) and spin ($\pm$180°) motions. For this study, the robotic arm was attached to a motorized plate that rotated ($\pm$180°) and moved the probe $\pm$4 cm from the center point along the selected diameter. This allowed for translational movements over the patient's skin within a circle with a diameter of 8 cm (Fig. 1a, b). The translation movements were controlled by two electric buttons (one to rotate the translational plate, and one for translating along the selected line), whereas the angular orientation of the probe (tilt, rotation and spin) was controlled by a single dummy probe (Fig. 1c) (Vieyres et al. 2003).

The robotic arm and translational plate were fixed to an inclinable mechanical arm (ITD) with 3 df. The mechanical arm was fixed to a stable cart that could be rolled around the bed (partially visible in Fig. 1a). The inclinable arm remained stable after being positioned, even though the total weight of the system attached to it was 8 kg. The pressure applied by the probe on the patient's skin was adjusted by the non-sonographer operator and limited by the arm to 1 kg of force. At any time the inclinable arm could be lifted up manually, which removed the probe holder from the patient.

Procedure for validation of tele-echocardiography

Forty-one patients scheduled for conventional echocardiography were recruited into the study. The patients were included in the order in which they were scheduled

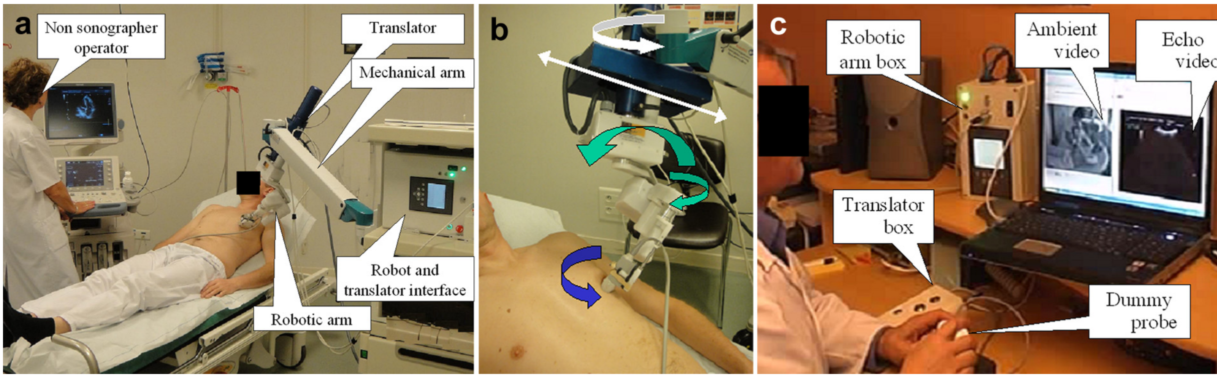

Fig. 1. (a) Patient room with the motorized probe holder on the patient, the ultrasound system and non-sonographer operator. The cardiac probe is attached to the robotic arm (tilt, rotation and spin movements), which is fixed to the translational plate to translate the probe within an 8-cm-diameter circle. This motorized system is fixed to an inclinable mechanical arm (ITD, Munich, Germany). The mechanical arm is fixed to a stable cart that can be moved around the bed on the floor. On the cart, the electronic interface box is connected to the Internet for receiving commands sent by the expert sonographer. (b) Proximal view of the robotic arm and translation platform. The white structure to which the probe is fixed is the robotic arm, which allows for changes in orientation within a 45° cone. The blue part (*top*) is the translator. Translation is operated along the diameter of the disk, which is rotated to select the direction along which the translation will be performed. (c) View of the expert center with the dummy probe for adjusting the orientation of the probe and an electronic box with two push-buttons for translating the probe. Using video, the expert can monitor both the location of the probe and the ultrasound image.

for conventional echocardiography. Patients were not recruited on the basis of morphology or type of cardiac pathology. The patients were informed about the entire protocol and signed an informed consent form. The protocol (for validation) was reviewed and approved by the French Committee for the Protection of Persons in Biomedical Research.

After being recruited into the study, patients underwent two echocardiography scans. The first scan was performed by tele-echocardiography, after which, another expert sonographer from the same department performed a conventional echocardiographic examination, which was used as a reference (reference echocardiography) for evaluation of the tele-echocardiography exam results. The same ultrasound system and probe were used for both the reference and tele-echocardiography examinations. The sonographer for the reference examination was not informed of the results of the tele-echocardiography examination. For both examinations, the patient remained in bed in the same room. To limit the duration of these two examinations for the patient, we decided to restrict the tele-echocardiography to 10 min and to collect the data through apical views only. This time was the duration of the tele-operated examination only; the initial setup of equipment occurred before the examination and cardiac measurements were made from the recorded video after the patient had left. The reference echocardiography examination took approximately 30 min and included measurements of cardiac parameters.

For the tele-echocardiography examination, the patient was in a room with a non-sonographer operator, the ultrasound system and the motorized probe holder. The expert (trained sonographer) was located in a second room 10 m away. The expert was equipped with the controls for the motorized probe holder and a screen to receive video of the patient and ultrasound. The robotic and video systems in the two rooms were connected to the Internet with a data flow rate of 1 Mbit/s. Over this connection, commands were sent to the motorized probe holder and ambient video of the patient (IP camera, 5014, Axis Communication SAS, Antony, France) and video from the ultrasound system connected to a video server (IP video server, 243, Axis Communication SAS) were received at 30 fps (frames per second). The 1 Mbit/s data flow rate was sufficient bandwidth for controlling the motorized probe holder and for receiving the ambient and ultrasound video. The probe holder positioning was monitored by the expert using the real-time ambient view of the patient and probe holder, as well as an audio link with the non-sonographer operator.

The orientation of the inclinable arm and the cart location on the ground were adjusted by the non-sonographer operator to locate the probe head close to the cardiac apical acoustic window (approximately within the 6 × 6-cm area below the left nipple). The 3 df at the extremity of the inclinable arm was used to orient the cardiac probe perpendicular to the thorax. The inclination of the mechanical arm and the positioning of the cart were adjusted to place the probe in contact with the patient. The expert then adjusted the translational positioning of the probe on the acoustic window. As soon as the cardiac beating structures appeared, the expert found

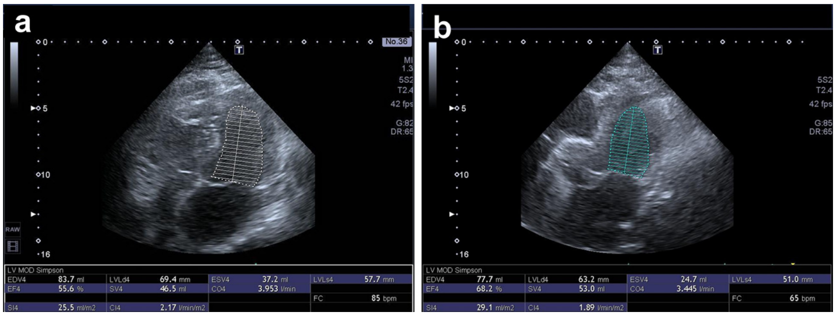

Fig. 2. Apical four-chamber views with left ventricle volume measurements for (a) tele-echocardiography and (b) reference echocardiography.

the right cardiac view needed for measurement and diagnosis by moving the dummy probe (tilt, rotation, and spin) while viewing the ultrasound images received. Settings of the ultrasound system (gain, depth) were adjusted by the non-sonographer at the request of the trained expert and depended on the morphology of the patient.

The same ultrasound system was used for both reference and tele-operated echocardiography (Artida, Toshiba Medical, Amsterdam, The Netherlands), with the phased array probe (3 MHz) being used in both exams.

Evaluation of performance of tele-echocardiography

The primary objective in tele-echocardiography was to perform (in 10 min) apical four/five-chamber views for (i) measuring the left atrium and right atrium in diastole; (ii) measuring the left ventricle in systole and diastole with the calculation of ejection fraction (Fig. 2); (iii) displaying the time motion pattern of the right ventricle; (iv) measuring aortic blood flow velocity by pulsed wave Doppler before and after the sigmoid valves; and (v) detecting, if applicable, mitral, tricuspid or aortic valve leaks or aortic stenosis by color Doppler and quantifying them by pulsed wave Doppler (Figs. 3 and 4) or visualization of valve remodeling. The same views and measurements were performed during reference echocardiography. The reliability of the tele-echocardiography examination was scored though a comparison of the results with those of reference echocardiography.

The image quality of the tele-echocardiogram was qualitatively scored from 1 (very poor) to 5 (excellent) with respect to the reference echocardiogram to quantify the amount of image degradation with tele-echocardiography. A visualization score, expressed as a percentage, was calculated as the number of tele-echocardiograms that were of

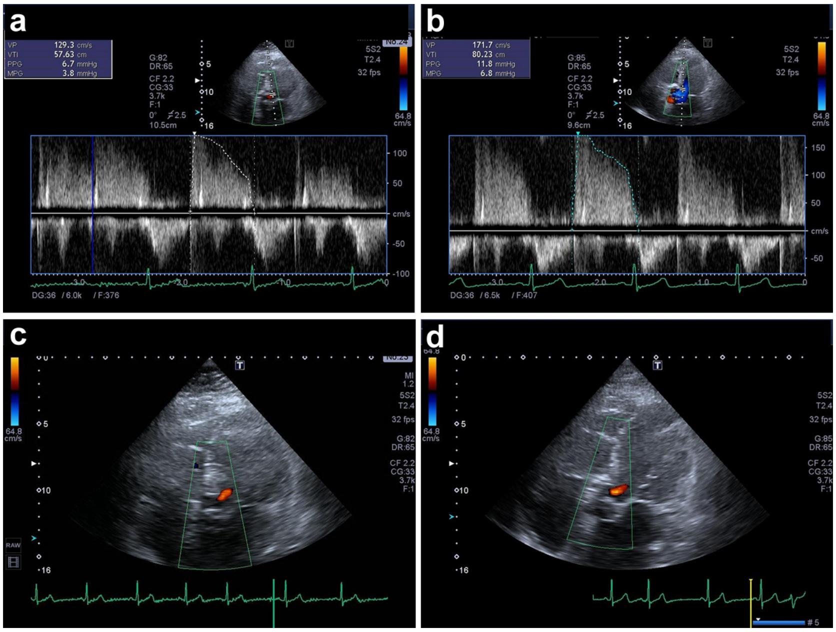

Fig. 3. Aortic regurgitation by (a, c) tele-echocardiography and (b, d) reference echocardiography.

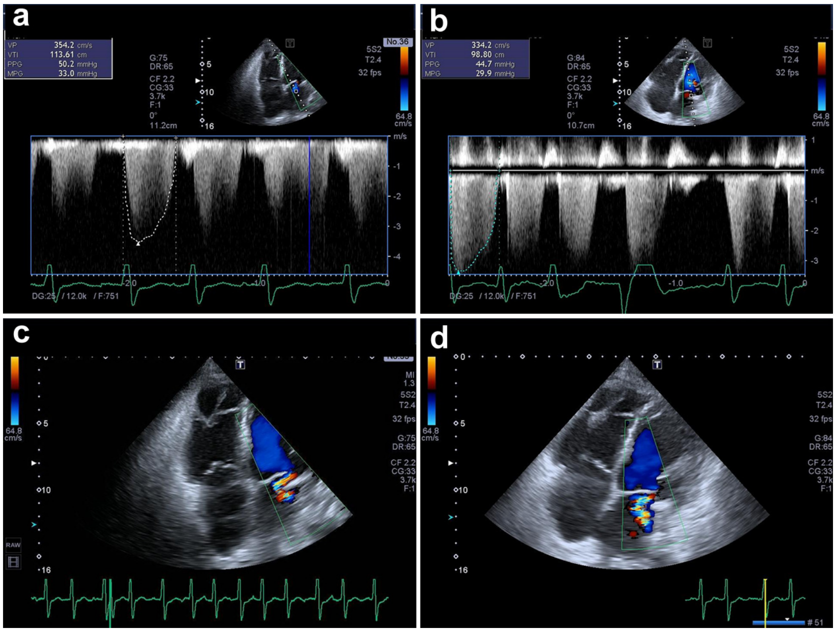

Fig. 4. Mitral regurgitation by (a, c) tele-echocardiography and (b, d) reference echocardiography.

sufficient quality to determine (i), (ii), (ii) and (iv) listed above with respect to the reference echocardiogram. A valve score was similarly calculated to determine the percentage of valve leaks or aortic stenoses (v) that were detected by tele-echocardiography with respect to reference echocardiography.

Measurements obtained from tele-echocardiography were compared with those from reference echocardiography. A paired *t*-test was performed to determine if measurements obtained with tele-echocardiography differed from those obtained at reference echocardiography. Additionally, Bland–Altman analysis was performed to determine the relationships between the two measurements. This provided an indication of the accuracy of tele-echocardiography measures compared with reference measures. The duration of the examination was not assessed, as tele-echocardiography was limited to 10 min.

RESULTS

Video used for analysis during tele-echocardiography was not significantly altered despite being limited to 30 fps by the video server (Axis 243). The quality (contrast, contours, graded 1–5) of the cardiac four-chamber view obtained with the motorized probe holder was lower than that of the reference echocardiography by 11 ± 14%. In general, the contours of the cardiac chambers on tele-echocardiography (Fig. 3c) were not as well defined as those on reference echocardiography (Fig. 3d), and the tele-echocardiography four-chamber view was not perfectly centered in the ultrasound field (Fig. 4c) compared with the reference echocardiography view (Fig. 4d). During the 41 tele-echocardiography examinations, four- and five-chamber views were correctly displayed in 93% to 100% of cases compared with reference echocardiography, with left ventricular ejection fraction, aortic flow and right ventricular ejection fraction being measured in 95%, 93% and 100% of cases, respectively (Table 1). The different orientations of the cardiac chamber in tele-echocardiography and reference echocardiography resulted in different angles between the Doppler beam and the valve flow and, thus, in differences between the velocities measured, as illustrated in Figures 3 (a, b) and 4 (a, b).

In 14% (10 of 71 cases) of the tele-echocardiography examinations, the expert could not identify mild valves leaks or aortic stenoses. Tricuspid,

Table 1. Visualization scores for tele-echocardiographic measures*

	Reference echo cases	Cases not measured	Visualization score with robot
Left ventricle ejection fraction (EF)	40	2	95%
Aortic velocity before sigmoid valves (Ao LVOT)	40	3	93%
Right ventricle ejection fraction (TAPS)	41	0	100%

* Values are the total number of cases measured with reference echocardiography, the number of cases in which measures could not be made with tele-echocardiography and the visualization score for each measure when using tele-echocardiography.

Table 2. Valve scores for tele-echocardiographic assessments*

	Total cases	Cases not detected	Valve score
Tricuspid leak	34	5	85%
Mitral leak	31	5	84%
Aortic leak	4	0	100%
Aortic stenosis	2	0	100%
Mitral valve remodeling	26	5	81%

* Values are the total number of cases detected with reference echocardiography, the number of cases in which abnormalities were not detected with tele-echocardiography and the valve score for each measure when using tele-echocardiography.

mitral and aortic valve leaks were identified in 85%, 84% and 100% of the scans, respectively. Aortic stenosis was identified in all cases using tele-echocardiography, but valve remodeling was identified in only 81% of the cases (Table 2, Figs. 3 and 4). These results yielded a mean visualization score of 94% and valve anomaly score of 86%. Measurement results from images obtained with tele-echocardiography and reference echocardiography are summarized in Table 3.

A paired *t*-test revealed no statistical difference in the majority of measurements assessed. Measurements of left ventricle diastolic volume and aortic blood flow velocity by pulsed wave Doppler after the sigmoid valves were obtained with tele-echocardiography statistically differed; however, when values were adjusted for the biases suggested by the Bland–Altman analysis (7.03 mL and –1.71 cm/s, respectively), no differences were found. Bland–Altman plots (Fig. 5) revealed random distributions of values within the 95% confidence interval, suggesting that measurements made with tele-echocardiography were consistent with those made during reference echocardiography (Figs. 2a, b; 3a, b; 4a, b).

DISCUSSION

This study was designed to test a method of tele-echocardiography performed with a specially designed motorized probe holder and robotic arm. The system consisted of three major components: a robotic arm, which controlled the orientation of the ultrasound probe (rotation, tilt, and spin); a plate, which allowed for translational movements of the probe over the skin surface of the patient; and an inclinable arm attached to a cart, which a non-sonographer operator adjusted to align the tele-operated components with the patient. In addition to locating the probe over the acoustic window area as directed by the expert sonographer via video and audio communication, the non-sonographer operator also made adjustments to the ultrasound settings (gain, depth, Doppler line, *etc.*) or triggered different ultrasound functions (color, pulsed wave Doppler, record, *etc.*) at the request of the expert sonographer. The use of a non-sonographer operator as opposed to a fully automated system increased tolerability for the patient, as the operator was able to move the robotic system away from the patient in the case of malfunction or at the request of the patient.

The procedure used in the present study was slightly different from those previously reported for the tele-echographic examination of abdominal and fetal organs (Arbeille et al. 2005, 2007). In the present study, we incorporated an additional function that allowed for tele-operated translational movements of the ultrasound probe. The cardiac apical acoustic window is very narrow compared with those of abdominal or fetal organs, is an intercostal window and is not located over soft tissue. Additionally, the cardiac probe must be maintained very still while the sonographer activates various ultrasound functions to allow for proper measurement. Therefore, the present study also incorporated an inclinable arm and cart that held the tele-operated components, allowing for the ultrasound probe to remain in a fixed position for measurement.

During the initial tele-echocardiography scans, the non-sonographer operator moved the inclinable arm and cart to approximately locate the probe at the position of the acoustic window. This was defined as an area 6×6 cm located below the left nipple. In some cases, adjustments to probe positioning were required for the

Table 3. Measurements made with the reference echocardiography and tele-echocardiography*

	Reference echocardiography	Tele-echocardiography	95% confidence interval
Left ventricle diastolic volume (mL)	78.67 ± 27.27	70.14 ± 24.36†	−13.79 to 27.85
Ejection fraction (%)	60.21 ± 9.98	56.00 ± 9.13	−12.67 to 14.62
Left atrium (cm^2)	15.85 ± 4.82	16.76 ± 5.06	−4.69 to 3.38
Aortic left ventricle outflow track velocity (cm/s)	20.76 ± 5.56	19.82 ± 4.37	−7.48 to 8.77
Aortic velocity after sigmoid valves (cm)	30.76 ± 14.33	33.35 ± 15.78†	–9.31 to 5.89
Right atrium (cm^2)	16.39 ± 5.39	15.44 ± 4.5	–4.48 to 4.47
Right ventricle ejection fraction (TAPS)	23.08 ± 4.39	22.1 ± 3.72	–6.45 to 7.91

* Values are measurement values (means ± standard deviations) obtained during the reference echocardiography and the tele-echocardiography examinations, as well as the 95% confidence interval from the Bland–Altman analysis. Note, when bias, as determined from the Bland–Altman analysis, was considered, no differences were seen between any values.

† Tele-echocardiography value differs from the reference value, $p < 0.05$.

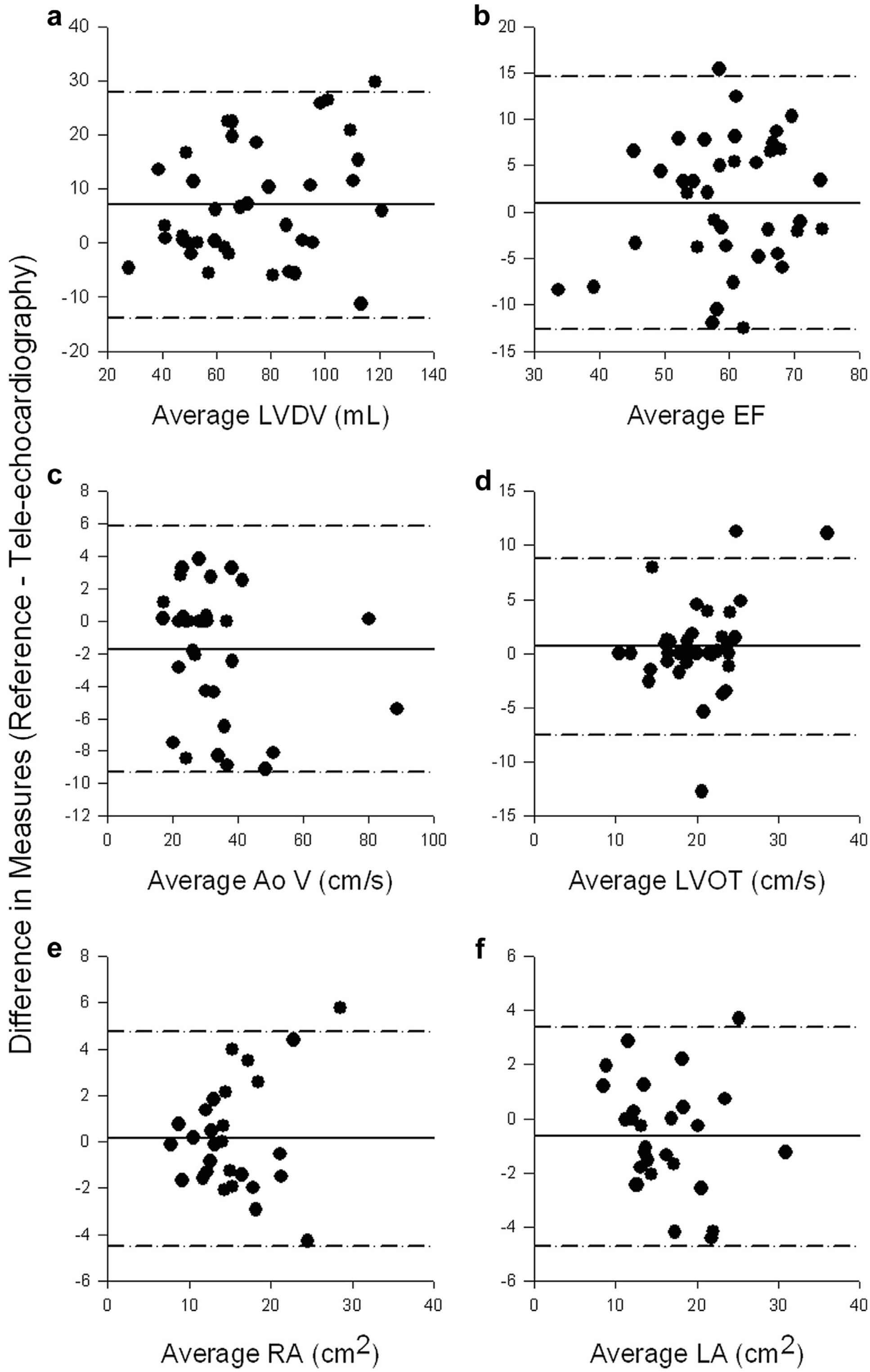

Fig. 5. Bland–Altman plots comparing tele-echocardiography measures with reference scan measures for (a) LVDV (left ventricle diastolic volume), (b) EF (ejection fraction), (c) Ao V (aortic velocity after sigmoid valve), (d) LVOT (aortic velocity before sigmoid valve), (e) RA (right atrium) and (f) LA (left atrium). The *solid line* represents the mean difference between the values, with *dashed lines* indicating 95% confidence intervals.

expert sonographer to locate the appropriate acoustic window. In these situations, the expert sonographer used the video conference link to illustrate the desired probe movement to the non-sonographer operator using either a mannequin or the expert's own body as a reference. Once the probe was positioned on top of the acoustic window, the non-sonographer operator did not adjust the robotic system and only changed settings or activated function on the ultrasound system at the direction of the expert sonographer. It should be noted that the functions performed by the operator did not require experience in echocardiography, but only a rudimentary understanding of the ultrasound system and the setup operation of the robot system.

Another research group has developed a fully robotic system with 6 df that maintains the ultrasound probe in a position (location, orientation) selected by the sonographer (Boman et al. 2008). This system was designed to keep the ultrasound probe motionless while the sonographer activated various ultrasound functions and, thus, reduce the effort exerted by the sonographer to maintain the probe in a fixed orientation as soon as he or she obtained the appropriate view. Tele-echocardiography testing using this system has been conducted with healthy volunteers but, to date, has not been conducted with cardiac patients for the detection of cardiac abnormalities.

Using the tele-echocardiography method developed for this study, the expert was able to generate cardiac images of sufficient quality for measurement in 93%–100% of cases depending on the parameter being measured. The study revealed no major differences between parameters measured by the two methods (Fig. 5), but differences existed because the robotic system did not allow acquisition of the same orientation of the cardiac chambers or of the Doppler beam as obtained during reference echocardiography (Figs. 2a, b; 3a, b; 4a, b). Similarly, the images allowed for the detection of cardiac abnormalities in 84% of cases. However, this detection rate is rather modest considering that false-negative diagnoses may have serious consequences for patients. It should be noted that the tele-echocardiography examination was limited to 10 min, as patients also had to undergo a reference (traditional) echocardiography examination, lasting approximately 30 min, afterward. Because of this time restriction, once an acoustic window was located, the robotic arm was not relocated on the patient to determine if a better window was available, which could have contributed to the reduced quality of tele-echocardiography images. Therefore, it is believed that with additional time, the number of cases in which images were of poor quality or not acquired with tele-echocardiography would be reduced and the rate of detection of cardiac abnormalities improved. Also because of the time restriction, only the apical cardiac view was obtained with tele-echocardiography, which allowed for assessment of the main cardiac morphologic (volume, diameter) and functional (wall movement, velocity) parameters. Other views may have facilitated the detection of some defects; however, acquisition of these views would have extended the length of the examination, which was not feasible during this study. It should be noted that although tele-echocardiography did not detect 100% of cardiac abnormalities, there were also no false positives using this method.

The system of tele-echocardiography used in this study did have some technical limitations. The lack of cardiac views of sufficient quality to perform measurements or valve leaks not being detected in 7% and 16% of cases, respectively, could have been related also to the technical limitations of the robotic arm versus the sonographer in addition to the limited time allocated for tele-echocardiography. In some cases, the robotic arm could not replicate all of the desired motions of the expert sonographer and could not apply sufficient pressure to obtain clear images though the intercostal space. The robotic arm could be equipped with an additional system to move the probe toward the skin and change the pressure being applied, but it is difficult to control and produce pressures equivalent to those applied by a sonographer, which poses potential safety concerns for the patient. Moreover, during pilot testing of this potential addition, it was noted that the system became larger and heavier with no obvious improvement in image quality.

Limitations on data flow rate between the patient site and the expert site could have contributed to changes in image quality. Using an Internet connection with a data flow rate of 1 Mbit/s required the compression and decompression of the video files, which may have altered video quality. In addition, the frame rate of the video server (30 fps) was lower than that of the ultrasound system (32–42 fps). During a previous study (data not published) using a modest satellite link (384 kbit/s, and 12 fps), good-quality ultrasound video of a fetal heart (140 bpm) was transferred to our hospital center from Ceuta, Spain. Although the video frame rate was only 12 fps, the rapidly moving structures of the fetal heart were still correctly displayed. Therefore, in the present study, it is unlikely that the slight reduction in frame rate contributed to a reduction in image quality.

A previous study qualitatively noted that the lower the quality of the original ultrasound image, the greater was the degradation in images received by the expert sonographer (Arbeille et al. 2007). Further work within our group supports this observation (data not published) that high-quality images tend to exhibit less degradation when transferred via the Internet. Therefore, in the present study, a high-quality ultrasound system was used that resulted in a lower level of image degradation.

In the present study, the expert sonographer and patient were both located in the same facility in two different rooms separate by only 10 m, which resulted in no major delay in data transfer between the two sites. In real situations, the expert and patient sites will be geographically separated by much greater distances, which may pose issues as transmission of video and robot commands may be delayed. It is unknown how much of an issue this will be as tele-echography examinations of abdominal and fetal organs between sites on different continents have reported delays <2 s, which allows for "quite real time" control of the robotic arm movements and the video generated by these movements (Arbeille et al. 2007).

The time required to educate the expert sonographer on the use of the tele-echocardiography system was approximately 2 h. In particular, the expert sonographer had to become accustomed to making small movements of the control probe at low velocities, as it is difficult for the robotic arm to move the probe back to a previous position if the control movements are too large or too fast. The expert was required to move the probe slowly, reconstructing a mental image of what was seen in the 2-D ultrasound images. Unlike live examinations, when using tele-echocardiography, the expert does not have physical contact with the patient and does not have a direct view of the patient and probe orientation on the patient; therefore, small movements are required, particularly when approaching the desired image. The expert must also learn to communicate with the non-sonographer operator to give direction regarding functions and settings of the ultrasound system. When asking for adjustments in settings or changes in function, the expert must speak slowly and wait after each instruction for the results of the action. All these considerations are consistent with those observed during previous studies on tele-echography with other organs (Arbeille et al. 2007).

CONCLUSIONS

The results of this study suggest that tele-echocardiography can be used for reliable diagnoses in cardiac patients located away from major hospital centers. A conventional Internet connection with a data flow rate of 1 Mbit/s is sufficient to tele-operate a motorized probe holder and transfer the video to the expert center in real time. Diagnoses of structural abnormalities such as valve leaks and aortic stenosis were delivered orally by the expert sonographer in real time, with measurements being performed by a non-sonographer operator under the supervision of the expert sonographer. No false diagnoses were reported during this study with cardiac patients.

The ultrasound images received at the expert center from the tele-echocardiography examination made it possible to visualize the four or five cardiac chambers, evaluate most of the parameters of cardiac function and detect cardiac valves leaks or stenosis. In many emergency situations, there is a need to make a quick and reliable diagnosis of various organs (abdominal, cardiac, pelvic, *etc.*) requiring several sonographers (radiologist, cardiologist, gynecologist, *etc.*). The possibility of tele-operating the ultrasound examination from an expert center (using a motorized probe holder) will provide patients living in isolated and small urban locations with the same diagnostic tools available in large hospitals, where expert sonographers in the different specialties are available at all times. The medical practitioner in charge of a general population, including unknown cardiac patients and patients already diagnosed with cardiac pathologies, will then have access to primary echocardiography as well as echocardiography for monitoring cardiac patient living in the area without the need for transportation of patients to large hospitals.

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