Development of an ultra-portable echo device connected to USB port

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Abstract

In practical cardiology, a stethoscope based auscultation has been used to reveal the patient’s clinical status. Recently, several hand-held echo devices are going on market and they are expected to play a role as “visible” auscultation instead of stethoscope. We have developed a portable and inexpensive echo device which can be used for screening of cardiac function. Two single element transducers were attached 180° apart to a rotor with 14-mm diameter. The mechanical scanner, integrated circuits for transmitting and receiving ultrasonic signals and an A/D converter were encapsulated in a 150×40 mm probe weighing 200 g. The scan was started and the image was displayed on a Windows based personal computer (PC) as soon as the probe was connected to USB 2.0 port of the PC. The central frequency was available between 2.5 and 7.5 MHz, the image depth was 15 cm and the frame rate was 30/s. The estimated price of this ultra-portable ultrasound is about 3000 US$ with software. For 69 cardiac patients with informed consent, image quality was compared with those obtained with basic range diagnostic echo machines. Left ventricular ejection fraction (EF) derived from normal M-mode image of standard machines (EFm) were compared with visual EF of the ultra-portable ultrasound device (EFv). The image quality was comparable to the basic range diagnostic echo machines although short axis view of aortic root was not clearly visualized because the probe was too large for intercostal approach. EFv agreed well with EFm. The ultra-portable ultrasound may provide useful information on screening and health care.

Keywords: Echography; Portable; Personal computer; USB 2.0

1. Introduction

In practical cardiology, a stethoscope based auscultation has been used to reveal the clinical status of patients. Recently, several hand-held echo devices have been going on market and they are expected to play a role as “visible” auscultation instead of stethoscope. Previous studies have shown that portable ultrasound devices detect major cardiovascular pathology better than the physical examination [1–6]. The miniaturized devices have been achieved by the development of nano-machining and informative technologies. Besides those innovations, the social need for the small and inexpensive ultrasound diagnosis is arising because the increase of elderly population and their high-quality in-home care are the common social problem in developed countries. For example, new insurance system for elderly care was established in Japan because the former social health care insurance system had not been able to cover the treatment in all ages. The ultra-portable ultrasound system may provide useful information for early detection of the disease and complications of the elderly people and patients at home.

We have developed an ultra-portable echo device which operated in connection with a USB 2.0 port of a personal computer (PC). The objectives of the present study were to evaluate the image quality of the ultra-portable echo device and to assess the feasibility for measuring cardiac function, by comparing the images obtained with the ultra-portable device to those obtained with conventional echocardiography machines.

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2. Materials and methods

Fig. 1 shows the appearance of the transducer connected to the USB 2.0 port of a laptop PC. A mechanical scanner, integrated circuits for transmitting and receiving ultrasonic signals and an A/D converter were encapsulated in a 150·40 mm probe weighing 200 g. The sampling frequency of the A/D converter was 12 MHz and the resolution was 8-bit. Envelope of the RF signal was sent to the PC through USB 2.0 connection. The depth of the image, sensitivity of receiving ultrasound and frame rate were controllable by PC. However, pulse repetition frequency or transmission power was fixed and these parameters were not controlled by PC.

Fig. 2 shows the schematic illustration of the scanning. Two single element transducers were attached 180° apart to a rotor with 14-mm diameter. The rotor rotated one-directional way to make mechanical scan. The electrical power was supplied via the USB 2.0 port. The scan was started and the image was displayed on a Windows based PC as soon as the probe was connected to USB 2.0 port of the PC. Both still images and movies were stored in the hard disk of PC. Measurements and analysis were available when the stored images and movies were displayed on the screen. In the present study, 3.5 MHz ultrasound transducer was used although the central frequency was available between 2.5 and 7.5 MHz for the system. The depth of the image was up to 15 cm and the frame rate was 30/s.

Thirty three healthy volunteers at a mass general examination and 36 patients at cardiology clinics without previous history of myocardial infarction were involved in the study. Each volunteer and patient accepted the study with written informed consent. Commercially available ultrasound machines used in the study were Nemio (Toshiba, Tokyo, Japan), SONOS 2500 (Philips, Mountainview, USA) and SSD 2000 (Aloka, Tokyo, Japan).

The assessment of the image quality was performed by comparing the movies stored in the hard disk from the portable ultrasound system and those recorded on SVHS video tapes from the commercial ultrasound machines. Two blinded cardiologists experienced in echocardiography were involved in the comparison study. One cardiologist recorded the parasternal long axis view, parasternal short axis view, apical four chamber view of the identical patient by both portable and conventional machines. The other cardiologist observed the movies and scored the image quality according to the following criteria: 0 point as poor image, 0.5 point as fair image and one point as good image, respectively. The portions of the interest were (1) motion of mitral valve (MV) for rapid movement, (2) visualization of left ventricular posterior wall (PW) of parasternal long axis view for blood-myocardium interface traceability, (3) visualization of aortic valve (AV) for short axis view, (4) visualization of left main trunk of coronary artery (LMT) for precise image, (5) visualization of pulmonary vein (PV) by apical approach for far field image, (6) visualization of apex (APEX) of left ventricle by apical approach for near field image, and (7) myocardium (MYO) for echo pattern.

Efficiency for clinical cardiology of the ultra-portable device was tested in assessment of systolic function. M-mode based calculation of left ventricular ejection fraction (LVEF) with Teicholtz method (EFm) was performed using the conventional machines. By viewing the stored movies, subjective estimation of LVEF from two-dimensional echocardiography (EFv) was performed. EFm and EFv were compared and correlation coefficient was calculated.
3. Results

Fig. 3 is an example of the image taken by the ultra-portable ultrasound device. This is normal heart. Fig. 4 is a case of pericardial effusion in a cardiology clinic.

Fig. 5 shows the absolute values of image quality. Significant differences were observed in all items. Fig. 6 shows the relative values of image quality compared with the conventional machines. LMT and AV of the ultra-portable machines scored half values of those in conventional machines. APEX and PW scored comparable to those of the conventional machines. Fig. 7 shows the correlation between EFm and EFv. The open circle and dotted line indicated the correlation of the volunteer and the closed circle and the solid line indicated the relation in patients. The correlation coefficient of EFm and EFv in the volunteers was $R^2 = 0.75$ and the coefficient in the patients was $R^2 = 0.94$. 

![Fig. 3. An image of a normal heart obtained with the ultra-portable ultrasound system.](image)

![Fig. 4. A case of a patient with pericardial effusion found at a cardiology clinic.](image)

![Fig. 5. Absolute values of image quality. Significant differences were observed in all items.](image)

![Fig. 6. Relative values of image quality compared with the conventional machines. (LMT: left main trunk of coronary artery, PV: pulmonary vein, Apex: apex of left ventricle, MV: mitral valve, AV: aortic valve, Myo: myocardium).](image)

![Fig. 7. Correlation between computed EF (EFm) and visual EF (EFv).](image)
4. Discussion

The latest development in echocardiography is the hand-held ultrasound device. Previous studies have shown that portable ultrasound devices detect major cardiovascular pathology better than the physical examination, but their diagnostic accuracy is still unknown. Some reports indicated that the image quality and signal accuracy were comparable to those obtained by the commercial machines. We have developed more portable and inexpensive ultrasound device which can be operated just by linking it to the USB 2.0 port of a PC. This “ultra-portable” ultrasound device featured only B-mode imaging. However, the targeted market price is 3000 US$ for the probe and software and it may be used not only screening at the clinics but also for elderly care at home. The purpose of this study was to compare the results of examinations made with ultra-portable devices to those obtained with conventional echocardiography.

The image quality of the device was inferior to that of conventional machines. Especially, scores for AV and LMT visualization were half of those in conventional machines. The limitation may cause from the large size transducer head for intercostal approach. The image quality of the PW and MV was comparable to those of conventional machines. Pericardial effusion was rightly detected by the ultra-portable machine. The minimum requirements of echocardiography in cardiology may be assessing left ventricular function and detecting pericardial effusion or aneurysms. In the period of first clinical testing of the device, a patient with aneurysm did not appear but a patient with pericardial effusion was detected at the clinic. This patient admitted to the hospital for further evaluation and treatments. The fact suggested that this ultra-portable device would be useful for mass screening for cardiac patients.

Another important requirement for cardiology is assessment of left ventricular function, especially systolic function. LVEF was derived from M-mode based formula and visual EF estimation from the ultra-portable device. Both values were correlated well. This indicates the ultra-portable ultrasound is useful in the some situations. One is the follow-up of the contractility of the patient once fully examined by high-end ultrasound machines. Other possibility of the use of this device is in-home care. Besides the conventional biological parameters such as body temperature, heart rate and blood pressure, this device may provide the information of nutrition or heart failure by observing heart movement and detecting pericardial and/or pleural effusions. The early detection of the abnormal status may rescue the patient’s life and it may reduce the total medical cost. The device can also be applied for telemedicine in corporation with the development of broadband communication systems.

For the use of hand-carried cardiac ultrasound (HCU) devices, American Society of Echocardiography (ASE) concerned about the inappropriate use or inaccurate data acquisition, interpretation, and response to the result [5]. ASE recommended a minimum of level 1 (number of personally performed examinations is 75 and number of personally interpreted examinations is 150) training for independent performance or interpretation of HCU and level 2 (number of personally performed examinations is 150 and number of personally interpreted examinations is 300) for independent performance or interpretation of comprehensive echocardiography. These recommendations indicate that experienced examiner and proper education system are required for the practical use in mass screening or in-home care although the cost for this ultra-portable device is low.

5. Conclusions

An ultra-portable ultrasound system was developed and its clinical efficiency was tested. The image quality was comparable of that in lower-range ultrasound devices except the short axis view. The visually estimated EF by this device was accurate and the result suggested the appropriate use of the device may open the new possibility in practical cardiology and in-home care. Although it requires skill and knowledge to visualize and to understand the image, this ultra-portable device provides more chance for general physicians, nurses working for in-home care to use the echo for monitoring patients.

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