

POCKET-SIZED ECHOCARDIOGRAPHY DEVICES: ONE STOP SHOP SERVICE?

ANDREAS SERAPHIM, MD¹, STAVROULA A PASCHOU, MD, PHD², JULIA GRAPSA, MD, PHD^{1,2}, AND PETROS NIHOYANNOPOULOS, MD²

¹DEPARTMENT OF CARDIOVASCULAR SCIENCES, ROYAL BROMPTON, LONDON, UNITED KINGDOM

²DEPARTMENT OF CARDIOVASCULAR SCIENCES, IMPERIAL COLLEGE OF LONDON, LONDON, UNITED KINGDOM

The introduction of portable, pocket-sized echocardiography devices in various healthcare systems has raised new questions with regards to their realistic use in clinical practice. Several studies have already attempted to provide information regarding their safety and diagnostic potential, the training required to operate them, as well as their direct comparison with standard echocardiography machines. This manuscript is a review of the literature of the documents or position papers which employ the use of pocket or handheld devices. Following review of the literature, we suggest that these miniaturized devices can provide a valuable diagnostic tool that can complement and improve the diagnostic yield of clinical examination. When operated by appropriately trained professionals, they can provide a limited but very reliable echocardiographic assessment. Pocket-sized echocardiography is a part of physical examination and should not be considered a complete echocardiographic scan. Optimal training is required for the smooth operation of handheld echocardiography.

KEY WORDS: Portable · Hand-held · Pocket · Echocardiography · Ultrasound.

INTRODUCTION

Due to limited resources and increasing demand in healthcare, technological advances and their application to clinical practice undergo careful evaluation with regards to both their safety and cost-effectiveness.

Several studies have suggested that the availability of hand-held portable ultrasound equipment, not only may increase the diagnostic accuracy of physicians, but can allow earlier disease detection, triage improvement and facilitate patient referral.¹⁾ However, the availability of these miniaturized hand-held ultrasound devices has raised several questions with regards to their current and future use in clinical practice.

Despite being an innovative technology, important issues arise with regards to their realistic use. Questions such as their true diagnostic use, the training needed to operate them, whether they can extract reliable information comparable to conventional echocardiography machines and their cost-effectiveness are still a matter of ongoing research. This is the main scope of this manuscript.

Interestingly, national and international bodies^{2,3)} issued

statements clarifying their views on the use of these hand-held echo machines. Although there is a clear consensus that these devices cannot be used as substitutes to the standard echocardiography, their exact role in clinical practice remains to be defined. The aim of this review manuscript was to summarize the types and utility of portable devices.

TYPES OF HAND-CARRIED ULTRASOUND DEVICES

The concept of portable echocardiography originates from as early as the 1970s, were the first descriptions of “ultrasonic stethoscope” appeared in the literature.^{4,5)} Since then, technological developments allowed the production of a range of echocardiography devices, ranging from mobile systems equipped with all standard modalities to the newer miniature “pocket” devices.³⁾

Evidently, the functions and capabilities of each device are different, prompting the European Association of Echocardiography to clearly differentiate between different types of portable echo machines. Important technical functions such as

• Received: December 20, 2015 • Revised: January 7, 2016 • Accepted: February 1, 2016

• Address for Correspondence: Julia Grapsa, Echocardiography Department, Hammersmith Hospital, Du Cane Rd, London W12 0HS, United Kingdom
Tel: +44-7478707021, Fax: +44-208-383-4392, E-mail: jgrapsa@gmail.com

• This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/3.0>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

the color-flow Doppler and spectral Doppler are not available in all hand-held portable devices.

The newer pocket-sized portable echocardiography machines are small devices similar to the size of a smart phone and may be easily carried by a healthcare professional. They are battery operated and may provide diagnostic quality 2D, with color Doppler imaging in real-time.³⁾ Images may be stored and may be transferred offline in a digital format. Their small size and low weight, allow them to be considered truly hand-held portable devices, easily carried by a healthcare professional.

USE OF POCKET-SIZED PORTABLE ECHOCARDIOGRAPHY DEVICES

There have been a number of studies assessing the clinical effectiveness of portable echocardiography devices. They have suggested that these devices may be safely used to enhance the diagnostic accuracy of cardiovascular examination and proposed their use in various clinical settings. Furthermore, since their introduction in clinical practice, several studies have compared these new pocket-sized echo devices with the standard, high quality transthoracic echocardiography devices, suggesting a high level of correlation in terms of basic diagnostic accuracy.

IMPROVEMENT OF DIAGNOSTIC ACCURACY WHEN ADDED TO CLINICAL EXAMINATION

Studies have previously demonstrated the limitations of the cardiovascular examination, and also highlighted the reduced emphasis on clinical examination skills in modern medical education.⁶⁷⁾ Various groups have also demonstrated that portable echocardiography may be used as an extension of the physical examination, enabling more accurate assessment of the cardiovascular system and often resulting in the modification of the initial diagnosis and management.⁸⁹⁾ More specifically, hand-held echocardiography has been shown to serve as a valuable tool in addition to clinical examination, in the detection of various cardiac abnormalities such as left ventricular (LV) dysfunction, LV hypertrophy, pericardial effusion, valvular heart disease and right atrial pressure (Table 1).

Although extrapolation of this data to the newer pocket-sized machines should be done with care given the technical differences among the “hand-held portable echo machines”, it is not surprising that similar levels of additional diagnostic benefit seemed to be gained from the use of the newer pocket-sized devices.¹⁰⁻¹²⁾

Appreciating the true benefit gained by the use if these devices seems to be a challenging task. A study by Spencer et al.,⁸⁾ demonstrated that the use of portable echocardiography increased the diagnostic accuracy of cardiologists by 50% for major cardiovascular abnormalities, whereas a more recent study by Galderisi et al.,¹⁰⁾ using a pocket-sized device showed a “theoretical” additional diagnostic power of 31.5%. More importantly, a study by Cardim et al.,¹²⁾ not only demonstrated an additive clinical value over clinical examination, but

showed various other benefits such as reducing the need for unnecessary standard echocardiography and discharge rate from the outpatient clinic.

The diagnostic benefit gained from these seems to apply to a range of healthcare professionals ranging from fully qualified cardiologists,¹³⁾ internal medicine residents,¹⁴⁾ junior doctors and medical students.¹¹⁾¹⁵⁾¹⁶⁾ Interestingly, Kobal et al.¹⁵⁾ showed that with the use of a hand-held echo device, the ability of medical students to detect various cardiac abnormalities, including valvular heart disease, LV dysfunction, enlargement, and hypertrophy was significantly greater to that of experienced cardiologists physical examination.

It could also be argued that the true impact that pocket-sized echo machines may have on the diagnosis and management of patients, extends beyond the field of cardiology patients. Indeed, a study by Mjølstad et al.¹⁷⁾ demonstrated that the addition of pocket-sized examination of < 10 min to usual care (cardiac and abdominal ultrasound), corrected the diagnosis in almost 1 of 5 patients admitted to a medical department.

HOW WELL DO THE LATEST POCKET-SIZED DEVICES COMPARE TO STANDARD TRANSTHORACIC ECHOCARDIOGRAPHY?

There is an increasing body of evidence comparing the diagnostic accuracy of the pocket-sized echo devices with standard, high quality echocardiography (Table 2). Several studies have demonstrated that these newer devices are not only easy to operate, but in appropriate conditions may provide diagnostic yield similar to that of standard echocardiography, with regards to basic echo parameters.

Most studies concluded that the images acquired with the new devices have very good correlation with standard echocardiography, especially with regards to the assessment of the LV, regional wall motion abnormalities, valvular abnormalities and pericardial effusions. It is however widely accepted, that despite their impressive diagnostic accuracy in identifying significant cardiac pathology, these devices do not provide a substitute for standard transthoracic echocardiography (sTTE) due to their limited technical capabilities.

ASSESSMENT OF THE LEFT VENTRICLE

Most studies comparing the quality of pocket-sized echo devices have used the assessment of the LV as a primary endpoint. Liebo et al.¹⁸⁾ compared the images obtained from 97 patients with those obtained from sTTE. Their group demonstrated that the images were adequate for interpretation of the LV ejection fraction in 95% of cases, regional wall motion abnormalities in 83%, whereas LV end-diastolic dimension in 95% of the studies. Compared to standard echocardiography, interpretation of the images by cardiologists had accuracy greater than 90% for all of the above LV parameters. Similar results were published by Andersen et al.,¹⁹⁾ after demonstrating that the pocket-sized echocardiography had almost perfect

Table 1. Summary of hand-held portable echo studies assessing the length of training and the added diagnostic benefit for cardiovascular pathology as an addition to clinical examination

| Study | No. | Operators | Clinical setting | Type of training | Type of assessment | Results |
|----------------------------------|-----|--|--|--|--|---|
| Galderisi et al. ¹⁰ * | 304 | Expert operators (102 studies), trainees (202 studies) | Outpatient cardiology clinic | 15 hr of teaching and 3 months experience in handling and visual interpretation | LV dilatation, hypertrophy and function, RV dilatation, valve calcification, pericardial/pleural effusions | Additional diagnostic power 31.5% compared to physical examination. Concordance with sTTE was good |
| Panoulas et al. ¹¹ * | 122 | 5 final year medical students, 3 junior doctors | Emergency department, cardiology ward | 2 hr bedside tutorial | LV function, RV function, valvular abnormalities | Improvement in diagnostic accuracy, for LV dysfunction and valvular disease |
| Cardim et al. ¹² * | 189 | 6 cardiologists | Outpatient cardiology clinic | Experienced operators | Pocket-size echo added to clinical examination | Increase in number of diagnosis, reduction in referrals for sTTE, facilitating discharges from cardiology clinic |
| Brennan et al. ¹⁴ | 40 | 4 internal medicine residents | Inpatients, < 1 hr after right sided catheterization | 4 hr didactic teaching and 20 studies | Assessment of right atrial pressure | Diagnostic accuracy for RA pressure > 10 mm Hg was higher compared to physical examination |
| Kobal et al. ¹⁵ | 61 | 2 medical students | Inpatients | 18 hr of training in cardiac US | Assessment of valvular heart disease, LV function/hypertrophy | Student's assessment with HCU resulted in higher diagnostic accuracy than that of cardiologists performing a physical examination |
| Spencer et al. ⁸ | 36 | 4 cardiologists | Outpatient | Experienced cardiologists who had performed 10–15 studies using the hand-held device | LV dysfunction, valvular heart disease, HCM, VSD | Improvement in diagnostic accuracy. Cardiac examination failed to identify 59% of findings, and this was reduced to 29% when portable echo was used |
| Martin et al. ¹³ | 354 | 10 hospitalists | Inpatients | 5 training studies | LV function, cardiomegaly, valvular disease, pericardial effusion | Improvement in diagnostic accuracy for LV function, cardiomegaly and pericardial effusion. No improvement in assessment of AR, AS, MR |
| Decara et al. ¹⁶ | 12 | 10 medical students | Outpatients | 15 days of training | Valvular heart disease, cardiomyopathy, ASD, VSD, pericardial effusion | Improvement in diagnostic accuracy, greater for valvular heart disease rather than cardiomyopathy |

*Studies that used pocket-sized portable echo devices. LV: left ventricle, RV: right ventricle, sTTE: standard transthoracic echocardiography, RA: right atrium, US: ultrasound, HCU: hand-carried cardiac ultrasound, HCM: hypertrophic cardiomyopathy, VSD: ventricular septal defect, AR: aortic regurgitation, AS: aortic stenosis, MR: mitral regurgitation, ASD: atrial septal defect

correlation with sTTE with regards to global and regional LV function r (95% confidence interval): 0.95 (0.90–0.99) and 0.92 (0.83–0.98), respectively. Fukuda et al.²⁰ also showed an excellent correlation between pocket-sized echo and sTTE with regards to assessment of LV dimensions and fractional shortening when experienced ultrasonographers performed the scan.

Studies also demonstrated a good correlation with sTTE with

regards to the LV assessment when the scan was performed by a non-specialist. Culp et al.²¹ demonstrated that a cardiology fellow with a 2-month experience in echocardiography was able to visually estimate the ejection fraction of the LV at an adequate degree, with a good correlation with sTTE. Furthermore, another study assessing the ability of medical students to acquire images with pocket-sized transthoracic echocardiography

Table 2. Studies comparing the diagnostic accuracy of pocket-sized echo devices with sTTE, showing operators, clinical setting and operator training

| Study | No. | Operators (no. of studies) | Clinical setting | Training | Type of assessment | Main findings |
|---|-----|--|-----------------------------------|---|--|---|
| Prinz and Voigt ²³⁾ | 349 | Experienced cardiologist | Echo department | Operators experienced in echocardiography | LV size and function, RWMA, pericardial effusion, valve stenosis and valve regurgitation | Good correlation with sTTE. Good concordance for valve regurgitation with slight overestimation of severity |
| Kono et al. ²⁵⁾ | 186 | Experienced ultrasonographers (121), less experienced ultrasonographers (65) | Echo department | Less experienced ultrasonographer had 6 months experienced in echocardiography | Assessment of MR and AR | Good correlation with sTTE, with slightly reduced correlations for the less experienced operator |
| Filipiak-Strzecka et al. ²²⁾ | 90 | 2 medical students | ITU/outpatients | 5 day course (5 hours a day) | LV function, pericardial effusion, RWMA, LV/RV/LA/ascending aorta | Moderate to very good agreement with sTTE, with notable learning curve effect |
| Culp et al. ²¹⁾ | 40 | 1 cardiology fellow | Echo department | 2 months experience in echocardiography | Visual estimation of EF | Good correlation for EF estimation |
| Andersen et al. ¹⁹⁾ | 108 | 3 cardiologists | Cardiac and non-cardiac units | Operators experienced in echocardiography | LV function, LA size, IVC, AA, pericardial effusion | Almost perfect correlation for LV function, AA, pericardial effusion. Strong correlation between RV and valvular function |
| Fukuda et al. ²⁰⁾ | 125 | Expert sonographer (90 patients) Physician (35) | Echo department (90) Bedside (35) | Operators experienced in echocardiography | Cardiac chamber size and function | Excellent correlation and agreement with sTTE |
| Kitada et al. ²⁴⁾ | 200 | Expert physician | Echo department | Operators experienced in echocardiography | LV size and function, RWMA, LA size, pericardial effusion, valvular heart disease | Strong correlation with sTTE. Overestimation of abnormalities in 14 patients, missed findings in 7 patients |
| Liebo et al. ¹⁸⁾ | 97 | Ultrasonographers | Inpatients, outpatients | Echo performed by ultrasonographers. Images interpreted by 2 cardiology fellows (2-month echo experience) and 2 cardiologists | EF, RWMA, LV end-diastolic dimension, pericardial effusion, valvular heart disease, IVC | Good correlation for LV function, RWMA, cardiac structures with sTTE. Suboptimal visualization of IVC |

LV: left ventricle, RWMA: regional wall motion abnormality, sTTE: standard transthoracic echocardiography, MR: mitral regurgitation, AR: aortic regurgitation, ITU: intensive therapy unit, RV: right ventricle, LA: left atrium, EF: ejection fraction, IVC: inferior vena cava, AA: abdominal aorta

(pTTE), showed good agreement between pTTE and sTTE with regards to the assessment of global LV function.²²⁾

ASSESSMENT OF VALVULAR HEART DISEASE

There is a general consensus that among the various cardiac parameters estimated, assessment of valvular heart disease appears to be one of the most limited functions of these pocket-sized devices, with slightly reduced correlation with sTTE findings. Prinz and Voigt²³⁾ reported an overestimation of the severity of valvular regurgitation. In their study, no valve stenosis was missed, whereas all valve regurgitations missed were graded as mild with sTTE. Kitada et al.²⁴⁾ demonstrated an

overestimated severity of valvular regurgitation in 17% of cases, who also highlighted the fact that no valvular stenosis was missed by pTTE. Finally, another study showed a modest underestimation of valvular pathology, especially with regards to the classification of aortic stenosis.¹⁹⁾

Certainly, the lack of spectral Doppler and the lower resolution of the pocket-sized devices, are thought to be the main limiting factors in the assessment of valvular heart disease. However, Kono et al.²⁵⁾ demonstrated that when pTTE was used by an experienced operator, there was a very good correlation with sTTE in the assessment of mitral and tricuspid regurgitation. Furthermore, their group reported that the sensi-

tivity and specificity of pTTE in detecting more than moderate mitral and tricuspid regurgitation was greater than 95%.

ASSESSMENT OF OTHER CARDIAC STRUCTURES

The assessment of the pocket-sized echo device in its ability to detect other cardiac structures such as right ventricle, the atria, pericardium and the great vessels has also been studied in various studies. Most studies showed excellent correlation with sTTE in the diagnosis of pericardial effusions^{18-20,23,24} whereas the assessment of right ventricular function was also found to have a good correlation with sTTE.¹⁹ Some groups reported difficulties in the visualization of the inferior vena cava and the right atrial size.^{18,19} This could be partly explained by the inability of these devices to show the cyclicity of the cardiac and respiratory phases, as well as the lack of other features such as M-mode and electrocardiography timing.

WHO SHOULD OPERATE THE POCKET-SIZED ECHO DEVICES

Evidently, the small size and limited technical features of these devices render them simple and convenient to use. Since these pocket-sized echo devices became available, several groups attempted to assess the training required for their safe use by various healthcare professionals with different levels of experience in echocardiography (Table 1 and 2). Training programs ranging from 2 hr bedside tutorials to several hours of didactic and practical training seem to have been used in different studies resulting in variable outcomes.

Studies using experienced operators in echocardiography (cardiologists, ultrasonographers) demonstrated that only minimal training is needed before these devices can be used to their maximal potential. In spite of the fact that most studies using inexperienced trainees such as medical students, demonstrated an impressive improvement in both diagnostic benefit compared to clinical examination alone^{11,15,16} as well as a satisfactory correlation with sTTE images,²² the widespread application of pTTE in clinical practice needs careful consideration. Studies have described the steep learning curve associated with the use of these devices,^{22,26} but have also emphasized the role of echocardiography experience in both acquisition and interpretation of findings with pTTE. Galderisi et al.¹⁰ demonstrated significant differences in both sensitivity and specificity of the diagnostic accuracy of pTTE between trainees and expert operators, whereas the majority of studies directly comparing the pTTE with sTTE used expert operators.

In view of the significant role of previous echocardiography experience in the appropriate use of pTTE, the European Society of Echocardiography has recommended that non-cardiologists should undergo dedicated training and revision of basic cardiac physiology, before the use of these devices. Furthermore, they proposed the idea of training specifically designed for this class of devices as a mandatory certification process, setting a clear standard of technical skill needed to operate them.³

DISCUSSION

Even though hand-held portable echo devices have been available for more than a decade, the introduction of new pocket-sized echo devices have raised new questions with regards to their clinical use. There is a growing body of evidence suggesting that not only these devices can provide a valuable diagnostic tool that can complement the clinical examination, but under certain conditions these devices can provide a limited but very reliable echocardiographic assessment. Furthermore, studies using these newer devices suggested a role in reducing the need for standard echocardiography and discharge rate from outpatient clinics.¹² Combining the evidence derived from this growing number of studies is a challenging task. Not only most of these studies included a very small number of patients, but there is a significant heterogeneity between them in terms of the type of portable devices used, the clinical setting, the training of the operator involved as well as their actual primary outcomes. Extrapolation of data derived from studies done using “hand-held portable devices” to the new pocket-sized machines should be done with caution. For example, the lack of colour Doppler in some models would have a significant effect on their diagnostic abilities, such as the assessment of valvular heart disease, whereas the lack of spectral Doppler results in a less complete assessment of the LV.

Although studies have already shown that their use by non-expert healthcare professionals yielded an additional diagnostic benefit, it seems clear that the clinical purpose for the use of these devices should be primarily determined by the expertise of the operator. Indeed, if these devices are used appropriately, ensuring a standardized training and competence level for non-expert operators, their scope for clinical application is wide. This can range from their use in the emergency department and acute medical assessment unit, facilitating the assessment of common cardiovascular pathologies such as LV systolic dysfunction, valvular heart disease and elevated central venous pressure, to their use by cardiologists on the coronary care unit. Evidently, their use in other clinical settings such as ambulances, community activities and outpatient settings is also a possibility, although a distinction of their diagnostic purposes should be made given the variability of operator experience.

The introduction of new technology in clinical practice is part of the process that allows the evolution of modern medicine. The use of these pocket-portable echo devices provides an additional tool, which if used appropriately has the potential of improving the standards of practice.

REFERENCES

1. Kimura BJ, DeMaria AN. *Technology insight: hand-carried ultrasound cardiac assessment—evolution, not revolution. Nat Clin Pract Cardiovasc Med* 2005;2:217-23; quiz 224.
2. Seward JB, Douglas PS, Erbel R, Kerber RE, Kronzon I, Rakowski H, Sahn LD, Sisk EJ, Tajik AJ, Wann S. *Hand-carried cardiac ultra-*

- sound (HCU) device: recommendations regarding new technology. A report from the Echocardiography Task Force on New Technology of the Nomenclature and Standards Committee of the American Society of Echocardiography. *J Am Soc Echocardiogr* 2002;15:369-73.
3. Sicari R, Galderisi M, Voigt JU, Habib G, Zamorano JL, Lancellotti P, Badano LP. *The use of pocket-size imaging devices: a position statement of the European Association of Echocardiography.* *Eur J Echocardiogr* 2011;12:85-7.
 4. Ligtervoet C, Rijsterborgh H, Kappen L, Bom N. *Real time ultrasonic imaging with a hand-held scanner. Part I--technical description.* *Ultrasound Med Biol* 1978;4:91-2.
 5. Roelandt J, Wladimiroff JW, Baars AM. *Ultrasonic real time imaging with a hand-held-scanner. Part II--initial clinical experience.* *Ultrasound Med Biol* 1978;4:93-7.
 6. Tavel ME. *Cardiac auscultation: a glorious past--and it does have a future!* *Circulation* 2006;113:1255-9.
 7. Oddone EZ, Waugh RA, Samsa G, Corey R, Feussner JR. *Teaching cardiovascular examination skills: results from a randomized controlled trial.* *Am J Med* 1993;95:389-96.
 8. Spencer KT, Anderson AS, Bhargava A, Bales AC, Sorrentino M, Furlong K, Lang RM. *Physician-performed point-of-care echocardiography using a laptop platform compared with physical examination in the cardiovascular patient.* *J Am Coll Cardiol* 2001;37:2013-8.
 9. Fedson S, Neithardt G, Thomas P, Lickerman A, Radzienda M, Decara JM, Lang RM, Spencer KT. *Unsuspected clinically important findings detected with a small portable ultrasound device in patients admitted to a general medicine service.* *J Am Soc Echocardiogr* 2003;16:901-5.
 10. Galderisi M, Santoro A, Versiero M, Lomoriello VS, Esposito R, Raia R, Farina F, Schiattarella PL, Bonito M, Olibet M, de Simone G. *Improved cardiovascular diagnostic accuracy by pocket size imaging device in non-cardiologic outpatients: the NaUSiCa (Naples Ultrasound Stethoscope in Cardiology) study.* *Cardiovasc Ultrasound* 2010;8:51.
 11. Panoulas VF, Daigeler AL, Malaweera AS, Lota AS, Baskaran D, Rahman S, Nihoyannopoulos P. *Pocket-size hand-held cardiac ultrasound as an adjunct to clinical examination in the hands of medical students and junior doctors.* *Eur Heart J Cardiovasc Imaging* 2013;14:323-30.
 12. Cardim N, Fernandez Golfín C, Ferreira D, Aubele A, Toste J, Cobos MA, Carmelo V, Nunes I, Oliveira AG, Zamorano J. *Usefulness of a new miniaturized echocardiographic system in outpatient cardiology consultations as an extension of physical examination.* *J Am Soc Echocardiogr* 2011;24:117-24.
 13. Martin LD, Howell EE, Ziegelstein RC, Martire C, Whiting-O'Keefe QE, Shapiro EP, Hellmann DB. *Hand-carried ultrasound performed by hospitalists: does it improve the cardiac physical examination?* *Am J Med* 2009;122:35-41.
 14. Brennan JM, Blair JE, Goonewardena S, Ronan A, Shah D, Vasaiwala S, Brooks E, Levy A, Kirkpatrick JN, Spencer KT. *A comparison by medicine residents of physical examination versus hand-carried ultrasound for estimation of right atrial pressure.* *Am J Cardiol* 2007;99:1614-6.
 15. Kobal SL, Trento L, Baharami S, Tolstrup K, Naqvi TZ, Cercek B, Neuman Y, Mirocha J, Kar S, Forrester JS, Siegel RJ. *Comparison of effectiveness of hand-carried ultrasound to bedside cardiovascular physical examination.* *Am J Cardiol* 2005;96:1002-6.
 16. Decara JM, Kirkpatrick JN, Spencer KT, Ward RP, Kasza K, Furlong K, Lang RM. *Use of hand-carried ultrasound devices to augment the accuracy of medical student bedside cardiac diagnoses.* *J Am Soc Echocardiogr* 2005;18:257-63.
 17. Mjølstad OC, Dalen H, Graven T, Kleinau JO, Salvesen O, Haugen BO. *Routinely adding ultrasound examinations by pocket-sized ultrasound devices improves inpatient diagnostics in a medical department.* *Eur J Intern Med* 2012;23:185-91.
 18. Liebo MJ, Israel RL, Lillie EO, Smith MR, Rubenson DS, Topol EJ. *Is pocket mobile echocardiography the next-generation stethoscope? A cross-sectional comparison of rapidly acquired images with standard transthoracic echocardiography.* *Ann Intern Med* 2011;155:33-8.
 19. Andersen GN, Haugen BO, Graven T, Salvesen O, Mjølstad OC, Dalen H. *Feasibility and reliability of point-of-care pocket-sized echocardiography.* *Eur J Echocardiogr* 2011;12:665-70.
 20. Fukuda S, Shimada K, Kawasaki T, Fujimoto H, Maeda K, Inanami H, Yoshida K, Jissho S, Taguchi H, Yoshiyama M, Yoshikawa J. *Pocket-sized transthoracic echocardiography device for the measurement of cardiac chamber size and function.* *Circ J* 2009;73:1092-6.
 21. Culp BC, Mock JD, Chiles CD, Culp WC Jr. *The pocket echocardiograph: validation and feasibility.* *Echocardiography* 2010;27:759-64.
 22. Filipiak-Strzecka D, John B, Kasprzak JD, Michalski B, Lipiec P. *Pocket-size echocardiograph--a valuable tool for nonexperts or just a portable device for echocardiographers?* *Adv Med Sci* 2013;58:67-72.
 23. Prinz C, Voigt JU. *Diagnostic accuracy of a hand-held ultrasound scanner in routine patients referred for echocardiography.* *J Am Soc Echocardiogr* 2011;24:111-6.
 24. Kitada R, Fukuda S, Watanabe H, Oe H, Abe Y, Yoshiyama M, Song JM, Sitges M, Shiota T, Ito H, Yoshikawa J. *Diagnostic accuracy and cost-effectiveness of a pocket-sized transthoracic echocardiographic imaging device.* *Clin Cardiol* 2013;36:603-10.
 25. Kono Y, Fukuda S, Shimada K, Oe H, Maeda K, Kawasaki T, Fujimoto H, Otsuka K, Kubo T, Jissho S, Taguchi H, Yoshiyama M, Ito H, Yoshikawa J. *Pocket-sized echo for evaluation of mitral and tricuspid regurgitation.* *JACC Cardiovasc Imaging* 2011;4:921.
 26. Prinz C, Dohrmann J, van Buuren F, Bitter T, Bogunovic N, Horstkotte D, Faber L. *The importance of training in echocardiography: a validation study using pocket echocardiography.* *J Cardiovasc Med (Hagerstown)* 2012;13:700-7.