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Personal mobile device-based pocket echocardiograph—The diagnostic value and clinical utility

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ABSTRACT

Purpose: A microUSB ultrasound probe, which can be connected to a personal mobile device constitutes a new class of diagnostic pocket-size imaging devices (PSID). The aim of this study was to assess the feasibility and diagnostic value of brief transthoracic echocardiographic examination (bTTE) performed with the use of such equipment.

Material and methods: The study population comprised 87 consecutive patients (58 men, mean age 61 ± 16 years), 53 of whom were admitted to intensive cardiac care unit and 34 patients, who were referred for transthoracic echocardiography from outpatient clinic. All patients underwent bTTE performed by cardiologist with the use of personal mobile device-based PSID. Within 18 h of bTTE all subjects underwent a standard TTE (sTTE) using a full sized echocardiograph by expert echocardiographer.

Results: In all patients, PSID imaging provided sufficient diagnostic image quality. Echocardiographic measurements were completed for both bTTE and sTTE in 98% of patients. The linear measurements obtained during bTTE showed good to excellent correlation with sTTE results ($r = 0.65–0.98$; $p < 0.001$). The agreement in detection of various pathologies between the bTTE and sTTE examination was very good ($k = 0.62–0.97$; $p < 0.01$).

Conclusion: Personal mobile device-based PSID allows for performing bTTE. The diagnostic value of such PSID in basic assessment of cardiac morphology and function as compared to standard echocardiography is very good.

1. Introduction

Recently a new class of pocket-size imaging devices (PSID) has been introduced - the ultrasound probe that can be plugged directly into a personal mobile device, such as mobile phone or tablet with dedicated application. Their diagnostic value has not yet been evaluated. Based on the studies performed with the use of previous generation of PSIDs, one can conclude that even though they do not provide all imaging modes, such as pulsed-wave Doppler, the benefits of using them in clinical practice are well documented [1–3]. The major advantage is the ability to provide immediate information regarding cardiac morphology and function in virtually every possible clinical setting. Echocardiographic examination performed at bedside with the use of PSID can instantaneously supplement findings of physical examination and improve its diagnostic accuracy [4]. Imaging with personal mobile device-based PSID could potentially allow for even more widespread use. However, such examinations are also associated with potential limitations regarding the image quality, feasibility and diagnostic value.

Therefore, we attempted to investigate the feasibility and accuracy of brief transthoracic echocardiographic examination (bTTE) performed by cardiologist with the use of personal mobile device-based PSID in the setting of intensive cardiac-care unit and outpatient clinic.

2. Material and methods

2.1. Study population

The study group consisted of 87 patients (58 men and 29 women; mean age 61 ± 16 years (18–88) years; mean BMI 28 ± 6 kg/m^2), 53 of whom were admitted or referred to the cardiac intensive care unit, and 34 patients from an outpatient clinic referred for scheduled echocardiographic examinations. We enrolled 2 different groups of patients – patients admitted in the intensive care unit and outpatient clinic patients – to evaluate the usefulness of PSID in patients from different scenarios – stable and unstable group of patients. Main indications for these examinations were suspected acute coronary syndrome, stable

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Table 1
Indications for echocardiographic examinations in patients from the cardiac intensive care unit, and from an outpatient clinic.

Indications for echocardiographic examination	Intensive care unit patients	Outpatient clinic patients
acute coronary syndrome	16	4
stable angina	–	8
symptomatic arrhythmias	11	–
suspected valve disease	6	3
chronic heart failure	19	12
arterial hypertension	1	7

angina, symptomatic arrhythmias, suspected valve disease, monitoring of patients suffering from chronic heart failure and exacerbation of chronic heart failure and hypertension (Table 1). The frequency of pathology in the studied population in the ICU and outpatients group was respectively: for mitral valve regurgitation - 79% and 71% (70% mild), aortic valve regurgitation - 13% and 11%, tricuspid valve regurgitation - 61% and 57%.

2.2. Pocket-size imaging device

We used Lumify echocardiograph (Philips Healthcare, Andover, USA), which is a PSID based on the microUSB probe S4-1 (4 to 1 MHz extended operating frequency range) enabling connection to a personal mobile device (tablet or smartphone) with the use of a dedicated application (Fig. 1). The application is available for compatible Android smart devices via the Google Play Store. The available imaging modes included: two-dimensional greyscale multivariate harmonic imaging (with a possibility of linear measurement), color Doppler mode (Fig. 2A and B), and additionally M-mode imaging - option not available so far in PSID. Images can be digitally stored and later reviewed.

2.3. Study protocol

All patients underwent echocardiographic examination performed with the use of PSID by two experienced cardiologists (level III of the ASE). Each examination included standard parasternal, apical, subcostal views and additionally other views (e.g. suprasternal) if needed. The duration of examination was recorded and quality of acquired images was graded as good, acceptable or unacceptable. Basic measurements and major findings were collected and noted using simplified scales (Table 2). Left ventricle function was assessed visually and regional wall motion abnormalities were described (hypokinesia, akinesia or dyskinesia). Right ventricle function was assessed by measuring tricuspid annular plane systolic excursion (TAPSE). Evaluation of the heart valves was based on a visual assessment of the presence of organic lesions (such as valve thickening, calcification, reduced leaflet mobility or prolapse) and using the color Doppler mode. The turbulences or the presence of a regurgitant jet was also noted and together with valve morphology interpreted as valvular regurgitation or stenosis. Evaluation of the inferior vena cava (IVC) included measurement of diameter and the respiratory collapse [5].

Fig. 1. Lumify - microUSB probe S4-1 connected to a personal mobile device.

Within 18 h of beside examination all patients underwent standard transthoracic echocardiographic (sTTE) examination, which was performed by another experienced cardiologist, blinded to the results of the bTTE, using a full-sized high-end echocardiograph and all imaging modes available (M-mode, grayscale imaging, color Doppler, pulsed wave Doppler, continuous wave Doppler, tissue Doppler imaging).

2.4. Ethics issues

The study protocol was approved by the Ethics Committee of our institution (approval number RNN/8/10KE) and written consent was obtained from all participants.

2.5. Statistical analysis

Continuous and categorical variables are expressed as mean ± SD and as percentages (%), respectively. Continuous variables were initially tested for normality of data distribution by the Kolmogorov-Smirnov test.

We used the Bland-Altman analysis with the limits of agreement defined as ± 1.96 SD to evaluate a bias between the mean differences, and to estimate an agreement interval for sTTE and bTTE. Parametric Pearson correlation (r) was used for the continuous values to estimate correlation coefficients between the analyzed groups. The results were considered to be statistically significant at $p < 0.05$. For the evaluation of parametric data the inter-rater agreement Kappa test was used. ROC curve analysis was used to assess the diagnostic value of the bTTE.

3. Results

In all patients PSID provided sufficient diagnostic image quality. Echocardiographic measurements were completed for both bTTE and sTTE in 85 (98%) patients. The average time required for the bTTE in ICCU patients was 450 ± 78 s. For patients referred from outpatient clinic the average time required for the shortened examination was 378 ± 74 s. The difference between the time of examination for the ICCU patients and for the outpatients was statistically significant ($p < 0.05$).

Using Bland-Altman method, the bias for the echocardiographic measurements by the bTTE and sTTE was −0.9 mm to 1.7 mm with appropriate values of limits of agreement as shown in Table 3.

The dimensions obtained in the bTTE showed excellent correlation with sTTE ($r = 0.78$-0.98; $p < 0.001$). The ranges of the echocardiographic measurements for all patients were: for left ventricular diastolic dimension (LVDD): 37–81 mm (mean 49 ± 8 mm), left ventricular systolic dimension (LVSD): 25–72 mm (mean 37 ± 9 mm), ascending aortic diameter (Ao): 22–47 mm (mean 33 ± 4 mm), left atrial dimension (LA): 27–67 mm (mean 44 ± 7 mm), right ventricular dimension (RV): 22–43 mm (mean 29 ± 4 mm), tricuspid annular plane systolic excursion (TAPSE): 12–27 mm, (mean 21 ± 3).

The correlations between the measurements in bTTE and sTTE in our group of patients were very high. The Pearson's correlation coefficient r varied from 0.65 (for right ventricle dimension in the

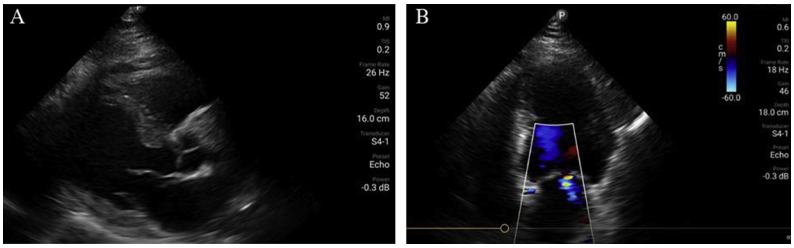

Fig. 2. Sample images recorded using PSID: a) parasternal view, b) apical 4-chamber view – a color Doppler showing mild mitral regurgitation.

Table 2
Basic measurements and major findings performed with the use of PSID.

Parameters	Semi/quantitatively
Cardiac chamber dimensions	LVDD, LVDS, IVS, LA, Ao, RV, IVC + collapse
LV function	visual assessment (WMA and EF)
RV function	TAPSE (mm)
Morphological valves changes	3 - grade scale (0–2)
Valvular regurgitation	3 - grade scale (0–2)
Valvular stenosis	3 - grade scale (0–2)

LVDD – left ventricular diastolic dimension, LVSD - left ventricular systolic dimension, IVS – intraventricular septum, LA – left atrium dimension, Ao – ascending aorta diameter, RV – right ventricular dimension, IVC – inferior vena cava diameter, WMA – wall motion abnormalities, EF – ejection fraction, TAPSE – tricuspid annular plane systolic excursion.

outpatient group) to 0.98 (for left ventricle diastolic dimension among the same group and left ventricle systolic dimension in the ICCU patients group); all measurements were statistically significant ($p < 0.001$) (Table 4).

The wall motion abnormalities (WMA) were identified in 45 (52%) patients during bTTE examination (60% in the ICCU group and 40% in the outpatient group) and 50 (57%) patients with the sTTE (62% in the ICCU group and 38% in the outpatient group). The sensitivity, specificity, positive predictive value and negative predictive value for the diagnosis of WMA in the ICCU patients were: 94%, 100%, 100% and 91%, respectively, and in the outpatient group: 75%, 94.4%, 92.3% and 81%, respectively. The agreement between bTTE and sTTE in the measuring of right ventricle function on the base of TAPSE was also very high (Table 3 and 4).

The concordance rate for the evaluation of other cardiovascular findings, such as morphological and functional valvular abnormalities, presence of pericardial effusion, diameter and respiratory collapse of the IVC for bTTE and sTTE was also very good. Table 5 contains the agreement of the results of echocardiographic examination (presence of valvular regurgitation, suspicion of aortic or mitral stenosis based on color Doppler and valve morphology). In addition, ROC curve analysis for all groups of patients, showed high diagnostic value of the bTTE as shown in Table 6.

4. Discussion

Our study is the first one to confirm that personal mobile device-based PSID (the ultrasound probe that can be plugged directly into a personal mobile device, such as mobile phone or tablet with dedicated application) allows for performing reliable brief bedside echocardiographic examinations. The ultra-portability of this new class of ultrasound tools may greatly expand its use.

Previous studies with the use of other PSIDs showed, that they allow for the detection of major abnormalities with acceptable diagnostic value and can provide accurate answers to basic clinical concerns [6–9]. Their use complements and improves the diagnostic yield of physical examination regarding cardiac morphology and function [8]. Importantly, our study confirms the findings of other reports based on different PSID, that show excellent correlation and agreement of the bTTE with sTTE [10,11]. For all subgroups the differences for our measurements, evaluated by Bland–Altman analysis were not clinically important, indicating that the two methods may be used interchangeably especially in some clinical situations requiring rapid and bedside echocardiography.

It is obvious that reliable assessment of cardiac morphology and function, including visual evaluation of global and regional left ventricular function, performed within few minutes can be a great advantage, especially in patients referred to the ICCU. The populations, when time is of the essence include patients with suspicion of pulmonary embolism, acute coronary syndrome, cardiogenic shock or acute aortic syndrome. However, not only patients referred to cardiology department can benefit from the bTTE. Mjolstad et al. [1] screened patients admitted to a medical department by performing a short, pocket-sized ultrasound examination, which allowed for the correction of the initial diagnosis in approximately 1 of 5 patients, resulting in a completely different treatment strategy without delay in many of the patients.

Previous pocket-size echocardiographs were not equipped with M-mode, which precluded the measurement of TAPSE [12]. Our results indicate that M-mode measurements obtained with this new class of PSIDs show a good correlation with sTTE measurements. However, PSIDs have several limitations, the most important of which seems to be the lack of spectral Doppler mode which makes in-depth analysis of

Table 3
The Bland-Altman analysis between the measurements obtained by bTTE and sTTE.

Parameter (mm)	aICCU patients		Out-patients		All patients	
	the mean difference	the limits of agreement	the mean difference	the limits of agreement	the mean difference	the limits of agreement
LA	−0.5	3.5 to −4.5	−0.3	4.2 to −4.8	−0.4	3.7 to −4.6
Ao	0.2	3.3 to −2.8	0.5	4.6 to −3.6	0.4	3.8 to −3.1
LVSD	−0.5	3.6 to −4.5	−0.9	3.3 to −5.1	−0.6	3.5 to −4.7
LVDD	1.2	4.4 to −2.1	1.5	5.0 to 1.9	1.3	4.7 to −2.0
RV	−0.3	4.4 to −5.0	0.2	5.3 to −5.0	−0.2	4.4 to −4.7
TAPSE	0.4	3.1 to −2.3	0.6	4.8 to −3.5	0.5	3.8 to −2.8
IVC	−0.4	4.1 to −4.9	−0.2	3.6 to −4.0	−0.3	3.9 to −4.6

LA – left atrial dimension, Ao – ascending aorta dimeter, LVSD – left ventricle systolic dimension, LVDD - left ventricle diastolic dimension, RV – right ventricle dimension, TAPSE – tricuspid annular plane systolic excursion, IVC – inferior vena cava diameter.

Table 4
The correlations between the measurements obtained by bTTE and sTTE.

Parameter (mm)	aICCU ptients			Out-patients		
	sTTE measurement [mm] (mean ± SD)	Mean difference in measurements between bTTE and sTTE [mm] (mean ± SD)	Pearson's Correlation Coefficient- Diameters' Comparison of bTTE and sTTE (r – value)	sTTE measurement [mm] (mean ± SD)	Mean difference in measurements between bTTE and sTTE [mm] (mean ± SD)	Pearson's Correlation Coefficient- Diameters' Comparison of bTTE and sTTE (r – value)
LA	45 ± 8	0.6 ± 0.4	r = 0.96	43 ± 7	0.7 ± 0.9	r = 0.95
Ao	33 ± 5	−0.4 ± 0.6	r = 0.95	33 ± 4	−0.6 ± 0.3	r = 0.89
LVSD	37 ± 9	0.5 ± 0.5	r = 0.98	35 ± 9	0.9 ± 0.6	r = 0.97
LVDD	51 ± 8	−1.2 ± 0.4	r = 0.97	49 ± 9	−1.3 ± 0.7	r = 0.98
RV	29 ± 3	0.4 ± 0.8	r = 0.75	28 ± 3	−0.5 ± 0.4	r = 0.65
TAPSE	22 ± 4	−0.4 ± 0.5	r = 0.93	21 ± 4	−0.7 ± 1.1	r = 0.92
IVC	22 ± 3	0.4 ± 0.4	r = 0.77	20 ± 2	0.4 ± 0.4	r = 0.83

LA – left atrial dimension, Ao – ascending aorta dimeter, LVSD – left ventricle systolic dimension, LVDD - left ventricle diastolic dimension, RV – right ventricle dimension, TAPSE – tricuspid annular plane systolic excursion, IVC – inferior vena cava diameter.

Table 5
The agreement between bTTE and sTTE in qualitative echocardiographic assessment in both groups of patients.

Agreement (Kappa Value)		
Echo parameter	ICCU	Out-patients
Wall motion abnormalities	99% (0.920)	97% (0.641)
LV global function	99% (0.873)	98% (0.918)
Mitral valve morphology (fibrosis, calcification, decreased mobility)	96% (0.625)	98% (0.686)
Aortic valve morphology (fibrosis, calcification, decreased mobility)	98% (0.682)	96% (0.616)
Aortic valve regurgitation	95% (0.698)	93% (0.638)
Mitral valve regurgitation	98% (0.637)	98% (0.653)
Tricuspid valve regurgitation	98% (0.626)	96% (0.969)
Aortic stenosis (based on color Doppler and valve morphology)	98% (0.706)	99% (0.617)
Mitral stenosis (based on color Doppler and valve morphology)	95% (0.698)	93% (0.638)
Pericardial effusion	97% (0.790)	97% (0.767)
Respiratory collapse of the IVC	96% (0.696)	97% (0.744)

Table 6
The ROC curve analysis for bTTE and sTTE assessment in qualitative echocardiographic parameters in all group of patients.

Diagnostic value (ROC curve analysis)				
Echo parameter	Sensitivity [%] (95% CI)	Specificity [%] (95% CI)	AUC (95% CI)	P
Wall motion abnormalities	88 (75.7–95.5)	97 (85.8–99.9)	0.926 (0.865–0.988)	< 0.0001
Mitral valve morphology (fibrosis, calcification, decreased mobility)	68 (52–82)	95.7 (85.2–99.5)	0.820 (0.724–0.915)	< 0.0001
Aortic valve morphology (fibrosis, calcification, decreased mobility)	73 (45–92.2)	92.5 (83.4–97.5)	0.832 (0.693–0.970)	< 0.0001
Mitral valve regurgitation	96.1 (86.5–99.5)	73.7 (48.8–90.9)	0.857 (0.739–0.946)	< 0.0001
Aortic valve regurgitation	71 (44.4–90.3)	100 (95.3–100)	0.773 (0.618–0.927)	0.0005
Tricuspid valve regurgitation	80 (64.4–90.9)	97.2 (85.5–99.9)	0.887 (0.819–0.995)	< 0.0001

intracardiac flows impossible. Nevertheless, combination of the color Doppler imaging and the grey-scale imaging, which allow for evaluation of leaflet thickening, calcification and mobility provide good sensitivity in the presence of valvular regurgitation or stenosis.

4.1. Limitations of the study

This study was based on a relatively small study group examined in one center. The bTTE was performed and interpreted by experienced cardiologist. One may assume that the results of the study would be different if the bTTE was performed by less experienced operator. However, recently published papers show that briefly trained non-expert echocardiographers, including medical students, may obtain an acceptable diagnostic value for the detection of basic structural and functional findings [13].

5. Conclusions

Personal mobile device-based PSID allows for performing brief bedside echocardiographic examinations. The diagnostic value of such PSID in basic assessment of cardiac morphology and function as compared to standard echocardiography is very good.

Conflict of interests

The authors declare no conflict of interests.

Financial disclosure

The authors have no funding to disclose.

The author contributions

Study Design: Paulina Wejner-Mik, Piotr Lipiec.
Data Collection: Paulina Wejner-Mik, Adrianna Lorens.
Statistical Analysis: Paulina Wejner-Mik, Jarosław D. Kasprzak, Piotr Lipiec.
Data Interpretation: Paulina Wejner-Mik, Jarosław D. Kasprzak,

Piotr Lipiec

Manuscript Preparation: Paulina Wejner-Mik.

Literature Search: Paulina Wejner-Mik, Dominika Filipiak-Strzecka, Dawid Miśkowiec.

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